INFLUENCE OF DIFFERENT HAND POSITIONS ON IMPACT FORCES AND ELBOW LOADING DURING THE ROUND OFF IN GYMNASTICS: A CASE STUDY

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A case study

Abstract

The round-off is a fundamental gymnastics skill and a key movement in the development of elite female gymnasts. The aim of this study was to determine whether differences in hand position during the round-off may influence the ground reaction forces and elbow joint moments in female artistic gymnastics. One international level active female gymnast from the Czech Republic participated in this study. Two force plates were used to determine ground reaction forces. A motion-capture system consisting of eight infrared cameras were employed to collect the kinematic data. The gymnast performed 10 trials of a round-off from a hurdle step to back handspring with a "parallel" hand position and 10 trials with a "T" shape hand position. Effect size statistics were used to establish differences in means. In conclusion "T" position of the second hand reduces vertical and anterior-posterior ground reaction forces. Differences in joint elbow moments and elbow kinematics indicated that the "T" position may prevent elbow joint complex and reduces potential of elbow injuries.

Keywords: *biomechanics, gymnastics, round-off, upper extremities, prevention*

INTRODUCTION

One of the most serious problems faced by contemporary gymnasts is the occurrence of injury (Sands, 2000). One of the aims of sports biomechanics is to prevent injury (Zatsiorsky, 2000; McGinnis, 2005). Consequently, targeted injury prevention strategies, based on biomechanical analyses, have the potential to help reduce the incidence and severity of gymnastics injuries (Bradshaw & Hume, 2012). Training loads in gymnastics are typically quantified by assessing weekly hours of gymnastics specific training (Burt, Naughton, Higham, & Landeo, 2010).

Gymnastics training has been 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). One of the specific training characteristics in female gymnastics is the alternation of support between upper and lower limbs, with the upper extremities often used for weight-bearing therefore, receiving high impacts in both the elbow and wrist (Amaral, Claessens, Ferreirinha, & Santos, 2011). 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). A previous study by Koh, Grabiner and Weiker (1992) showed that a combination of high reaction forces and corresponding joint valgus moments during back handspring may contribute to the occurrence of lateral compression injuries of the elbow complex.

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 (e.g. back handspring with/without multiple somersaults, Tsukahara and/or Yurchenko vaults). Lindner and Caine (1990) identified the floor exercise event as the most hazardous gymnastics event and most injuries happened with moves that were basic or moderately difficult and well-established. McIntosh and Davis (1997) investigated osteochondritis dissecans of the elbow and saw greater injury incidences in the second hand of the round-off. Panzer et al. (1987) stated that during the Tsukahara vault elbow joint reaction forces ranged from 1.7 – 2.2 body weight (BW). Seeley and Bressel (2005) examined reaction forces transmitted to the upper extremities of high level gymnasts during the round-off phase of the Yurchenko vault and round-off on the floor exercise. They stated that vertical and anterior-posterior reaction forces, normalized to body weight, were greater ($p<0.05$) during the round-off phase of the Yurchenko vault (2.38 BW vertical and 0.78 BW anterior-posterior) than during the floor exercise round-off (2.15 BW vertical and 0.60 BW anterior-posterior). Cossens (2012) hypothesis 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 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 position.

The aim of this study was to determine whether the differences in hand position during round-off may influence the ground reaction forces and elbow joint moments in female artistic gymnastics. The overall purpose being to bring to the training practice information on the issue of injury prevention of the upper extremity in gymnastics, which will be particularly useful for coaches, clinicians and scientist.

METHODS

Participant

One international level active female gymnast from Czech Republic participated in this study. Gymnast age, height and mass were 22 years, 165 cm and 60 kg. The gymnast was a former member of the junior and senior national team of Czech Republic with more than 15 years experience with systematic training and competitive gymnastics. The gymnast was many times winner of national and international competitions and also three times participated on Teamgym European Championship. The gymnast had no previous history of upper extremities injury and at the time of testing was injury-free. The aim of research and all procedures were orally explained to the gymnast and informed consent was obtained in accordance with the guidelines of the University and Human Motion Diagnostics Centre Ethics Committee.

Experimental set-up

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 and synchronized with force plates. Before the testing session, a right handed global coordinate system were employed and defined using an L-frame with four markers of the known location. A two-marker wand of the known length was used to calibrate the global coordinate system. The global coordination system was set up so that the z-axis was vertical, y-axis was in anterior-posterior and the x-axis was in the medio-lateral direction. Data from the force plates and the cameras were collected simultaneously. Retroreflective markers (diameter of 19 mm) were attached to the gymnasts' upper limbs and trunk (Figure 1) according to a recommendation of the C-motion Company (C-motion, Rockville, MD, USA).

Figure 1. *Marker placement on gymnast body.*

Markers were placed on each participant at the following body location: left and right acromio-clavicular joints, left and right shoulders, left and right lateral epicondyle of humerus, left and right medial epicondyle of humerus, left and right radius-styloid, left and right ulna-styloid, left and right head of second metacarpal, left and right head of fifth metacarpal, seventh cervical vertebrae, left and right illiac crest tubercle, left and right angulus inferior of scapula, tenth thoracic vertebrae. Two clusters with three markers were placed on left and right upper arm a left and right forearm. Two photocells were used to controlled hurdle step velocity. Based on pilot study the hurdle step velocity was standardized at range of 3.3 – 3.7 m/s.

Protocol

One week prior testing gymnast was asked to practice both techniques as a part of her training session. At each floor training session the gymnast was asked to perform 10 trials of round-offs to back handspring with "parallel" hand position and 10 trials with "T" shape position.

The research was conducted in the biomechanical lab of the Human Motion Diagnostic Centre. The gymnast completed her usual warm up and completed a number of practice round-off trials with different hand position, 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 (Figure 2).

Figure 2. *A thin floor mats at each force plate and mat for handspring and landing.*

First technique was defined with "parallel" hand position on the ground (Figure 3). Second technique was defined with "T" shape hand position on the ground. After warm up and practice the gymnast performed 10 trials of a round-off from a hurdle step to back handspring with "parallel" hand position and 10 trials of round-off from a hurdle step to back handspring with "T" shape hand position. Before each trial, the gymnast applied gymnastic chalk to her hands to allow the research a measure of her prescribed hand placement. All trials were performed with a maximal effort from a technical perspective and separated by a one minute rest period.

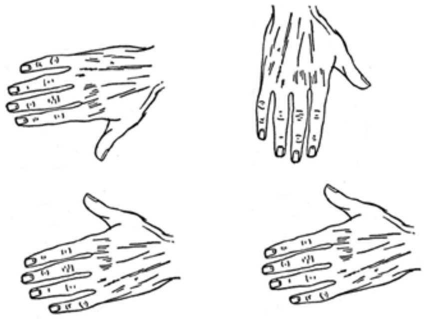


Figure 3. *“Parallel” hand position and “T” shape hand position.*

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. The local coordinate systems were defined using a standing calibration trial in handstand position (Figure 4).

Figure 4. *Handstand calibration trial and marker placement on gymnast body.*

All analysis focused on the contact phase of the second hand during the round off. Kinematic variables included sagittal, frontal and transverse elbow angles. Kinetic variables included peak vertical, anterior-posterior and medio-lateral ground reaction forces; temporal characteristics of these forces; and elbow joint moments in sagittal, frontal and transversal plane. The net three dimensional joint moments for the upper extremity joints were calculated a using Newton-Euler inverse dynamics technique (Hamill & Selbie, 2004). Net elbow moments are expressed in the local coordinate system of the proximal segment (upper arm). The coordinate data were low-pass filtered using the fourth-order Butterworth filter with a 12 Hz cutoff frequency. All force plate data were low-pass filtered using the fourth-order Butterworth filter with a 50 Hz cutoff frequency.

Statistical analysis

Means and standard deviations (*M* ± *SD*) were calculated for all measured variables. Effect size statistics were used to establish differences in means. Effect sizes (*ES*) were calculated and interpreted as <0.2 trivial, 0.2 - 0.6 small, 0.6 - 1.2 moderate, 1.2 - 2.0 large, 2.0 - 4.0 very large and >4.0 nearly perfect (Hopkins, 2002). The effect of >1.2 was considered to be practically significant (Manning, Irwin, Gittoes, & Kerwin, 2011).

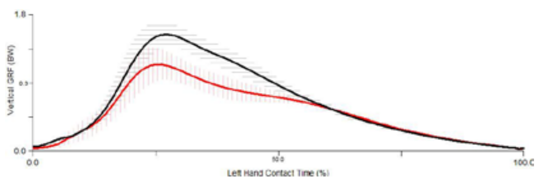
RESULTS

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. The results of this case study showed that there are differences in impact characteristics between different hand positions during round off. Effect size statistics showed a *very large* effect size (ES=2.55) for peak vertical ground reaction force with decrease of 0.26 BW in vertical ground reaction force between “T” position in compare with “Parallel” position (Figure 5a). There was also *nearly perfect* effect size (ES=6.00) with decrease of 0.18 BW in peak anterior-posterior ground reaction force in “T” position compared with “Parallel” position (Figure 5b). A *very large* effect size (ES=2.33) was founded in time to peak vertical ground reaction force and in “T” position peak of this force become of 0.007 s earlier than in “Parallel” position (Table 1).

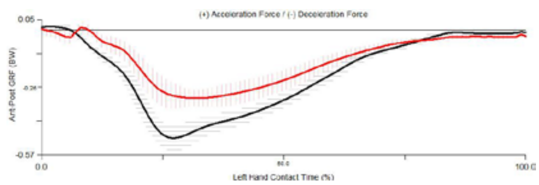
Means and standard deviations for left elbow internal moments for both type of round offs are displayed in Table 2. Effect size statistics showed *nearly perfect* effect size in peak elbow joint moment in transversal plane (ES=6.32) with increased in “T” position in compare with “Parallel” position (Figure 6a). *Nearly perfect* effect size was found in peak elbow joint moment in frontal plane (ES=6.67) with decrease in “T” position in compare with “Parallel” position (Figure 6b). *Very large* effect size was found in peak elbow joint moment in sagittal plane (ES=2.35) with increase in “T” position in compare with “Parallel” position (Figure 6c).

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	Effect size	Effect
Peak VGRF (BW)	1.50 ± 0.12	1.24 ± 0.08	**2.55**	**very large**
Peak APGRF (BW)	-0.49 ± 0.03	-0.31 ± 0.03	**6.00**	**nearly perfect**
Peak MLGRF (BW)	-0.12 ± 0.02	-0.10 ± 0.03	0.78	moderate
Time to peak VGRF (s)	0.050 ± 0.003	0.043 ± 0.003	**2.33**	**very large**
Time to peak APGRF (s)	0.050 ± 0.003	0.049 ± 0.004	0.28	small
Time to peak MLGRF (s)	0.081 ± 0.041	0.060 ± 0.039	0.52	small



5a

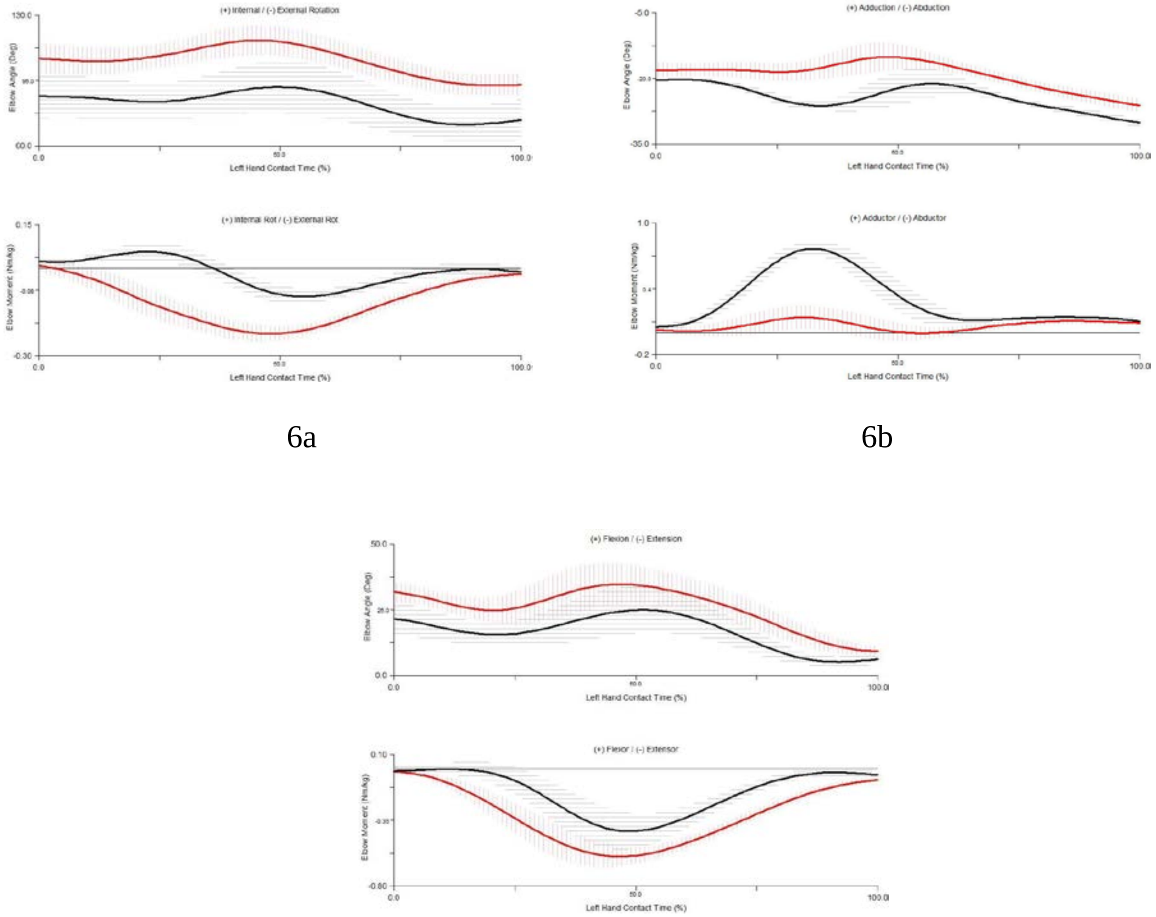


5b

Figure 5. *Vertical (5a) and anterior-posterior (5b) ground reaction forces of second (left) hand over normalized time (%) during round off. Black curve shows mean and standard deviation of “Parallel” position, red curve shows mean and standard deviation of “T” position.*

Table 2. *Left elbow internal joint moments of second contact hand during round off with two different hand positions.*

Variable	“P” position	“T” position	Effect size	Effect
Peak elbow joint transversal moment (Nm/kg)	-0.10 ± 0.02	-0.20 ± 0.01	**6.32**	**nearly perfect**
Peak elbow joint frontal moment (Nm/kg)	0.79 ± 0.06	0.24 ± 0.10	**6.67**	**nearly perfect**
Peak elbow joint sagittal moment (Nm/kg)	-0.55 ± 0.09	-0.73 ± 0.06	**2.35**	**very large**



6a 6b

6c

Figure 6. *Left elbow angle and left elbow internal moments over normalized time during round off in transversal (internal/external rotation) (a); frontal (adduction/abduction) (b); and sagittal (flexion/extension) (c) plane. Black curve shows mean and standard deviation of "Parallel" position, red curve shows mean and standard deviation of "T" position.*

DISCUSSION

One of the major challenges in gymnastics is to identify specific techniques, for performing skills that increase the potential for injury. This study aimed to explain 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 trials type provided basic insights into how ground reaction forces values are associated with different hand position during ground contact of second hand. In our case study, peak of vertical reaction force of second hand was higher in parallel position (Figure 5a). Also there was higher anterior-posterior reaction force in parallel position (Figure 5b). In "T" position values for vertical and anterior-posterior reaction forces was lower compared to values reported during the Yurchenko vault and floor exercise round-off (Seeley & Bressel, 2005). Koh et al. (1992) states that during back handspring hand producing large compression forces and may contribute to upper-extremity injuries. Based on literature, peak force is the most fundamental element in injury and magnitude of force is a key injury-causing factor (Whiting & Zernicke, 2008). Whereas, in current study the "T" hand position reduced vertical and anterior-posterior ground reaction forces produced by the second hand and in this point of view provides safety technique of this skill.

In present study the greater peak elbow internal joint moment in transversal plane was found in round off with “T” position in compare with “parallel”. This is associated with internal rotation of forearm during round off in “T” position (Figure 6a). Moreover, the greater internal adduction elbow moment (valgus stress) was found in round off with parallel hand position in compare with “T” hand position (Figure 6b). Hume, Reid and Edwards (2006) stated that chronic elbow injuries typically stem from overuse and valgus stress. Repetitive valgus stress placed on the joint can lead to microtraumatic injury and valgus instability (Field & Savoie, 1998). Moreover, Grana (2001) stated that repeated valgus loading can presage medial epicondylitis. Thus, it is possible that this internal adduction moment during the round off in parallel position maybe, for the gymnast from our study, a high risk factor for elbow injury. The study by Sands and McNeal (2006) showed that by turning the hands inward during back handspring the gymnasts, particularly females, can reduce the problem of injuring an elbow (due to the carrying angle) and reduce the risk of damage to the wrist (by reducing wrist hyperextension). Observations from these results concur and found greater peak elbow joint internal moment in sagittal plane which is associated with greater elbow flexion during round off in “T” position (Figure 6c). Chou et al. (2001) stated that during fall with outstretched hand the action of flexion could decrease the maximal axial force of elbow and delay the time of peak, thus it can provide enough time to adjust and avoid the injury. Also, Koh et al. (1992) found that correlations of measures of elbow angle and measures of reaction force showed that elbow flexion during back handspring may protect the elbow joint from large valgus loads.

CONCLUSIONS

This case study brings some new findings about different hand position during fundamental gymnastics skill, the round off. In conclusion “T” position of second hand reduces vertical and anterior-posterior ground reaction forces. Differences in joint elbow moments and elbow kinematics indicated that “T” position may prevent elbow joint complex and reduces potential of elbow injuries. These findings provide a foundation to investigate this area further, with a larger sample and more detailed kinematics and kinetic analysis. Next stage of our research will be focus on understanding of kinetics of elbow joint complex during these two variations of this skill with overall purpose to bring to the training practice the initial findings and information on the issue of injury prevention of the upper extremity in gymnastics. 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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