Title:

The influence of hand positions on biomechanical injury risk factors at the wrist joint during the round-off skills in female gymnastics

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Key words:

biomechanics, gymnastics, fundamental skill, technique selection, injury prevention

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Abstract

The aim of this study was to examine the biomechanical injury risk factors at the wrist, including joint kinetics, kinematics and stiffness in the first and second contact limb for parallel and T-shape round-off (RO) techniques. Seven international-level female gymnasts performed 10 trials of the RO to back-handspring with parallel and T-shape hand positions. Synchronized kinematic (3D motion analysis system; 247 Hz) and kinetic (two force plates; 1235 Hz) data were collected for each trial. A two-way repeated measure ANOVA assessed differences in the kinematic and kinetic parameters between the techniques for each contact limb. The main findings highlighted that in the both RO techniques the second contact limb wrist joint is exposes to higher mechanical loads than the first contact limb demonstrated by increased axial compression force and loading rate. In the parallel technique the second contact limb wrist joint is exposing to higher axial compression load. Differences between wrist joint kinetics highlight that the T-shape technique may potentially lead to reducing these bio-physical loads and consequently protect the second contact limb wrist joint from overload and biological failure. Highlighting the biomechanical risk factors facilitates the process of technique selection making more objective and safe.

Key words: biomechanics, gymnastics, fundamental skill, technique selection, injury prevention

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Introduction

Developing understanding of the biomechanical risk factors that predispose athletes to injury is a fundamental in developing knowledge of injury aetology. The sport of gymnastics provides as a unique set of circumstance with the gymnasts frequently uses the upper extremities to support body weight (DiFiori, Caine, & Malina, 2006). Repetitive weight-bearing impacts onto the hands resulting in compressive forces can lead to both acute and chronic injuries to the upper extremities in young gymnasts (Davidson, Mahar, Chalmers, & Wilson, 2005). Gymnasts are often involved in activities requiring weight-bearing with their wrist in dorsiflexion, such as the beam, tumbling, vault, and floor routines. During these activities the wrist is exposed to mechanical stress, including repetitive motion, high impact loading, axial compression, torsional forces, hyper-dorsiflexion, ulnar and radial deviations, and is the most frequently injured site in the upper extremity of female gymnasts followed by the elbow (Webb & Rettig, 2008). Previous studies show that during gymnastics weight-bearing activities expose the wrist to forces that can exceed twice body weight (BW) and loading rates up to 16 times BW (Markoff, Shapiro, Mandelbaum, & Teurling, 1990; Koh, Grabiner, & Weiker, 1992).

The floor exercise is the most frequently associated with wrist pain in female gymnasts. Moreover, research by Lindner and Caine (1990) highlighted the floor exercise as the most hazardous gymnastics event, whilst injuries happened with skills that are basic or moderately difficult as well as well established. Farana et al. (2014) stated that in the more fundamental skills of gymnastics, the high frequency of performance repetition may have a significant influence on injury potential.

Previous studies investigated upper limb loading and risk factors during the performance of floor fundamental gymnastics skills e.g., back handspring (Davidson et al., 2005; Koh, Grabiner, & Weiker, 1992), front handspring (Exell, Irwin, Godden, & Kerwin, 2012; Exell, Robinson, & Irwin, in press) and round-off (Seeley & Bressel, 2005; Farana et al., 2014). With gymnasts' preforming high volumes of these skills within a session and across seasons the implications for micro traumas become apparent. The mechanical load affects the nature and severity of injury particularly at vulnerable joints such as the elbow and the wrist (Irwin, 2011). Koh et al. (1992) used force analysis of six young female gymnasts to show that reaction forces at the hand during back handsprings produced large compression forces higher than 2 times BW. Seeley and Bressel (2005) reported that vertical and anterior–posterior reaction forces were significantly greater during the round-off (RO) phase of the Yurchenko vault (vertical: 2.38 BW; anterior–posterior: 0.78BW) than during the floor exercise RO (vertical: 2.15 BW; anterior–posterior: 0.60 BW). These authors stated that high peak reaction forces during the RO phase of the Yurchenko vault may be responsible for upper-extremity injuries. Previous study by Davidson et al. (2005) highlighted that greater wrist joint stiffness during back handspring may have influence on wrist joint injury potential in young gymnasts. Sports and clinical biomechanists are typically interested in the role of stiffness as it relates to both performance and injury (Butler, Crowell, & Davis, 2003). During gymnastics training the RO is highly repetitive movement (Daly, Rich, Klein, & Bass, 1999). The high frequency of performance repetition may have a significant influence on wrist pain and injury, which is often associated with a sensation of wrist stiffness (Brouwer, Mazzoni, & Pearce, 2001).

The round-off (RO) (FIG, 2013) 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 (Farana et al., 2014). Two common techniques are used to perform RO, the parallel hand position and the T-shape hand position (Figure 1). Research groups from Ostrava and Cardiff have examined injury risk and technique selection associated with the choice of hand placement in RO skills (Farana et al., 2014). These authors showed increased elbow joint abduction loads (Farana et al., 2014) and lower levels of biological variability (Farana, Irwin, Jandacka, Uchytil, & Mullineaux, 2015) in parallel technique RO skills.

The aim of this study was to examine the biomechanical risk factors at the wrist of the first and second contact limb during the RO for both parallel and T-shape techniques. The hypotheses were 1) **Between Limbs:** there will be greater peak wrist joint reaction forces and loading rates in the second versus first contact limb in both techniques, and 2) **Between Techniques:** different hand positions will affect wrist joint kinematics, kinetics and stiffness of the second contact limb which may be related to injury risk factors. The data presented in this paper are from the same participant groups as that reported in Farana et al. (2014) which investigated changes in impact loading, elbow kinematics and kinetics for the second contact limb. In general, there is a lack of research, which has focused on the interaction between impacting limbs in sports like gymnastics. The current research is building on this earlier work (Farana et al., 2014) by examining the wrist joint, which is a primary injury site in gymnastics (DiFiori et al., 2006). The need for this research is supported theoretically to develop understanding of the stochastic nature of injury. Building on previous research by Farana et al. (2014) the current study provides a more holistic approach to RO technique selection to increase the understanding upper limbs injury risk, which would provide useful insights into technique selection for coaches, athletes and highlight injury risk factors for clinicians.

Insert Figure 1 Above Here

Material and Methods

Participants and Protocol

Seven international level female gymnasts participated in this study. The gymnasts were members of the junior and senior national gymnastics team of the Czech Republic with an average training and competition experience of 14 ± 2 years. Their mean ± *SD* height was 162.9 ± 3.9 cm; mass 56.7 ± 5.2 kg and age 20.7 ± 1.6 years. All gymnasts were injury free at the time of testing. From these seven gymnasts, three of them preferred the T-shape hand position, and four of them preferred the parallel hand position. One week prior to testing gymnasts were asked to practice both techniques as part of their training session. At each floor training session, gymnasts were asked to perform 10 repetitions of the skill sequence round-off to back handspring (FIG, 2013) with parallel hand position and 10 repetitions with T-shape hand position. Informed consent was obtained in accordance with the guidelines of the Institute's Ethics and Research Committee. 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 in both techniques. A thin gymnastic floor cover mat (dimension 20 mm, Baenfer, Germany) was used that was taped down onto each force plate to replicate the feel of a typical gymnastics' floor. Landing mats were used to provide safety for the gymnasts' landings. After the warm up and practice, all gymnasts performed 10 trials of RO with a parallel hand position from a hurdle step to a back handspring, and 10 trials of RO with a T-shape hand position from a hurdle step to a back handspring. All trials were performed with a maximal effort, in random order and separated by a one-minute rest period.

Data Collection

Two force plates (Kistler, Switzerland) embedded into the floor determined GRF at a sampling rate of 1235 Hz. Since the dimension of mats covering each force plate could affect kinetic calculations, depth of the transducer was set as the sum of the manufacturer depth for the specific force plate and depth of mat, correcting the centre of pressure location. The force plates were synchronized with a motion-capture system (Qualisys Oqus, Sweden) consisting of eight infrared cameras collecting kinematic data at a sampling rate of 247 Hz. The global coordinate system was set with the z-axis as vertical, y-axis as anterior-posterior and x-axis as medio-lateral. Retroreflective markers (19 mm diameter) were attached to the gymnasts' upper limbs and trunk (C-motion, Rockville, MD, USA). Markers were bilaterally placed on each participant at the following anatomical locations: the acromio-clavicular joint, shoulder, lateral epicondyle of the humerus, medial epicondyle of the humerus, radial-styloid, ulnar-styloid, head of the second metacarpal, head of the fifth metacarpal, iliac crest tubercle, inferior-medial angle of the scapula, and markers were placed on the seventh cervical and tenth thoracic vertebrae. Two clusters containing three markers each were also placed bilaterally on the upper arm and forearm. Two photocell timing gates were used to control hurdle step horizontal velocity. Based on a previous study (Farana, Jandacka, & Irwin, 2013), the hurdle step velocity was standardized at range of 3.3 to 3.7 m/s.

Data processing

Raw coordinate data were processed using Visual 3D software (version 4; C-motion, Rockville, MD, USA). All upper extremity segments were modelled as frusta of right circular cones and the trunk as an elliptical column. The local coordinate systems (LCS) were defined using a static calibration trial in the handstand position. LCS for the wrist was oriented such that the y-axis points anteriorly, z-axis points vertically, and x-axis is perpendicular to the plane of the other two axes with its direction defined by the right-hand rule (Hamill, Selbie, & Kepple, 2014). Three-dimensional joint angles for the wrist were calculated using an x (plantarflexion/dorsiflexion), y (ulnar/radial deviation), z (axial rotation) Cardan rotation sequence. All angles were referenced to the coordinate systems embedded in the proximal segment (Hamill, Gruber, & Derrick, 2012). All analyses focused on the contact phase of the first and second hand during the round-off. Kinematic variables included peak sagittal (+ plantarflexion/- dorsiflexion) and frontal (+ ulnar deviation/- radial deviation) wrist angles, sagittal wrist angles and angular velocities at touchdown and take off from the ground. These variables were calculated using a XYZ order of rotation. Kinetic variables included peak wrist axial compression force, peak wrist anterior shear force and loading rates of these forces. Loading rate was determined as the slope of the force–time profile of the period between initial hand contact and the impact peak. Wrist joint torsional loading stiffness was calculated as the change in joint moment divided by the change in joint angle (Hamill, Moses, & Seay, 2009; Hamill, Russell, Gruber, & Miller, 2011; Hamill, Gruber, & Derrick, 2012). Sagittal plane wrist joint stiffness was determined from initial hand contact (touchdown) to mid-contact (i.e., maximum wrist dorsiflexion). A Newton-Euler inverse dynamics approach was used to calculate internal joint moments of the wrist (Selbie, Hamill, & Kepple, 2014). Net internal wrist moments are expressed in the local coordinate system of the forearm. The coordinate and force plate data were low-pass filtered using the fourth-order Butterworth filter with a 12 Hz and 50 Hz cut off frequency, respectively. The wrist joint force data and wrist moment data were normalised to body mass.

Statistical analysis

Statistical tests were used to examine the effects caused by the independent variables “hand position” (parallel hand position versus T-shape hand position) and “contact limb” (first contact limb versus second contact limb) on the dependent variables (i.e., wrist joint kinematics and kinetics, and wrist stiffness). The intra-class correlation coefficient (ICC) was applied for the assessment of the measurements’ reliability (Hopkins, 2000). Mean values of the 10 trials for each gymnast in each technique were calculated for all measured variables and used in statistical analysis. A Shapiro-Wilk test confirmed the normality assumption for the data and a two-way repeated measure ANOVA (2 × 2, limb × technique) was performed. The Holm's (Holm, 1979) step-down procedure to control the Type I Error due to multiple statistical comparisons was used (Lundbrook, 1998). This approach was previously recommended by Knudson (2009) for sports biomechanical research where multiple statistical comparisons of variables may increase Type I Error. Effect sizes were calculated for the ANOVA via partial η^2 and presented as < 0.01 trivial; 0.01 – 0.06 small; 0.06 – 0.14 medium and >0.14 large (Cohen, 1992). In order to overcome the inherent limitations of a small sample statistical power was kept above 0.8 (Cohen, 1992). Statistical tests were processed using the IBM SPSS Statistics 20 Software (IBM SPSS Inc., Chicago, IL, USA). The significance level was set to $p < 0.05$.

Results

Descriptive statistics with means, standard deviations and statistical results for the two techniques and first and second contact limb are presented in Table 1. The values of the intra-class correlation coefficient (ICC) calculated from repeated measures was in the range (0.75 – 0.99) for all variables.

Insert Table 1 Above Here

A significant main effect of contact limb ($p = 0.009$, $\eta^2 = 0.835$), technique ($p = 0.040$, $\eta^2 = 0.771$), and contact limb × technique interaction ($p = 0.027$, $\eta^2 = 0.797$) were observed for peak axial compression force (Table 1). As for peak anterior shear force a significant difference for contact limb × technique interaction ($p = 0.018$, $\eta^2 = 0.703$) were found (Table 1). A significant main effects of contact limb ($p = 0.000$, $\eta^2 = 0.900$), technique ($p = 0.000$, η^2

= 0.929), and contact limb × technique interaction (p = 0.032, η^2 = 0.771) existed for axial compression force loading rate (Table 1). Contrasting between round-off techniques for the second hand demonstrated that the parallel hand position elicited greater peak values of axial compression forces (Figure 2A and 2B) and loading rates compared to the T shape (Table 1). No significant differences were observed for anterior shear force loading rate (Table 1).

Insert Figures 2A and 2B Above Here

Wrist dorsiflexion angles showed a significant difference for contact limb × technique interaction (p = 0.020, η^2 = 0.832) (Table 1 and Figure 3A and 3B). An ulnar/radial deviation angle showed significant main effect of contact limb (p = 0.000, η^2 = 0.907), and contact limb × technique interaction (p = 0.011, η^2 = 0.841) (Table 1). No significant differences were found for wrist dorsiflexion angle and angular velocity at touchdown and take-off. No significant differences significant differences, but large effect sizes for main effects of technique (p = 0.096, η^2 = 0.677), and contact limb x technique interaction (p = 0.084, η^2 = 0.677) existed for wrist joint stiffness (Table 1).

Insert Figures 3A and 3B Above Here

Discussion

Developing understanding of the underlying mechanisms that may create biological over load is an important part of reducing injury and improving performance. Therefore, the aim of this study was to investigate injury risk factors at the wrist with the inclusion of joint kinetics, kinematics and stiffness in first and second contact limb for both parallel and T-shape RO techniques. This study provided insights into how wrist joint kinematics, kinetics and stiffness are associated with different hand positions during ground contact of the first and second hand during RO skills.

The first hypothesis considered between limb comparisons and highlighted an increase in peak wrist joint reaction forces and loading rates in the second versus first contact limb in both techniques and as such was accepted. Table 1 and Figure 2A and 2B show that for both techniques the second contact limb is exposed to higher load, demonstrated by a significant increase in peak wrist joint axial compressive force and loading rates. One of the most common mechanisms of wrist injuries is a compressive force applied to a dorsiflexed wrist (Webb & Rettig, 2008). From an injury perspective these observations concur with the comments of Davidson et al. (2005) who stated that peak impact forces are among the fundamental injury risk factors associated with the wrist joint in gymnastics. Moreover, findings from the current study are in accordance with study by DiFiori et al. (1996), who identified axial compression force as wrist joint injury risk factor. DiFiori et al. (2002) also postulated that these compressive loads are transmitted through the carpals to the radius and ulna, with the radius accepting approximately 80% of the load. These authors highlight the risk of repetitive loads placed on the wrist joint due to the contribution to distal radius stress injury (DiFiori et al., 2002).

The second hypothesis suggested that different hand positions will affect wrist joint kinematics, kinetics and stiffness of the second contact limb which may be related to injury was accepted. In the current study higher wrist joint dorsiflexion and radial deviation was found in the T-shape technique compared with the parallel technique (Table 1). Previous research by Weber and Chao (1978) demonstrated that > 95° of hyper-dorsiflexion of the wrist in radial deviation places the scaphoid waist at the highest risk for fracture. However, Figures 3A and 3B shows that in the current study the wrist dorsiflexion was < 80° in both RO techniques. Furthermore, from an injury perspective, the use of very soft mats may exaggerate the amount of dorsiflexion and thus increase the risk of chronic distal radial injury (DiFiori, Caine, & Malina, 2006). No significant differences were found for wrist angle and angular velocity dorsiflexion at touchdown and take-off (Table 1). These could be explained from the performance perspective, due to the fact that wrist flexion/extension is biomechanically a key contributor to the important take off characteristics from the RO. This finding suggests these take off characteristics are not influenced by the different hand position namely parallel and T-shape. The take-off from the ground determines the trajectory of the gymnast in flight in terms of the linear and angular motion. With the hands being the final segments of kinematic chain in contact with ground the wrists motions will have an effect on this take off and hence performance. However, we are not able to state how the wrist contributes to success as the outcome of the round off leads to the back handspring and subsequent acrobatic tables, which are beyond the scope of the current study.

In the parallel hand position greater wrist joint stiffness was observed for the second contact limb (Table 1). Previous study by Davidson et al. (2005) highlighted that greater wrist joint stiffness during back handspring may have an influence on wrist joint injury potential in young gymnasts. However, the level of wrist joint stiffness, which may lead to injury, is unknown. Evidence from running research shows that increased leg stiffness is typically associated with reduced lower extremity excursions and increased peak forces (Butler, Crowell, & Davis, 2003). This combination of factors typically leads to increased loading rates, which have been associated with increased shock to the lower extremity (Hamill et al., 2011). In the current study a significant increase in wrist joint axial compression force, and loading rate of this force were found for the second contact limb in the parallel hand position (Table 1). These observations are consistent with findings from the study by Grimston et al. (1991) who state that increased peak forces, loading rates, and shock place athlete at a greater risk for bony injuries such as stress fractures.

Findings from the current study further reinforce that the second contact limb is exposed to greater bio-physical loads and support use of the T-shape technique of the round-off 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. These findings provide a foundation to investigate this area further, with different performance levels, gender and age of gymnasts and stages of learning to examine other factors that may influence the occurrence of injury and also improve performance. Long-term prospective studies that include descriptive and analytical components would be useful to clarify the distribution and determinants of wrist pain and injury potential.

Conclusions

The results of the current study extend previous findings and increases understanding about different hand positions during the round-off skill in female gymnastics. Overall, the results highlighted that there were inherent differences in key biomechanical characteristics between the first and second contact limb and between parallel and T-shape round-off skill techniques. Specifically, the second contact limb during the RO is exposing the performers to higher mechanical loads than the first contact limb demonstrated by increases axial compression force and loading rates. Moreover, in the parallel technique the second contact limb wrist joint is exposing to higher axial compression load. Significant differences observed between wrist joint kinetics highlight and reinforce that the T-shape technique reduces bio-physical load, and consequently may protects the second contact limb wrist joint from overload and biological failure. The ecological validity of this study and scientific methodology has provided useful insights into technique selection that will help coaches, athletes and clinicians.

Practical implications

- The second contact limb during the round-off skill is exposing the wrist joint complex to higher bio-physical loads than the first contact limb.
- The T-shape technique reduces the wrist joint loads compared to other technique, highlighting this technique from injury perspective as the desirable one.
- The T-shape technique protects the second contact limb wrist joint from overload and biological failure.
- Coaches, Sports Scientist and Clinicians can better inform practitioners regarding the risk factors of these fundamental skills in gymnastics techniques.

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Figure 1. Hand positions: (a) parallel and (b) T-shape for the round-off.

Figure 2. Wrist joint axial compressive force profiles (M ± SD) of the first contact limb (A) and the second contact limb (B) in parallel (solid line) and T-shape (dash line) hand positions (n = 7).

Figure 3. Wrist dorsiflexion angle profiles (M ± SD) of the first contact limb (A) and the second contact limb (B) in parallel (solid line) and T-shape (dash line) hand positions (n = 7).