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KINEMATIC ADJUSTMENTS DURING SUCCESSFUL AND UNSUCCESSFUL WOLF JUMPS ON THE BALANCE BEAM

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The current study examined differences in the kinematics between successful and failed landings of a wolf jump on the balance beam. Subjects were 35 elite level gymnasts performing in competition. Discrete point analysis and Analysis of Characterizing Phases found that failed landings involved higher initial longitudinal component of the inertia tensor, body angle in the anterior-posterior direction at takeoff and landing, and the medial-lateral component of angular velocity during the descent of the jump ($p < 0.05$). While initial higher longitudinal inertial tensor values may have been adjusted during the descent, it is possible that focusing on this factor may have prevented the gymnasts from dealing with other errors in body position; specifically the angle of the body in the anterior-posterior direction.

KEYWORDS: Gymnastics, wolf jump, landing, kinematics

INTRODUCTION: In gymnastics, high scores on the balance beam and other apparatus are based on the competition exercise that is judged in respect to the difficultly on the performed element (D-value) and its execution (E-value). According to the rules of the Fédération Internationale de Gymnastique [FIG] (2009), small faults, e.g. extra arm swings or steps, lead to deductions from the E-value. Larger faults can minimize the E-value as well as the D-value. Consequently, it is important to minimize faults to reduce score deductions to reach a high ranking. There are few studies investigating balance beam performances. Hars et al. (2005) examined reaction forces during support phases of back walkovers. However, only good performances, from the judges' point of view, were examined. Most other studies focused on balance beam dismounts (Brown et al., 1996; Gittoes, Irwin, Mullineaux & Kerwin, 2009a; 2009b). There is a lack of studies investigating inaccurate gymnastic elements on the beam in order to improve gymnasts' performances and to reduce score deductions.

The purpose of this study was to investigate the causes of additional balancing movements to maintain balance during the touchdown of the wolf jump on balance beam in the side position (Level of Difficulty: A; Figure 1). For the wolf jump the gymnast has to jump up and move their legs as in Figure 1. There is no angular momentum necessary for the whole body movement. By comparing wolf jump performances with and without additional movements, is it possible to identify differences between these performances. The wolf jump was chosen because of its high use in gymnastic exercises (Delaš Kalinski, Božanić & Atiković, 2011).

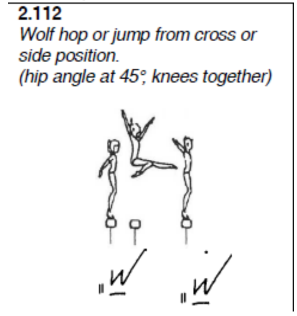

Figure 1. Wolf jump

(FIG, 2009)

METHODS: Subjects in the current study were 35 female gymnasts from the 2011 European Gymnastics Championships held in Berlin, Germany (4th -11th April 2011). They were filmed using two calibrated, synchronized, 50 Hz cameras, one stationary and one swivel-mounted.

The stationary camera was positioned 20 m away from the beam and looked along the length of it. The other camera was positioned perpendicular to the beam, 12 m away. We used a right-handed coordinate system with the anterior-posterior axis named X, the longitudinal one Y, and the medial-lateral axis Z. Only wolf jumps fulfilling the technical requirements (without a fall from the beam) were included in the data analysis (FIG, 2009). The data were manually analyzed using a Mess3d digitizing system. To keep the labor input at a moderate level, digitizing was done at 10 Hz for the 16 landmarks (right and left side of the body: ear, shoulder, elbow, wrist, hip, knee, ankle, and the great toe).

The data was labeled to achieve kinematic variables from a simulation system (SolidDynamics 6.2) running an inverse dynamics routine. To get an optimal simulation result we used StatFree 7 (Vieten, 2006) to prepare the data. First an interpolation of the data to 900 Hz was done and then a residual analysis (Winter, 2005) was performed, which resulted in a 3 Hz cutoff frequency for the airborne movement. Finally, an F^3 low pass filter (Vieten, 2004) was used to obtain the final input for the simulation system.

The primary simulation outputs were discrete points and continuous waveform data. The discrete point measures that were examined are listed in Table 1. Most of these variables were defined at the takeoff point of the jump. Exceptions were: the distance that the body's center of gravity (CoG) travelled in the anterior-posterior direction, the final body angle in X and Z directions, and the flight time. The mean values for the discrete point kinematic measures were compared for successful and failed landings using an independent *t*-test. Alpha level was set at $p < 0.05$. Landings without any deductions were defined as successful. Landings showing landing faults according to the code of points (FIG, 2009), e.g. extra arm swing, lack of balance, etc., were defined as failed.

To assess the effect of the kinematic variables during the entire jump on landing success, an independent *t*-test was used to examine subject scores generated during an Analysis of Characterising Phases (Richter et al., 2012). Analysis of Characterising Phases detects key phases within the data to examine data determining phases in the time, magnitude and magnitude-time domain. Participant scores for the statistical analysis were generated by calculating the area between a participant's curve (p) and the mean curve across the data set (q) for every point (i) within the key phases (Equation 1 & 2). For further explanation, the reader is referred to the paper by Richter and colleagues (2012).

$$score = \int p_i - q_i \qquad \text{Eq. (1)}$$

$$score = \int 0.5 * (\Delta_{time} p_{i,i+1} + \Delta_{time} q_{i,i+1}) * \Delta_{magnitude} p_i q_i \qquad \text{Eq. (2)}$$

The continuous measures variables that were examined included the diagonal elements of the inertia tensor, and the vector components of momentum, angular momentum, and angular velocity. All elements and components were expressed in a coordinate system fixed to the beam.

RESULTS: The independent *t*-test for the discrete point kinematic variables revealed that only YY component (vertical direction) of the inertia tensor was significantly different between successful gymnasts and those who failed in completing the landing correctly. For this variable, the successful gymnasts had a lower value of the inertia tensor's YY component (0.639 ± 0.015 versus 0.704 ± 0.027). Other examined variables did not differ significantly different between groups ($p > 0.05$; Table 1).

The Analysis of Characterising Phases separated the captured waveforms into from 5 to 9 data characterizing phases (key phases) for the kinematic variables. The analysis of the separated key phases found only one phase being different between successful and failed landings in both the magnitude and magnitude-time domain ($p < 0.05$). This phase occurred in the Z-component of the angular velocity (somersault axis) at 71-79% of the curve. It indicated that gymnasts who failed the landings produced higher angular velocity in the Z-direction, which occurred slightly later in time than in successful landings (see Figure 2). No other key phases across the examined variables were different for the two groups ($p > 0.05$).

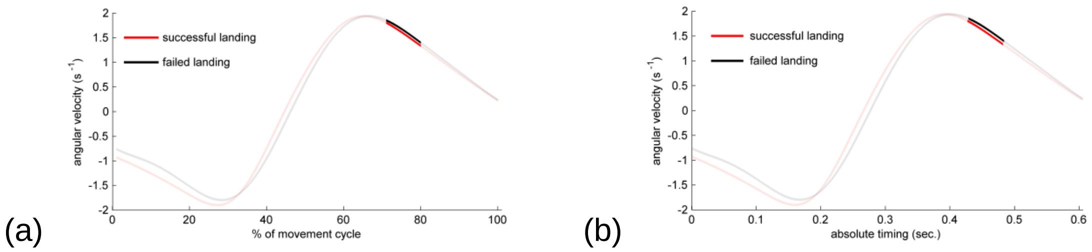

Figure 2. Illustrates the angular velocity defined between successful and failed landings. Shown are curves for (a) percent of the movement and (b) absolute timing (seconds). The transparent phases did not differ significantly between the groups ($p > 0.05$).

Table 1. Mean (± SEM), independent t-Test value, and probability of a significant difference between failed/successful landings for selected kinematic variables of women gymnasts performing a wolf jump.

	Mean (± SEM)		t-Test	Probability
	Successful (20)	Failed (15)		
Flight time (ms)	604.1 (38.4)	604.9 (28.7)	0.066	0.948
Initial Inertia XX (Lab)	6.916 (0.055)	6.828 (0.045)	1.180	0.246
Initial Inertia YY (Lab)	0.784 (0.026)	0.818 (0.042)	0.723	0.475
Initial Inertia ZZ (Lab)	7.051 (0.055)	6.987 (0.043)	0.861	0.396
Initial Inertia XX (Body)	7.068 (0.061)	6.955 (0.048)	1.385	0.175
Initial Inertia YY (Body)	0.639 (0.015)	0.704 (0.027)	2.215	0.034*
Initial Inertia ZZ (Body)	7.044 (0.055)	6.974 (0.044)	0.942	0.353
Initial Momentum X	6.140 (3.921)	2.461 (4.001)	0.645	0.523
Initial Momentum Y	99.802 (4.126)	101.217 (2.431)	0.271	0.788
Initial Momentum Z	0.156 (0.881)	-0.841 (1.435)	0.622	0.538
Angular Momentum X	0.018 (0.104)	-0.208 (0.188)	1.115	0.273
Angular Momentum Y	0.113 (0.059)	-0.002 (0.079)	1.188	0.243
Angular Momentum Z	0.413 (0.262)	0.388 (0.294)	0.064	0.949
Initial Foot distance (m)	0.437 (0.017)	0.462 (0.021)	0.954	0.347
Initial Angle X°	0.710 (0.133)	1.230 (0.168)	2.467	0.018*
Final Angle X°	1.510 (0.255)	3.190 (0.633)	2.460	0.021*
Initial Angle Z°	-0.488 (0.036)	-0.408 (0.044)	0.697	0.490
Final Angle Z°	-0.469 (0.036)	-0.444 (0.039)	0.504	0.617
CoG traveled X (m)	0.231 (0.030)	0.188 (0.031)	0.984	0.332

* Significant difference ($p < 0.05$) between successful and failed landings.

DISCUSSION: To the authors' knowledge, this study is the first known to have assessed differences in kinematic variables between successful and failed landings of a wolf jump on a balance beam. Results indicated that at takeoff those gymnasts who failed the jump had higher longitudinal inertial tensor values than those who landed successfully (see Table 1). Perhaps in an effort to correct for this, gymnasts with failed landings also had a higher medial-lateral component of angular velocity during the descent (see Figure 1). In addition, those who failed landings had higher body angles in the anterior-posterior direction at both takeoff and landing. This along with the non-significant, but perhaps noteworthy, 20 cm travel of the COG would likely have made it difficult to complete a successful landing.

Gittoes et al. (2009b) note that discrepancies in spatial orientation during an aerial phase of gymnastics may need to be compensated for at the onset of landing. While their study dealt with dismounts, a similar situation may occur during any aerial movement. The inability to control body angle in the wolf jump was likely a factor in the resulting failed landing. The fact that most of the variables assessed in the current study could not differentiate between successful and failed landings, illustrates that there may be a variety of factors controlling positioning and orientation of the body during landing. Variables in the current study primarily examined whole body movement. Thus, an analysis of multi-joint movements within the body may be required to better distinguish successful landings.

Finally, McNitt-Gray and coworkers suggest “that control of total body momentum during landing activities may involve a hierarchical relationship between more than one control criteria” (2001, p 1481). Thus depending on what is currently happening to the spatial orientation of their body, what the gymnast needs to do to land an aerial movement may vary. Perhaps those gymnasts with higher longitudinal inertial tensor values focused on this problem and in making a correction were unable to accommodate the other angular issue, specifically the angle of the body in the anterior-posterior direction.

CONCLUSION: The success or failure of landing a wolf jump on the balance beam appears to be influenced by the angle of the body in the anterior-posterior direction. Those gymnasts failing to land successfully had higher angles at takeoff and landing. While initial higher longitudinal inertial tensor values may have been adjusted during the descent, it is possible that focusing on this factor may have prevented the gymnasts from dealing with the other error in body position, i.e. the angle of the body in the anterior-posterior direction.

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