ELBOW AND WRIST JOINT LOADING IN GYMNASTICS: INJURY RISK IN ROUND OFF TECHNIQUE SELECTION

Roman Farana[1], Gerda Strutzenberger[2,1], Timothy Exell[3,1], Jiri Skypala[1] 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 current study was to investigate key elbow and wrist joint injury risk factors during different round-off (RO) techniques performed by young female artistic gymnasts. Ten active female gymnasts performed 30 successful trials of RO from a hurdle step with three different hand positions (parallel (10), T-shape (10) and reverse (10)). Synchronized kinematic and kinetic data were collected for each trial. One-way ANOVA and effect-size statistics determined differences between each hand position. Significant differences ($p<0.05$) and large ES (>0.8) among hand positions were found for peak VGRF, peak elbow and wrist compression force, and elbow internal adduction moment. Decrease in VGFR, elbow and wrist joint kinetics indicated that the T-shape technique may prevent elbow and wrist joint complex and reduces potential of injuries.

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

INTRODUCTION: Gymnastics is a sport in which the musculoskeletal system is exposed to extensive loads, which must be distributed through the elbow and wrist joints when the body is supported by the upper-extremities (Farana, Jandacka, Uchytil, Zahradnik & Irwin 2014; 2017). In gymnastics, the round-off (RO) is a fundamental skill and is defined as the primary way for gymnasts to change from forward-rotating to backward-rotating movements. Previous research by Farana et al. (2014 and 2017) examined injury risk and technique selection associated with the choice of hand placement in RO skills performed by elite female gymnasts. These authors found that the T-shape hand position reduced vertical, horizontal and resultant ground reaction forces (GRF), decreased elbow joint moments (Farana et al., 2014) and axial compression force applied on the wrist joint compared to a parallel hand position (Farana et al., 2017), indicating a safer technique for the RO skill. Previous gymnastics research showed that serious injuries, such as osteochondritis of the humeral capitellum (Chan, Aldridge, Maffulli & Davies) and distal radius physeal stress fracture (DiFiori, Caine, Malina 2002) may affect the elbow and wrist joints of young gymnasts in the age of 10–14 years (Gabel, 1998). These injuries are primarily a disorder of the young adolescent athletes, typically involved in a highly repetitive loading activity such as gymnastics (Baker, Romeo, & Baker 2010). In general, there is a lack of research that has focused on the different hand placement during fundamental skills (i.e. RO) of young female gymnasts. Moreover, observations within gymnastics trainings and competitions shows that gymnasts often use three different hand positions during RO skills (parallel, T-shape and reverse) (Figure 1). Therefore, the aim of the current study was to investigate key elbow and wrist joint injury risk factors including impact forces, elbow and wrist joint kinetics during different RO techniques in female artistic gymnastics. It was hypothesized that the reverse and parallel technique would increase upper limb injury risk factors included external forces, elbow and wrist kinematics and kinetics.

METHODS:

Participant & Protocol: Ten young active female gymnasts, with more than 5 years' experience with systematic training and competitive gymnastics, from Czech Republic

participated in the current study (age: 10.3 ± 1.4 years, height: 1.40 ± 0.8 m and mass: 31.9 ± 4.8 kg). Informed assent and parental consent was obtained from each gymnast and her 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.

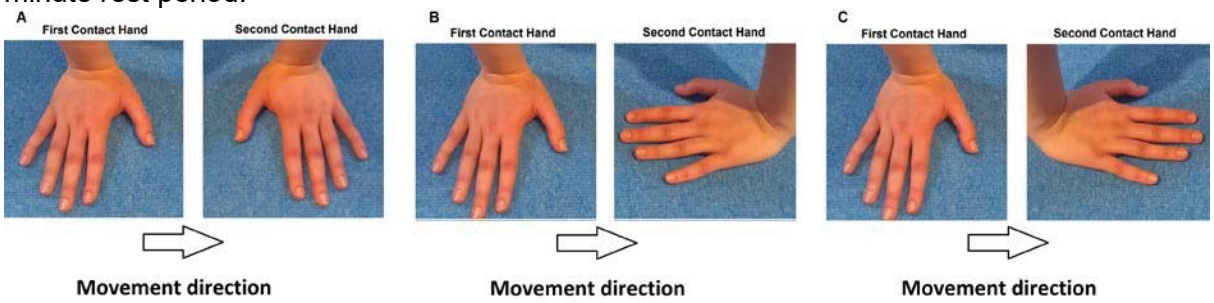

Figure 1: Round-off hand positions (A) Parallel, (B) T-shape and (C) Reverse.

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. Key injury risk variables included peak vertical GRF (VGRF), elbow joint internal adduction moment and elbow and wrist joint vertical reaction forces. 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. One-way repeated measure ANOVA and effect-size (ES) statistics determined significant differences between each hand position. The significance level was set at $p < 0.05$. ESs were interpreted as trivial (<0.2), small (0.21–0.5), medium (0.51–0.8), or large (>0.8) (Cohen, 1988).

RESULTS: Means, standard deviations and effect size values for VGRFs, elbow and wrist joint kinematics and kinetics for all techniques of RO skills are displayed in Table 1.

Table 1
Ground reaction forces and elbow joint kinetics of the second contact hand during round off with three different hand positions.

Variable	parallel technique	T-shape technique	reverse technique	ES (PxT)	ES (PxR)	ES (TxR)
Peak VGRF (BW)	1.07±0.25	0.81±0.19[ab]	1.11±0.23	**1.2**	0.2	**1.4**
Elbow adduction moment (Nm/kg)	0.36±0.19	-0.11±0.20[ab]	0.41±0.25	**2.4**	0.2	**2.3**
Elbow vertical RF (N/kg)	-7.90±1.67	-6.34±1.53[b]	-8.48±2.15	**1.0**	0.3	**1.1**
Wrist vertical RF (N/kg)	-9.41±2.12	-7.41±1.90[b]	-9.90±2.13	**1.0**	0.2	**1.2**
Wrist dorsiflexion (°)	-59.31±12.18	-64.40±13.65	-58.57±12.80	0.4	0.1	0.4

Notes: VGRF, vertical ground reaction force; BW, body weight; RF, reaction force; [a] = significantly different from parallel technique; [b] = significantly different from reverse technique; ES, effect size.

The highest magnitude of VGRF was observed in the reverse technique (Table 1 and Figure 2A). Significant differences and large effect sizes were found between parallel and T-shape techniques ($p=0.04$, ES=1.2) and between reverse and T-shape technique ($p = 0.018$, ES = 1.4). As for elbow joint internal adduction moment, significant differences and large effect

sizes were observed between parallel and T-shape technique (p=0.000, ES=2.4), and between T-shape and reverse technique (p=0.000, ES=2.3). The highest magnitude of elbow internal adduction moment was observed in the parallel technique (Figure 3 and Table 1).

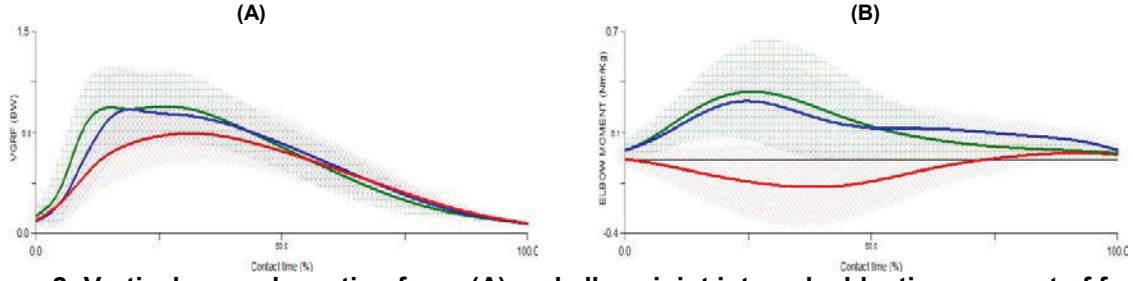

Figure 2: Vertical ground reaction force (A) and elbow joint internal adduction moment of force (B) profiles of the second contact hand in parallel (blue), T-shape (red) and reverse (green) techniques.

Elbow joint vertical reaction force displayed significant difference and large effect size between reverse and T-shape techniques (p=0.04, ES=1.1), no significant differences but large effect size were found between T-shape and parallel techniques (p=0.194, ES=1.0). The highest magnitude of elbow joint reaction force was observed in the reverse technique (Table 1, Figure 3A). As for wrist joint vertical reaction force, a significant difference and large effect size was found between T-shape and reverse techniques (p=0.034, ES=1.2, nearly perfect). No significant difference but a large effect size was found between parallel and T-shape techniques (ES=1.0). The highest magnitude of wrist joint reaction force was observed in the reverse technique (Table 1 and Figure 3B). No significant differences were found in wrist joint dorsiflexion (Table 1).

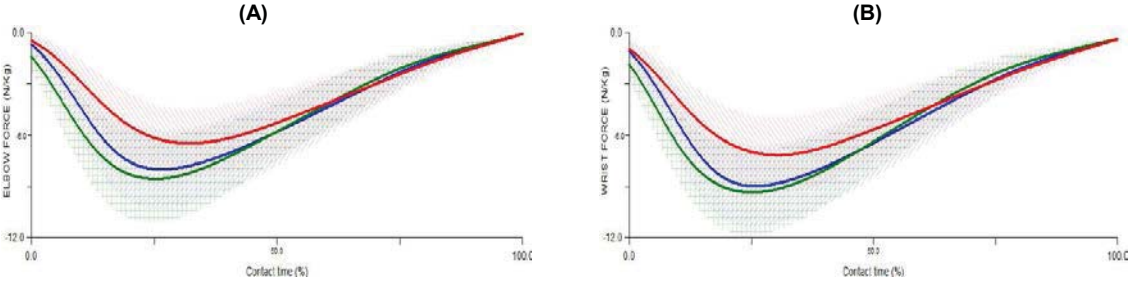

Figure 3: Wrist joint compression force (A) and elbow joint compression force (B) profiles of the second contact hand in parallel (blue), T-shape (red) and reverse (green) techniques.

DISCUSSION: The current study provided basic insights into how impact forces and elbow and wrist joint kinetics are associated with different hand positions during ground contact of the second hand during RO skills performed by young female gymnasts. We accepted our hypothesis, that the reverse technique would increase upper limb injury risk factors included external forces, elbow and wrist kinematics and kinetics. Previously, Farana et al. (2014) highlighted that, T-shape hand positions reduced peak VGRF of the second contact hand compared to the parallel technique. In the current study, peak VGRF of the second hand was higher in the parallel and reverse techniques compared with the T-shape technique (Table 1, Figure 2A). From an injury perspective, these observations concur with the comments of Davidson, Mahar, Chalmers and Wilson (2005), who stated, that peak impact forces are among the fundamental injury risk factors associated with the upper limb in gymnastics. Previous studies highlighted an important role of a forearm rotation on the elbow and wrist joint loading during the RO in female elite gymnasts (Farana et al., 2014; Farana et al., 2017). Current findings found significant differences and large effect sizes for peak internal adduction moment in the RO with parallel and reverse hand position compared with the T-shape hand position (Table 1, Figure 2B). These findings are in accordance with previous

research (Farana et al. 2014), identifying significantly lower magnitudes of internal adduction moment in the T-shape technique compared with parallel hand position during the RO performed by elite female gymnasts. Furthermore, significantly higher magnitudes of elbow joint vertical reaction force were observed in the reverse technique compared with the T-shape technique (Table 1, Figure 3A). Previous findings by Koh, Grabiner and Weiker (1992) indicated, that these compression forces and sizeable adduction moments placed on the elbow joint may be responsible for chronic injuries. In the current study, significantly higher magnitudes of wrist joint vertical reaction force were found in the reverse technique compared with the T-shape technique (Figure 3B). It has been highlighted that these compressive loads are transmitted through the carpals to the radius and ulna, with the radius accepting approximately 80% of the load (DiFiori et al., 2002). Evidence from previous research has identified that repetitive loads placed on the wrist joint can lead to distal radius stress injury (DiFiori et al., 2002). Findings from the current study further reinforce and support use of the T-shape technique of the RO skill. These results have implications for injury, when potential risk factors are identified and the process of technique selection may be more objective and safe.

CONCLUSION: The reverse technique increases peak VGRF, elbow and wrist compression forces and elbow internal adduction moment. These differences indicated, that the reverse technique of RO may increase the potential of elbow and wrist injuries in young gymnasts.

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