ELBOW JOINT VARIABILITY DURING THE ROUND OFF IN FEMALE GYMNASTICS

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Based on a within-gymnast analyses this study aimed to examine the variability in elbow joint kinematics and kinetics of expert gymnasts in the execution of the round-off with different hand position. Six international level female gymnasts performed 10 trials of the round-off from a hurdle step to back handspring with “parallel” and “T-shape” hand position. Two force plates were used to determine ground reaction forces. Eight infrared cameras were employed to collect the kinematic data. Gymnast-specific variability was calculated using coefficient of variation (*CV%*) in each discrete kinematic and kinetic measures. In conclusion higher variability in the elbow joint abduction angle and adduction moment of force in the T-shaped hand position may leads to reducing repetitive abduction stress and thus protect elbow joint from overload.

KEY WORDS: biomechanics, gymnastics, round-off, upper extremities, injury prevention

INTRODUCTION: Movement variability (MV) is particularly important in many sport skills. The traditional motor learning perspective suggests that a reduction in MV will aid in the development of a skilled performance (Wilson, Simpson, van Emmerick, & Hamill, 2008). In adherence to the traditional motor learning perspective, Bates (2010) stated that for some activities (e.g. gymnastics) where the goal is precision/replication MV has negative connotations. In contrast to the traditional motor learning theory, the dynamical systems perspective suggests high MV in the localized joint and segmental movement strategies to be beneficial to the task outcomes (Gittoes, Irwin, Mullineaux, & Kerwin, 2011), and has previously been considered to be an essential element to normal, healthy function, thus offering flexibility in adapting to perturbations (Hamill, van Emmerik, Heiderscheit, & Li, 1999). From an injury perspective this is a positive feature since it helps minimize chronic injury potential (Bates, 2010). In gymnastics when a gymnast performs the same skill a number of times, it may be expected that he/she is attempting to use the same technique (Hiley, Zuevsky, & Yeadon, 2013). Gittoes, Irwin, Mullineaux, & Kerwin (2011) investigated variability in whole-body and multi-joint kinematic control strategies of expert gymnasts in the execution of fundamental backward rotating dismount skills from balance beam. The authors states that self-selected modulations to the multi-joint kinematic strategy used in the impact phase suggested customization of the joint loading adjustments in executing the fundamental dismount skills. Hiley et al. (2013) investigated variability in the important aspects of high bar swinging technique. The main observation from their research was that elite gymnasts had lower variability in the key aspects of technique compared to the less elite gymnasts, and the more elite gymnasts demonstrated higher variability in some of the less mechanically important aspects. These studies are focused on movement variability of whole body coordinated movements. However, there is lack of information relating to the level of MV in gymnastics, focused on weight-bearing limbs kinematics and kinetics during fundamental skills. In the sport of artistic gymnastics the round-off (RO) is a fundamental skill and a key movement in the development of elite female and male gymnasts, owing to its association with learning more complex skills (Farana, Jandacka, Uchytil, Zahradnik, & Irwin, in press). Farana et al. (in press) found that different hand positions during RO performed by female gymnasts significantly influence elbow loading of second contact hand. The aim of the present study was to conduct within-gymnast analyses to develop understanding of the variability in elbow joint kinematics and kinetics of expert gymnasts in the execution of the RO with two different hand positions. The current study may provide useful insights into technique selection that will help coaches, athletes and clinicians.

METHODS: Participants & Protocol: Six international level female gymnasts from the Czech Republic were recruited as participants for this study. Their mean ± *SD* height was 162.0 ± 4.4 cm; body mass 55.8 ± 5.1 kg and age 21.0 ± 1.9 years. All gymnasts were injury free at the time of testing. From these six gymnasts three of them (P1, P2, P3) preferred RO with parallel hand position (Group P), and three of them (T1, T2, T3) preferred RO with T-shape hand position (Group `T`). All procedures were verbally explained to each gymnast and informed consent was obtained in accordance with the guidelines of the principal author´s Ethics and Research Committee of the University of Ostrava. The research was conducted in the Biomechanical Laboratory of Human Motion Diagnostic Centre. The gymnasts completed their self-selected warm up and completed a number of practice RO trials with both hand positions. A thin floor mat was used and taped down at each force plate with double sided tape to replicate the feel of the floor. After the warm up and practice, all gymnasts performed 10 trials of RO with a parallel hand position from a hurdle step to a flic-flac, and 10 trials of RO with a T-shape hand position from a hurdle step to a flic-flac. All trials were performed with a maximal effort, in random order and separated by a one minute rest period.

Data Collection & Processing: Two force plates (Kistler, 9286 AA, Switzerland) embedded into the floor were used to determine ground reaction force data at a sampling rate of 1235 Hz. A motion-capture system (Qualisys Oqus, Sweden) consisting of eight infrared cameras were employed to collect the kinematic data at a sampling rate of 247 Hz. The global coordination system was set up so that the z-axis was vertical, y-axis was in antero-posterior and the x-axis was in the medio-lateral direction. Retroreflective markers (diameter of 19 mm) were attached to the gymnasts' upper limbs and trunk according to a recommendation of the C-motion Company (C-motion, Rockville, MD, USA). Two photocells were used to control hurdle step velocity. The hurdle step velocity was standardized at a range of 3.3 – 3.7 m/s.

Data Analysis: The markers data were processed using the Visual 3D software (C-motion, Rockville, MD, USA). The local coordinate systems were defined using a static calibration trial in the handstand position. All analyses focused on the contact phase of the second hand during the round-off. Kinematic variables included sagittal (flexion/extension), frontal (adduction/abduction) and transverse (internal rotation/external rotation) elbow angles were calculated using Cardan´s angle of rotation sequence XYZ. In addition, net three-dimensional internal joint moments for the elbow in the sagittal (flexion/extension), frontal (adduction/abduction) and transversal (internal rotation/external rotation) planes were quantified using the Newton-Euler inverse dynamics technique (Hamill & Selbie, 2004). Net internal elbow moments of force are expressed in the local coordinate system of the upper arm. The coordinate data were low-pass filtered using the fourth-order Butterworth filter with a 12 Hz cut off frequency. Force plate data were low-pass filtered using the fourth-order Butterworth filter with a 50 Hz cut off frequency. Gymnast-specific variability was calculated using coefficient of variation (*CV%*) in each discrete kinematic and kinetic measure for the 10 trials performed by the respective gymnast. The within-gymnast coefficients of variation were calculated across gymnasts as CV% = (Standard deviation / Mean) * 100. If the *CV* value was less than 10%, the variable was considered to have low variability (Queen, Gross, & Liu, 2006).

RESULTS: Within-gymnast variability in the elbow joint kinematics (Table 1) was typically lower (<10%) for the abduction angle for the parallel hand position compared to the T-shape hand position for each gymnast in both groups. As illustrated in Table 1, the within-gymnast *CV%* was larger for the flexion angle at the parallel position for each gymnast. Moreover, in the parallel hand position *CV%* was greater than 10% for gymnasts P1, P3, T1 and T2. Within-gymnast variability for the internal rotation angle was typically lower (<10%) for both hand positions. For the gymnast T1 *CV%* was larger than 10% in the parallel hand position (Table 1).

Table 1
Gymnast individual and group coefficient of variation (*%CV*) for elbow joint angles for the round-off with "Parallel" hand position and "T-shape" hand position.

	Parallel hand position			T-shape hand position		
	Peak Abduction %CV	**Peak Flexion %CV**	**Peak Internal rot. %CV**	**Peak Abduction %CV**	**Peak Flexion %CV**	**Peak Internal rot. %CV**
Gymnast P1	4.7	15.6	2.1	11.5	8.2	3.4
Gymnast P2	7.4	7.7	2.5	27.8	5.8	2.9
Gymnast P3	5.8	13.3	1.5	23.7	7.4	1.9
Group P M ± SD	**6.0 ± 1.1**	**12.2 ± 3.3**	**2.0 ± 0.4**	**21.0 ± 6.9**	**7.1 ± 1.0**	**2.7 ± 0.6**
Gymnast T1	8.6	29.9	14.0	23.4	18.8	6.4
Gymnast T2	9.2	19.3	2.0	14.6	7.0	2.0
Gymnast T3	4.9	6.0	2.8	11.0	5.8	2.1
Group T M ± SD	**7.6 ± 1.9**	**18.4 ± 9.8**	**6.3 ± 5.5**	**16.3 ± 5.2**	**10.5 ± 5.9**	**3.5 ± 2.1**

Legend: Gymnasts P1, P2, P3 prefers "parallel" hand position; Gymnasts T1, T2, T3 prefers "T-shape" hand position

Within-gymnast variability in the elbow joint kinetics (Table 2) was typically lower for the adduction moment of force at the parallel hand position compared to the T-shape hand position for each gymnast in both groups. In contrast, the T-shape hand position was associated with a greater *CV%* for the extension and external rotation moment of force compared to the parallel hand position.

Table 2
Gymnast individual and group coefficient of variation (*%CV*) for elbow joint moments of force for the round-off with "Parallel" hand position and "T-shape" hand position.

	Parallel hand position			T-shape hand position		
	Peak Adduction %CV	**Peak Extension %CV**	**Peak External rot. %CV**	**Peak Adduction % CV**	**Peak Extension % CV**	**Peak External rot. % CV**
Gymnast P1	10.6	17.9	18.2	17.8	7.6	4.8
Gymnast P2	12.2	13.3	30.5	40.0	5.1	11.1
Gymnast P3	14.6	21.9	25.0	33.3	7.9	15.4
Group P M ± SD	**12.5 ± 1.6**	**17.7 ± 3.5**	**24.6 ± 5.0**	**30.4 ± 9.3**	**6.9 ± 1.3**	**10.4 ± 4.4**
Gymnast T1	8.7	20.3	16.7	39.1	8.5	9.1
Gymnast T2	4.4	14.5	11.8	18.8	12.5	16.0
Gymnast T3	4.8	10.8	16.7	22.7	7.6	9.5
Group T M ± SD	**6.0 ± 1.9**	**15.2 ± 3.9**	**15.1 ± 2.3**	**29.6 ± 8.8**	**9.5 ± 2.1**	**11.5 ± 3.2**

Legend: Gymnasts P1, P2, P3 prefers "parallel" hand position; Gymnasts T1, T2, T3 prefers "T-shape" hand position

DISCUSSION: Sports biomechanics plays a vital role in understand factors that may influence injury (McGinnis, 2005). A contemporary dynamical systems perspective suggests MV to have a functional role in the execution of athletic tasks (Hamill et al., 1999; van Emmerik, Hamill, & McDermott, 2005). The current study examined the within-gymnast variability of elbow joint kinematic and kinetic measures associated with the execution of two different techniques of RO skills performed by expert female gymnasts. In the current study higher gymnast individual in the elbow joint abduction angle (Table 1) and adduction moment of force (Table 2) was observed in the "T-shape" hand position compared with the "parallel" hand position for each gymnast. Based on the literature, repetitive abduction stress leads to microtrauma and chronic elbow injuries (Hume, Reid, & Edwards, 2006). Farana et al. (in press) states that differences in peak elbow joint abduction angle and corresponding moments of force may provide a "T-shape" hand position that could prevent elbow joint complex overload that subsequently reduces the potential for elbow injuries. Higher variability in the elbow joint movement in the frontal plane might allow a broader distribution of stresses among different tissues, potentially reducing the cumulative load on internal structures of the elbow joint (Hamill et al., 1999). Experienced gymnasts preferring parallel hand position (Group P) showed reduced variability in the non-preferred technique for flexion angle (Table 1), extension moment of force and external rotation moment of force (Table 2). In contrast, it was found that the gymnasts preferring T-shape hand position (Group T), had higher variability in the non-preferred technique. The higher variability for non-preferred technique can be explained from a traditional motor learning perspective, when in the early stages of learning a movement, higher variability may be present (Wilson et al., 2008). Low within-gymnast variability was observed for internal rotation angle for both techniques, and only one gymnast from Group “T” (Gymnast T1) showed higher variability for internal rotation angle in the non-preferred technique (Table 1). Discrete measures of variability allow the quantification of MV in a way that does not rely on a very large sample size, and provides information which is easy to interpret and understand by the athlete or coach (Preatoni et al., 2013). On the other hand, it has been recognized that, sometimes, analyzing discrete variables from isolated joints does not effectively capture the complexity of the coordinated motions of components of the body (Bartlett, Wheat, & Robins, 2007). Further research will examine inter-segmental co-ordination movement patterns in different techniques of RO skill.

CONCLUSION: It was found that expert gymnasts in both groups displayed higher variability in the elbow joint peak abduction angle and adduction moment of force in the T-shaped hand position. This may leads to reducing repetitive abduction stress and thus protect elbow joint from overload and biological failure that occur due to repetitions of similar motor tasks.

REFERENCES:

Bates, B.T. (2010). Accommodating strategies for preventing chronic lower extremity injuries. In R. Jensen, W. Ebben, E. Petushek, C. Richter, and K. Roemer (Eds.), *XXVIII International Symposium on Biomechanics in Sports 2010*. Northern Michigan University: USA, MI.

Bartlett, R., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists?. *Sports Biomechanics*, 6(2), 224-243.

Farana, R., Jandacka, D., Uchytil, J., Zahradnik, D., & Irwin, G. (in press). Musculoskeletal loading during the round-off in female gymnastics: The effect of hand position. *Sports Biomechanics*.

Gittoes, M.J.R., Irwin, G., Mullineaux, D.R., & Kerwin, D.G. (2011). Whole-body and multi-joint kinematic control strategy variability during backward rotating dismounts from beam. *Journal of Sports Sciences*, 29(10), 1051-1058.

Hamill, J., van Emmerik, R.E.A., Heiderscheit, B.C., & Li, L. (1999). A dynamical systems approach to lower extremity running injuries. *Clinical Biomechanics*, 14(5), 297-308.

Hamill, J., & Selbie, S. (2004). Three-Dimenzional Kinetics. In: G.E. Robertson, G. Caldwell G, J. Hamill, G. Kamen, & S. Whittlesey (Eds.). *Research methods in biomechanics* (pp. 145-162). Champaign, IL: Human Kinetics.

Hiley, M., Zuevsky, V., & Yeadon, M. (2013). Is skilled technique characterized by high or low variability? An analysis of high bar giant circles. *Human Movement Science*, 32(1), 171–180.

Hume, P.A., Reid, D., & Edwards, T. (2006). Epicondylar injury in sport. *Sport Medicine,* 36(2), 151-170.

McGinnis, P.M. (2005). *Biomechanics of sport and exercise* (2nd ed.). Champaign, IL: Human Kinetics.

Preatoni, E., Hamill, J., Harrison, A.J., Hayes, K., van Emmerik, R.E.A., Wilson, C., & Rodano, R. (2013). Movement variability and skill monitoring in sports. *Sports Biomechanics*, 12(2), 69-92.

Queen, R.M., Gross, M.T., & Liu, H.Y. (2006). Repeatability of lower extremity kinetics and kinematics for standardized and self-selected running speeds. *Gait & Posture*, 23(3), 282-287.

van Emmerik, R.E.A., Hamill, W.J. & McDermott (2005). Variability and coordinative function in human gait. *Quest,* 57(1), 102-123.

Wilson, C., Simpson, S.E., van Emmerik, R.E.A., & Hamill, J. (2008). Coordination variability and skill development in expert triple jumpers. *Sports Biomechanics*, 7(1), 2-9.

Acknowledgement

The authors would like to thank Dr. Scott W. Selbie from C-motion, Inc. for his assistance and help in this research. This research was supported by a grant of the University of Ostrava (no. 6150).