

## THE EFFECT OF DIFFERENT HAND POSITION ON IMPACT FORCES AND ELBOW LOADING DURING THE ROUND OFF IN FEMALE GYMNASTICS

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Elbow injuries from tumbling in gymnastics present a real problem for performers. The aim of this study was to determine whether differences in hand position during the round-off influence the contact forces and elbow joint moments in female gymnasts. Five international level female gymnasts performed 10 trials of 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. T-test and effect size statistics established differences. In conclusion the “T” position of the second hand reduces vertical and antero-posterior contact forces. Differences in joint elbow moments indicated that “T” position may prevent elbow joint complex and reduces potential of elbow injuries.

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

**INTRODUCTION:** In gymnastics the upper extremities are used as weight-bearing limbs causing high impact loads to be distributed through the elbow and wrist (Webb & Rettig, 2008). Gymnastics training was associated with on average more than 100 impacts per one training session on the upper extremities with peak magnitudes of 3.6 body weight (Daly, Rich, Klein, & Bass, 1999). Lindner and Caine (1990) identified the floor exercise event as the most hazardous gymnastics event and most injuries happened with skills that were basic or moderately difficult and well-established. In the sport of artistic gymnastics the round-off is a fundamental gymnastics skill and a key movement in the development of elite female gymnasts, owing to its association with learning more complex skills. The elbow is an integral link in the athlete's upper extremity function transferring force, position, and load-bearing capability to the hand (Guerra & Timmerman, 1996). Chronic elbow strain is an injury involving inflammation or fracture, which is caused by repeated bending, stretching or rotating of the elbow over long period of time, or by squeezing from external force (Qu, Liu, & Li, 2000). Cossens (2012) hypothesised that the “T” shape hand position during round-off hand contact phase may be used to reduce weight bearing load through the elbow. However, this hypothesis is not yet supported by any biomechanical research. Currently, there appears to be little or no studies in the literature that investigate the mechanism of injury and injury prevention of the elbow joint during round off with two different hand positions. The aim of this study was to determine whether the differences in hand position during the round-off may influence the ground reaction forces and elbow joint moments in female artistic gymnastics.

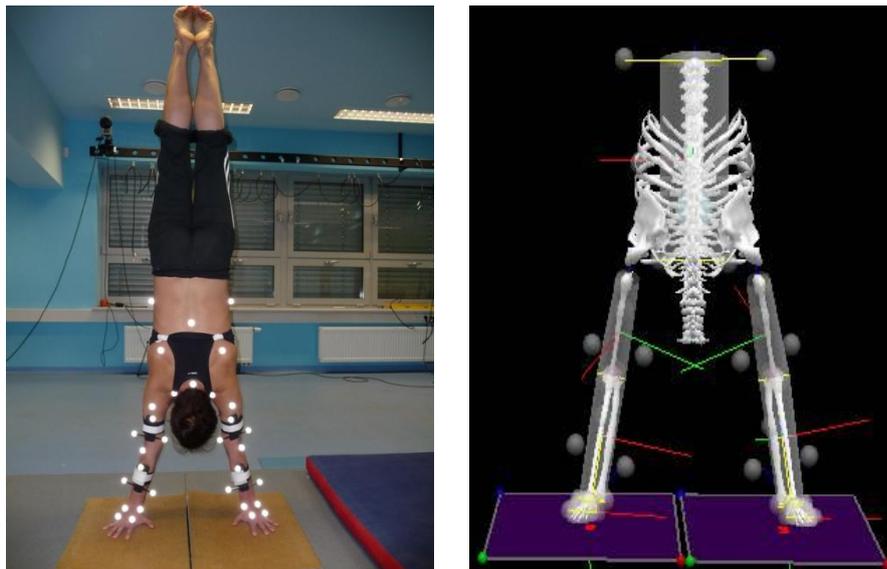
### **METHODS:**

**Participants & Protocol:** Five international level active female gymnasts from Czech Republic participated in this study. All gymnasts had no upper extremity injury history and at the time of testing they were injury-free. All procedures were orally explained to each gymnast and informed consent was obtained in accordance with the guidelines of the University of Ostrava Ethics Committee. The research was conducted in the biomechanical lab of the Human Motion Diagnostic Centre. The gymnasts completed their usual warm up and completed a number of practice round-off trials with different hand positions, three trials for both techniques. 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 warm up and practice trials each gymnast

performed 10 trials of round-off from a hurdle step to back handspring with “parallel” hand position (n=50) and 10 trials of round-off from a hurdle step to back handspring with “T” shape hand position (n=50). All trials were performed with a maximal effort from a technical perspective, 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. The coordinate data were low-pass filtered using the fourth-order Butterworth filter with a 12 Hz cut off frequency. All force plate data were low-pass filtered using the fourth-order Butterworth filter with a 50 Hz cut off frequency.

**Data analysis:** The marker data were processed using the Visual 3D software (C-motion, Rockville, MD, USA). All upper extremity segments were modelled as frusta of right circular cones and trunk as a cylinder (Figure 1). The local coordinate systems were defined using a standing calibration trial in handstand position (Figure 1). All analysis focused on the contact phase of the second hand during the round off. Kinetic variables included peak vertical ground reaction force (VGRF) and peak anterior-posterior ground reaction force (APGRF); temporal characteristics of these forces; and peak elbow joint moments in transversal (- internal rotation, + external rotation), frontal (- varus; + valgus) and sagittal (- flexion; + extension) plane. The net three dimensional joint moments for the upper extremity joints were calculated using Newton-Euler inverse dynamics technique (Hamill & Selbie, 2004). Net joint moments are expressed in the local coordinate system in the local coordinate system of the upper arm. Effect size statistics were used to establish differences in means. Statistical significance in variables were quantified using paired t-tests with alpha set to a conservative 0.01. Effect sizes (*ES*) were calculated and interpreted as <0.2 trivial; 0.2-0.5 small; 0.5-0.8 medium and >0.8 large (Cohen, 1988). Statistical analyses were performed using IBM SPSS Statistics 20 and Microsoft Excel software.



**Figure 1: Handstand calibration trial, marker placement on gymnast body. Model of trunk and upper extremities from C-motion software.**

**RESULTS:** Means and standard deviations for ground reaction forces and temporal characteristics for ground reaction forces for both type of round offs are displayed in Table 1. Significant differences were found for peak VGRF ( $p<0.01$ ) and peak APGRF ( $p<0.01$ ). In both these variables we found also large effect sizes, for peak VGRF ( $ES=0.84$ ) and for peak APGRF ( $ES=1.05$ ). Significant differences ( $p<0.01$ ) and moderate effect sizes were found for time to peak VGRF ( $ES=0.53$ ) and time to peak APGRF ( $ES=0.77$ ).

Table 1

Ground reaction forces and temporal characteristics of ground reaction forces of second contact hand during round off with two different hand positions.

| Variable               | “P” position  | “T” position  | ES   | Sig. |
|------------------------|---------------|---------------|------|------|
| Peak VGRF (BW)         | 1.67 ± 0.17   | 1.48 ± 0.27   | 0.84 | **   |
| Peak APGRF (BW)        | -0.59 ± 0.06  | -0.51 ± 0.09  | 1.05 | **   |
| Time to peak VGRF (s)  | 0.049 ± 0.009 | 0.054 ± 0.010 | 0.53 | **   |
| Time to peak APGRF (s) | 0.050 ± 0.008 | 0.057 ± 0.010 | 0.77 | **   |

ES, effect size; \* $p<0.05$ ; \*\* $p<0.01$

Means and standard deviations for elbow joint moments for both type of round offs are displayed in Table 2. Significant differences ( $p<0.01$ ) were found for all elbow joint moments. Also large effect sizes were found for elbow joint moment in transversal ( $ES=2.18$ ), frontal ( $ES=1.45$ ) and sagittal ( $ES=0.95$ ) plane.

Table 2

Elbow joint moments of second contact hand during round off with two different hand positions.

| Variable                         | “P” position | “T” position | ES   | Sig. |
|----------------------------------|--------------|--------------|------|------|
| Elbow moment transversal (Nm/kg) | -0.12 ± 0.03 | -0.21 ± 0.05 | 2.18 | **   |
| Elbow moment frontal (Nm/kg)     | 0.85 ± 0.19  | 0.52 ± 0.26  | 1.45 | **   |
| Elbow moment sagittal (Nm/kg)    | -0.50 ± 0.16 | -0.63 ± 0.11 | 0.95 | **   |

ES, effect size; \* $p<0.05$ ; \*\* $p<0.01$ ; values for transversal plane (-) internal rotation; for frontal plane (+) valgus; for sagittal (-) flexion

**DISCUSSION:** Sports biomechanics plays a vital role in understand factors that may influence injury, with this in mind the aim of this study was to increase understanding of whether differences in hand position during round-off influence the ground reaction forces and elbow joint moments in female artistic gymnastics. The comparison of different round off techniques provided basic insights into how ground reaction forces values are associated with different hand position during ground contact of second hand. Previous study by Koh, Grabiner, and Weiker (1992) stated that during the back handspring hand producing large compression forces and may contribute to upper-extremity injuries. In current study peak VGRF of second hand was higher in parallel position and also there was higher peak APGRF in parallel position. Seeley and Bressel (2005) reported that high peak reaction forces during round-off phase of Yurchenko vault may be responsible for upper extremities injuries. Moreover, Whiting & Zernicke (2008) states that peak forces are the most fundamental element in injury and magnitude of force is a key injury-causing factor. Also longer time of peak VGRF and peak APGRF in “T” position indicated higher loading rate during parallel position. This high loading rate may be an upper extremity injury risk factor (Whiting & Zernicke, 2008). In the current study the “T” hand position reduced VGRF and APGRF produced by the second hand and also time to peak of these forces is longer. In this point of view “T” hand position may provide more safety technique of this skill.

In the current study significantly higher peak elbow joint moments in transversal plane were found in round off with “T” position which may be associated with internal rotation of forearm during round off in this position. The study by Sands and McNeal (2006) showed that by turning the hands inward during back handspring the female gymnasts may reduce the problem of injuring an elbow and also reduce the risk of damage to the wrist. Significantly

higher peak elbow joint moment in sagittal plane may associate with higher elbow flexion during round off in “T” position. Moreover, the greater valgus elbow moment was found in round off with parallel hand position in compare with “T” hand position (Figure 3). Based on the literature, repetitive valgus stress leads to microtraumatic and chronic elbow injuries (Field & Savoie, 1998; Hume et al., 2006). Thus, it is possible that this valgus moment during the round off in parallel position may be, for the gymnasts in current study, a high risk factor for elbow injury. Study by Koh et al. (1992) founded that correlations of measures of elbow angle and measures of reaction force showed that large elbow flexion during back handspring may protect the elbow joint from large valgus moments.

**CONCLUSION:** Observations from the current study provide initial findings and information about different hand position during fundamental gymnastics skill, the round off. In conclusion “T” position of second hand reduces vertical and antero-posterior ground reaction forces. Differences in joint elbow moments indicated that “T” position may prevent elbow joint complex and reduces potential of elbow injuries. The ecological validity of this study and the fine-grained scientific theory provide a useful mechanism that will help coaches, athletes and clinicians potentially reduce the occurrence of injury.

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