GENDER DIFFERENCES IN TECHNIQUE SELECTION: ELBOW AND WRIST JOINT LOADING DURING ROUND OFF IN GYMNASTICS

Roman Farana[1], Gerda Strutzenberger[2,1], Timothy Exell[3,1], Jiri Skypala[1], Huw Wiltshire[4] and Gareth Irwin[4,1]

Department of Human Movement Studies, University of Ostrava, Czech Republic[1]; Department of Sport Science and Kinesiology, University of Salzburg, Austria[2]; Department of Sport and Exercise Science, University of Portsmouth, UK[3]; Cardiff School of Sport, Cardiff Metropolitan University, Cardiff, UK[4]

The aim of the study was to determine sex differences in the key elbow and wrist joint injury risk factors during different round-off (RO) techniques performed by young male and female gymnasts. Eight male and female young gymnasts performed 30 successful trials of RO with different hand positions (parallel [10], T-shape [10] and reverse [10]). Synchronized kinematic and kinetic data were collected for each trial. Two-way repeated measures ANOVA (3×2, technique x sex) and effect-size (ES) were used for statistical analysis. Risk factors including peak vertical ground reaction forces (VGRF), elbow and wrist compression forces, elbow internal adduction moments and elbow extension suggest that a RO in reverse and parallel techniques can be hazardous especially for young female gymnasts compared to male.

KEY WORDS: technique, fundamental skills, upper limbs, injury prevention, coaching.

INTRODUCTION: In gymnastics, the round-off (RO) is a fundamental skill and is defined as the primary method for gymnasts to change from forward-rotating to backward-rotating movements. Gymnastics training requires a high frequency of performance repetition of these fundamental skills. Previous gymnastics research has shown, this can result in serious chronic elbow and wrist joint injuries (Baker et al., 2010; Daly et al., 1999; Singh et al., 2008). Previous studies have examined injury risk and technique selection associated with the choice of hand placement in RO skills performed by elite and young female gymnasts, highlighted that different hand placements during the RO skill have a direct influence on the bio-physical demand placed on the performer (Farana et al., 2014; Farana et al., 2017; Farana, Exell, Strutzenberger & Irwin, 2018). These authors observed that the T-shape hand position reduced peak ground reaction forces (GRF), decreased elbow joint moments (Farana et al., 2014 and 2018) and axial compression force applied on the wrist joint (Farana et al., 2017 and 2018), when compared to parallel and reverse hand positions. This indicates that the T-shape is a safer technique for the RO skill. RO skills are repeatedly performed by both male and female gymnasts of all abilities. In younger age populations the physical abilities in terms of strength and technical accuracy may differ between male and female gymnasts as male gymnasts participate in more apparatus using upper limbs as weight-bearing such as pommel horse, parallel bars or rings. Moreover, male and female gymnasts also differ in terms of morphology as reported in previous research (e.g. Malina et al., 2013). Increasing knowledge of the sex differences in RO techniques may help in decrease mechanical load by informing technique selection to be less risky for each sex, and also may help the FIG in terms of aligning the male and female Code of Points. Therefore, the aim of the current study was to determine if sex differences exist in the key elbow and wrist joint injury risk factors during different CW and RO techniques performed by young male and female artistic gymnasts.

METHODS:

Participant & Protocol: The experimental sample consisted of 8 female (age: 10.0 ± 0.7 years, height: 137.7 ± 5.6 cm and mass: 30.6 ± 3.1 kg) and 8 male (age: 9.7 ± 1.1 years, height: 136.7 ± 7.0 cm and mass: 30.9 ± 3.3 kg) active young gymnasts with at least four

years' experience of systematic training and competitive gymnastics. Informed assent and parental consent was obtained from each gymnast and her/his parents, respectively, in accordance with the guidelines of the Institute's Ethics and Research Committee. After warm up and practice, the gymnasts performed 10 trials for each condition of RO skill from a hurdle step with "parallel", "T-shape" and "reverse" hand positions (Figure 1). All trials were performed in a random order and separated by a one-minute rest period.

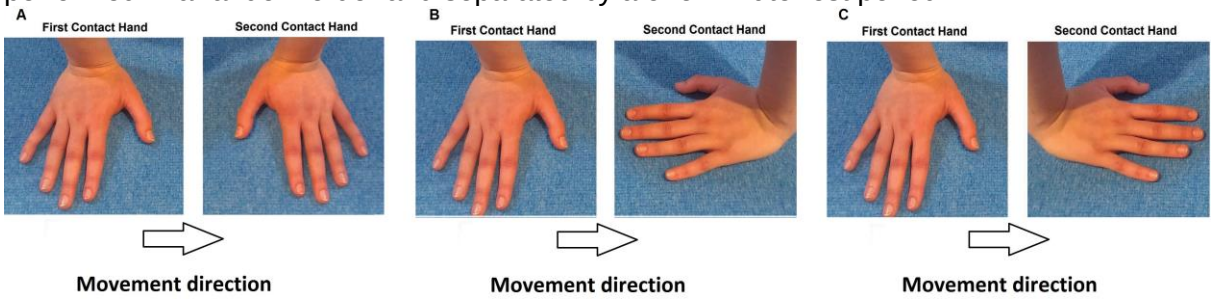

Figure 1: Round-off hand positions (A) Parallel, (B) T-shape and (C) Reverse.

Data Collection: Synchronized kinematic (9 QUALISYS cameras; 240 Hz) and kinetic (2 KISTLER force plate; 1200 Hz) data were collected for each trial. Based on C-motion Company (C-motion, Rockville, MD, USA) recommendation, retroreflective markers and clusters were attached to the gymnasts' upper limbs and trunk.

Data analysis: Raw data were processed using the Visual 3D software (C-motion, Rockville, MD, USA). The local coordinate systems were defined using a standing calibration trial in the handstand position (Farana et al., 2014). All analyses focused on the contact phase of the second hand during the three different RO techniques. Based on previous studies (Farana et al., 2014 and 2017) key injury risk variables included peak vertical ground reaction force (VGRF), elbow joint internal adduction moment (+ adduction / – abduction), elbow and wrist joint axial compression forces, elbow joint flexion (+ flexion / – extension), and wrist joint dorsiflexion (+ plantarflexion / – dorsiflexion). The coordinate data were low-pass filtered using a fourth-order Butterworth filter with a 12 Hz cut off frequency. All force plate data were low-pass filtered using a fourth-order Butterworth filter with a 50 Hz cut off frequency. Means and standard deviations (M ± SD) were calculated for all measured variables. Two-way repeated measure ANOVA (3 × 2; technique × sex) determined significant differences between each hand position. The significance level was set at $p < 0.05$. In order to overcome the inherent limitations of a small sample Cohen´s *d* was used and interpreted as trivial (<0.2), small (0.21–0.5), medium (0.51–0.8), or large (>0.8) (Cohen, 1988).

RESULTS: Descriptive statistics with means and standard deviations for the three techniques, male and female gymnasts for RO skills are presented in Table 1.

Table 1: Summary of elbow and wrist joints kinetic and kinematic measures (M ± SD).

Measures	Parallel		Reverse		T-shape	
	Male	Female	Male	Female	Male	Female
Ground reaction forces						
Peak VGRF (BW)	0.72(0.22)	1.10(0.26)	0.74(0.23)	1.15(0.23)	0.74(0.24)	0.83(0.21)
Elbow						
Peak flexion (°)	48.73(5.16)	35.92(9.33)	43.77(10.78)	19.44(11.73)	51.14(5.63)	41.10(9.42)
Adduction moment (Nm/kg)	0.16(0.08)	0.33(0.19)	0.16(0.09)	0.40(0.27)	0.08(0.04)	0.03(0.14)
Compression force (N/kg)	-4.18(1.32)	-8.11(1.76)	-3.88(1.38)	-8.87(2.07)	-3.99(1.37)	-6.51(1.65)
Wrist						
Peak dorsiflexion (°)	-67.53(4.39)	-61.25(12.83)	-52.81(12.23)	-53.69(10.99)	-67.06(8.54)	-66.07(13.70)
Compression force (N/kg)	-5.28(1.67)	-9.65(2.28)	-4.95(1.59)	-10.27(2.10)	-4.90(1.67)	-7.57(2.07)

Notes: VGRF, vertical ground reaction force; BW, body weight; Nm/kg, Newton-meter per kilogram; N/kg, Newton per kilogram; °, degree

For the RO skills, significant main effects for sex were found for peak VGRF (p=0.028, η2=0.524), for peak elbow compression forces (p=0.001, η2=0.815), for peak wrist compression forces (p=0.002, η2=0.762), and for peak elbow flexion (p=0.002, η2=0.782). Significant main effects of technique were observed for peak VGRF (p=0.000, η2=0.770), peak elbow compression forces (p=0.001, η2=0.719), peak wrist compression forces (p=0.000, η2=0.794), peak elbow internal adduction moment of force (p=0.000, η2=0.783), peak elbow flexion (p=0.003, η2=0.715), and peak wrist dorsiflexion (p=0.001, η2=0.700). Interaction effects were found for peak VGRF (p=0.000, η2=0.825), peak elbow compression forces (p=0.003, η2=0.678), peak wrist compression forces (p=0.000, η2=0.732), peak elbow joint internal adduction moment (p=0.004, η2=0.548), and peak elbow flexion (p=0.003, η2=0.618). Subsequent pairwise comparisons using ES found large effects for peak VGRF between males and females in the parallel technique (d=1.6), reverse technique (d=1.8), and a small effect in T-shape technique (d=0.4) (Figure 2A). Comparing RO techniques for the second contact hand demonstrated that the T shape hand position elicited significantly lower peak values of VGRF to the parallel (p=0.002) and reverse (p=0.003) hand positions in both sexes (Figure 2A). Comparing RO techniques for the second contact hand demonstrated that the T shape hand position elicited significantly lower peak values of internal adduction moments compared to the parallel (p = 0.000) and reverse (p=0.003) hand positions in both sexes. In addition, large ES values were found between males and females in the parallel (d=1.2) and reverse (d=1.2) hand positions (Figure 2B). ES statistics found differences in peak elbow flexion between males and females in the parallel technique (d=1.7), reverse technique (d=2.2) and T-shape technique (d=1.3) (Figure 2C). Comparisons of RO techniques for the second contact hand demonstrated that the T-shape hand position elicited significantly higher peak elbow flexion compared to the parallel (p=0.017) and reverse (p=0.007) hand positions in both sexes. Significant differences were also found between parallel and reverse hand positions (p=0.025) (Figure 2C).

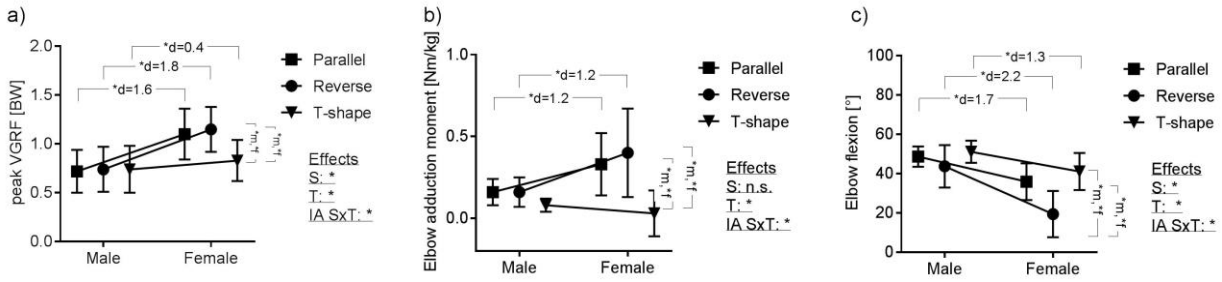

Figure 2: Means, standard deviations and statistical differences for (A) peak ground reaction forces, (B) internal adduction moment, (C) peak elbow flexion angles across all participants for the parallel, reverse and T-shape techniques during RO skills.

DISCUSSION: The aim of the study was to determine if sex differences exist in the key elbow and wrist joint injury risk factors during different RO techniques performed by young male and female artistic gymnasts. Young female gymnasts exhibited greater peak VGRF of the second contact hand during the RO in all three hand positions (Figure 2A). During RO skills in both sexes, peak VGRFs of the second contact hand was highest in the reverse technique followed by the parallel and then T-shape technique with the lowest peak VGRF (Table 1 and Figure 2A). These finding are in accordance with previous studies on elite and young female gymnasts (Farana et al., 2014; Farana et al., 2018) that highlighted that the T-shape hand position reduced peak VGRF of the second contact hand compared to other techniques of these fundamental skills. Current findings show significant differences for peak internal adduction moments in the RO (Table 1, Figure 2B) for parallel and reverse hand positions compared with the T-shape hand position for both sexes. This could be explained through the observations at the elbow joint, where male gymnasts demonstrated significantly higher elbow flexion across all three techniques (Table 1 and Figures 2C). Evidence from

previous studies has highlighted the role that elbow flexion plays in decreasing external and elbow internal loads. Chou et al. (2001) compared the elbow loads induced in forward falls, when elbows were flexed and fully extended. Results from the current study suggest that the elbow and its anatomical structure means that increased flexion accompanied by an increase in internal rotation during RO skills prevents abduction loading of the elbow joint. This finding concurs with Chou, Lou, Chen, Chiu & Chou (2009) who examined elbow load during falling onto an out stretched arm in three hand positions, concluding falls with the forearm internally rotated resulted in a greater elbow flexion and a 50% lower abduction load than those of falls with the forearm externally rotated. Thus, elbow flexion plays an important role in minimizing the risk of impact injury of the elbow joint. In addition, another potential cause of injury risk could be from the elbow joint anatomical perspective, through the observation that females show larger elbow carrying angles than males (van Roy, Baeyens, Fauvart, Lanssiers, & Clarijs, 2005). Consequently it can be speculated that young female gymnasts from the current study will have higher abduction loads during weight bearing conditions.

CONCLUSION: Female gymnasts exhibited significantly greater peak vertical ground reaction forces (VGRF), elbow and wrist compression forces and elbow internal adduction moments compared with male gymnasts. This could be due to differences in elbow joint flexion when increased flexion in young male gymnasts results in decrease in elbow and wrist loading. Injury risk factors including elbow extension and internal adduction moment with axial compression force suggest that a RO in reverse and parallel techniques can be hazardous especially for young female gymnasts.

REFERENCES:

Baker, C. L., & Romeo, A. A. (2010). Osteochondritis dissecans of the capitellum. *The American journal of sports medicine*, *38*, 1917-1928.

Chou, P. H., Chou, Y. L., Lin, C. J., Su, F. C., Lou, S. Z., Lin, C. F., & Huang, G. F. (2001). Effect of elbow flexion on upper extremity impact forces during a fall. *Clinical Biomechanics*, *16*(10), 888-894.

Chou, P. H., Lou, S. Z., Chen, H. C., Chiu, C. F., & Chou, Y. L. (2009). Effect of various forearm axially rotated postures on elbow load and elbow flexion angle in one-armed arrest of a forward fall. *Clinical Biomechanics, 24*, 632-636.

Cohen, J. (1988). *Statistical power analysis for the behavioral science* (2nd ed.). New Jersey, NJ: Lawrence Erlbaum.

Daly, R. M., Rich, P. A., Klein, R., & Bass, S. (1999). Effects of High-Impact Exercise on Ultrasonic and Biochemical Indices of Skeletal Status: A Prospective Study in Young Male Gymnasts. *Journal of Bone and Mineral Research, 14*, 1222–1230.

Farana, R., Exell, T., Strutzenberger, G., & Irwin, G. (2018). Technique selection in young female gymnasts: Elbow and wrist joint loading during the cartwheel and round-off. *European Journal of Sport Science, 18*, 423-430.

Farana, R., Jandacka, D., Uchytil, J., Zahradnik, D., & Irwin, G. (2014). Musculoskeletal loading during the round-off in female gymnastics: the effect of hand position. *Sports Biomechanics, 13*, 123–134.

Farana, R., Jandacka, D., Uchytil, J., Zahradnik, D., & Irwin, G. (2017). The influence of hand positions on biomechanical injury risk factors at the wrist joint during the round-off skills in female gymnastics. *Journal of Sports Sciences, 35*, 124-129.

Malina, R. M., Baxter-Jones, A. D., Armstrong, N., Beunen, G. P., Caine, D., Daly, R. M., ... & Russell, K. (2013). Role of intensive training in the growth and maturation of artistic gymnasts. *Sports Medicine*, *43*(9), 783-802.

Singh, S., Smith, G. A., Fields, S. K., & McKenzie, L. B. (2008). Gymnastics–related injuries to children treated in emergency departments in the United States, 1990–2005. *Pediatrics, 121*, 954–960.

Van Roy, P., Baeyens, J. P., Fauvart, D., Lanssiers, R., & Clarijs, J. P. (2005). Arthro-kinematics of the elbow: study of the carrying angle. *Ergonomics*, *48*, 1645-1656.

Acknowledgements

This research was supported by a Czech Science Foundation (GACR) [project no. 16-14133Y].