EFFECT OF DIFFERENT HAND POSITIONS ON ELBOW LOADING DURING THE ROUND OFF IN MALE GYMNASTICS: A CASE STUDY

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Original article

Abstract

Elbow lesions are a potential reason for ending a gymnastics career, and presents a real concern for coaches, scientist and clinicians. Previous research has focused on female gymnastics and as such the aim of the current study was to investigate key elbow joint injury risk factors including impact forces, elbow joint kinetics, and kinematics during different round-off techniques in male artistic gymnastics. An international level active male gymnast performed 15 successful trials of a round-off from a hurdle step to back handspring with three different hand positions (parallel (5), T-shape (5) and reverse (5)). Synchronized kinematic (3D-automated motion analysis system; 240 Hz) and kinetic (force plate; 1200 Hz) data were collected for each trial. Effect-size statistics determined differences between each hand position. The key conclusions were, the T-shape technique reduces vertical, anterior-posterior and resultant ground reaction forces. Differences in elbow joint internal adduction moment and elbow joint compression force indicated that the T-shape technique may prevent elbow joint complex overload and reduces potential of elbow injuries.

Keywords: *biomechanics, gymnastics, round-off, upper limbs, injury prevention.*

INTRODUCTION

Artistic gymnastics is a unique sports due to the fact that the upper limbs are used for weight-bearing activities (Webb & Rettig, 2008). Artistic gymnastics training was previously associated with on average more than 100 impacts per one training session on the upper limbs with peak ground reaction force (GRF) magnitudes more than 3 times body weight (BW) (Daly, Rich, Klein, & Bass, 1999). The consequence of upper limbs being weight - bearing causes high impact loads to be distributed through the wrist and elbow (Webb & Rettig, 2008). There are both negative and positive effects of this weight-bearing impact (Bradshaw, 2010). Positive effects include increased bone mass and reduced risk of osteoporosis later in life (Zanker, Osborne, Cooke, Oldroyd, & Truscott, 2004). As for negative effects, elbow pain and injury in young athletes include both acute traumatic and chronic overuse injuries

(Kramer, 2010). Elbow injuries from tumbling and vaulting in gymnastics present a serious problem for performers, where elbow lesions are a potential reason for ending a gymnastics career (Chan, Aldridge, Maffulli, & Davies, 1991). Previous research by Koh, Grabiner and Weiker, (1992) highlighted that, during the back handspring, the hands experience large compression forces, and sizable moments at the elbow that may contribute to upper limb injuries. In a study that examined reaction forces transmitted to the upper extremities, Panzer, Bates and McGinnis, (1987) found that during the Tsukahara vault, elbow joint reaction forces ranged from 1.7 to 2.2 BW. Evidence from review studies has showed that chronic elbow injuries typically stem from abduction load (Hume, Reid, & Edwards, 2006) and probably contributes to some of the overuse injury patterns such as valgus extension overload (Magra, Caine, & Majfulli, 2007).

In gymnastics the round-off (RO) is one of the most fundamental skills. The importance of this skill is that it is simple and effective way for the gymnast to change from forward-rotating to backward-rotating movements while moving in one direction along a straight line (Hay, 1993). Previous research investigated GRF of the second contact hand during the RO phase of the Yurchenko vault and RO on the floor exercise (Seeley & Bressel, 2005). They found significantly greater peaks of vertical GRF (VGRF) and anterior-posterior GRF (APGRF) in the RO phase of the Yurchenko vault than on the floor exercise. Research groups from Ostrava and Cardiff have examined injury risk and technique selection associated with the choice of hand placement in RO skills in female gymnastics. These authors showed increased in elbow joint loading (Farana, Jandacka, Uchytil, Zahradnik, & Irwin, 2014) and lower levels of biological variability (Farana, Irwin, Jandacka, Uchytil, & Mullineaux, 2015) in parallel technique. More specifically, Farana et al. (2014) found that the T-shape hand position reduces VGRF, APGRF, resultant GRF (RGRF) and has decreased loading rates indicating a safer technique for the RO. Significant differences observed in joint elbow moments highlighted that the T-shape position may prevent overloading of the joint complex and consequently reduce the potential for elbow injury. The main findings from study by Farana et al. (2015) was a higher level of biological variability in the elbow joint abduction angle and adduction moment of force in the T-shaped hand position, which may lead to a reduced repetitive abduction stress and thus protect the elbow joint from overload. The focus of previous research has been with female gymnastics and there is a paucity of research examining the mechanisms of injury risk of the elbow joint during round-off with different hand position in male gymnastics. Moreover, our observations within gymnastics trainings and competitions shows that male gymnasts use three different hand positions during RO skills.

The aim of the current study was to investigate key elbow joint injury risk factors including impact forces, elbow joint kinetics, and kinematics during different round-off techniques in male artistic gymnastics. It was hypothesized that (a) hand position would change the biomechanical characteristics of impact forces and (b) hand position would change elbow joint kinematics and kinetics. Building on previous research by Farana, Jandacka, and Irwin (2013) and Farana et al. (2014) the overall purpose of this research is to increase the understanding of upper limbs injury potential in male gymnastics, which would be useful for coaches, clinicians, and scientists.

METHODS

Participant and protocol

An international level active male gymnast from Czech Republic participated in the current study. Gymnast age, height and mass were 18 years, 1.68 m and 68 kg. The gymnast is a member of the national team of the Czech Republic with more than

10 years' experience with systematic training and competitive gymnastics. The gymnast had no previous history of upper extremities injury and at the time of testing was injury-free. 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 gymnast completed his self-selected warm up and completed a number of practice RO trials with different hand positions. A thin gymnastic floor mat (dimension 20 mm, Baenfer, Germany) was used that was taped down onto force plate to replicate the feel of a typical gymnastics' floor. Landing mats were used to provide safety for the gymnasts' landings (Figure 1).

Figure 1. Force plate with a thin floor mat, and mat for back handspring and landing.

After warm up and practice the gymnast performed 5 trials of a round-off from a hurdle step to back handspring with "parallel" hand position, 5 trials of round-off from a hurdle step to back handspring with "T-shape" hand position and 5 trials of round-off from a hurdle step to back handspring with "reverse" shape hand position (Figure 2). All trials were performed with a maximal effort, in random order (from all 15 trials) and separated by a one minute rest period.

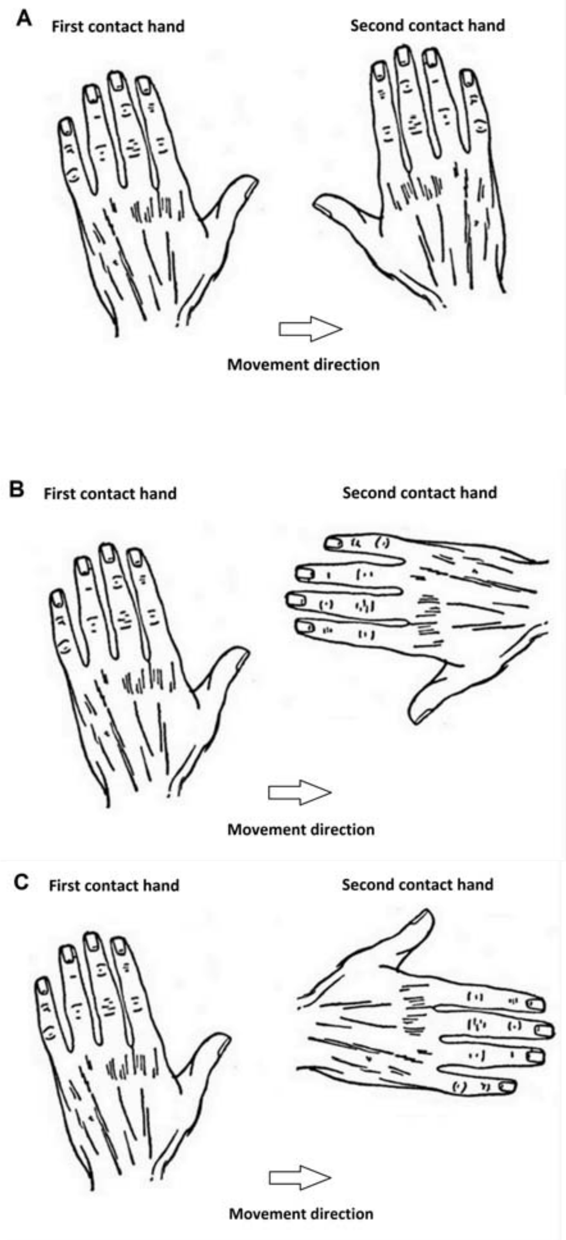

Figure 2. Round-off hand positions (A) Parallel, (B) T-shape and (C) Reverse.

Experimental set-up

One force plate (Kistler, 9286 AA, Switzerland) embedded into the floor were used to determine ground reaction force data at a sampling rate of 1200 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 240 Hz and synchronized with force plate. 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 known length was used to calibrate the global coordinate system and it was set up so that the z-axis was vertical, the y-axis was anterior–posterior, and the x-axis was medio-lateral. Data from the force plates and the cameras were collected simultaneously. Based on C-motion Company (C-motion, Rockville, MD, USA) recommendation, retroreflective markers (diameter of 19 mm) were attached to the gymnasts' upper limbs and trunk (Figure 3). 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, and 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 photocells were used to controlled hurdle step velocity. Based on previous studies by Farana et al. (2013, 2014 and 2015) the hurdle step velocity was standardized at the range of 3.3 – 3.7 m/s.

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 handstand position (Farana et al., 2014). All analysis focused on the contact phase of the second hand during the round off. Key injury risk variables included peak VGRF, APGRF and RGRF; loading rates of these forces; elbow joint vertical reaction force, frontal plane (+ adduction; - abduction) elbow internal moment of force and corresponding frontal plane (+ adduction; - abduction) elbow angle. The net three dimensional elbow joint moments and elbow joint reaction forces were quantified using the Newton–Euler inverse dynamics technique (Selbie, Hamill, & Kepple, 2014) and are expressed in the local coordinate system of the upper arm. 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 GRF data, moment of force data and joint reaction force data were normalized to body mass. Continuous profiles of the GRF, elbow joint reaction forces and elbow joint moments were time-normalized to 101 points, which represents an interval from 0 to 100% of the second hand contact time.

Figure 3. Marker placement on gymnast body.

Statistical analysis

Means and standard deviations (M ± SD) were calculated for all measured variables. Due to research design of this case study, an effect size (ES) statistics were used to establish differences in means. ESs were calculated and interpreted as <0.2 trivial, 0.21 - 0.6 small, 0.61 - 1.2 moderate, 1.21 - 2.0 large, 2.01 - 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

Peak VGRF displayed large ESs between parallel and T-shape technique (ES = 1.3, large), and between T-shape and reverse technique (ES = 1.5, large). Additionally, for peak APGRF very large to nearly perfect ESs were found between parallel and T-shape technique (ES = 3.7, very large), between parallel and reverse technique (ES = 2.1, very large), between parallel and T-shape technique (ES = 4.4, nearly perfect). RGRF displayed large ESs between parallel and T-shape technique (ES = 1.5, large), and between T-shape and reverse technique (ES = 1.6, large). The highest magnitude of VGRF, APGRF and RGRF were observed in the reverse technique (Table 1). Figure 4 shows magnitudes for RGRF in three RO techniques.

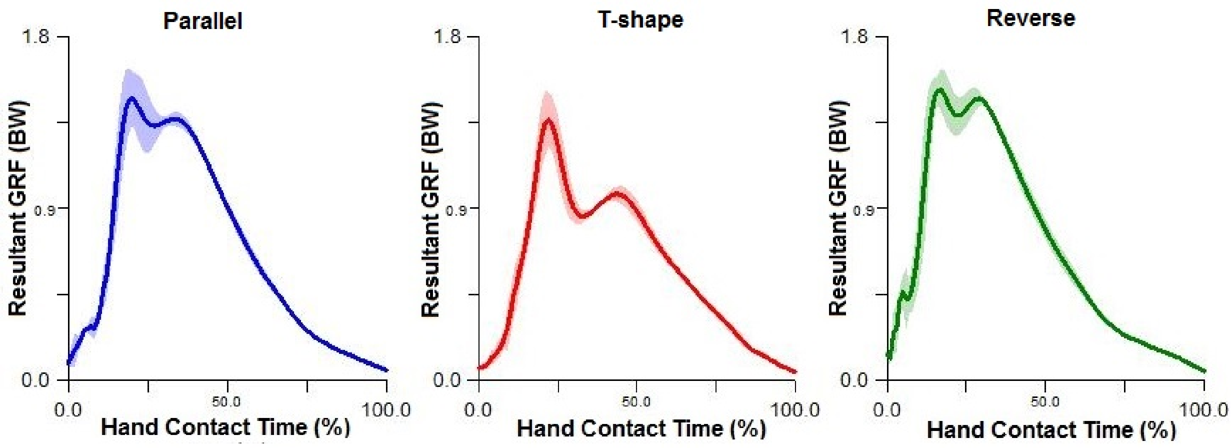

Figure 4. Resultant ground reaction force (RGRF) profiles of the second contact hand in parallel (blue), T-shape (red) and reverse (green) techniques.

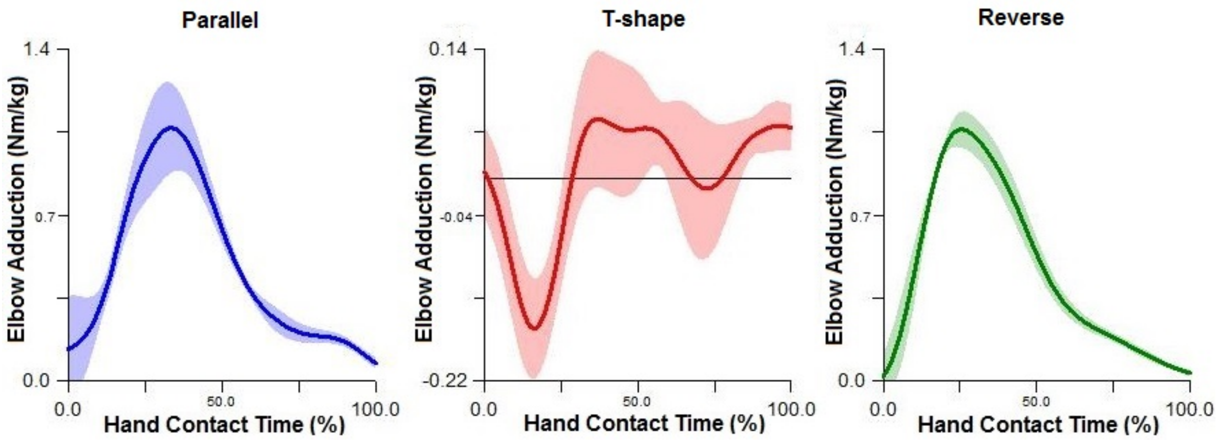

Figure 5. Elbow joint internal adduction moment of force profiles of the second contact hand in parallel (blue), T-shape (red) and reverse (green) techniques.

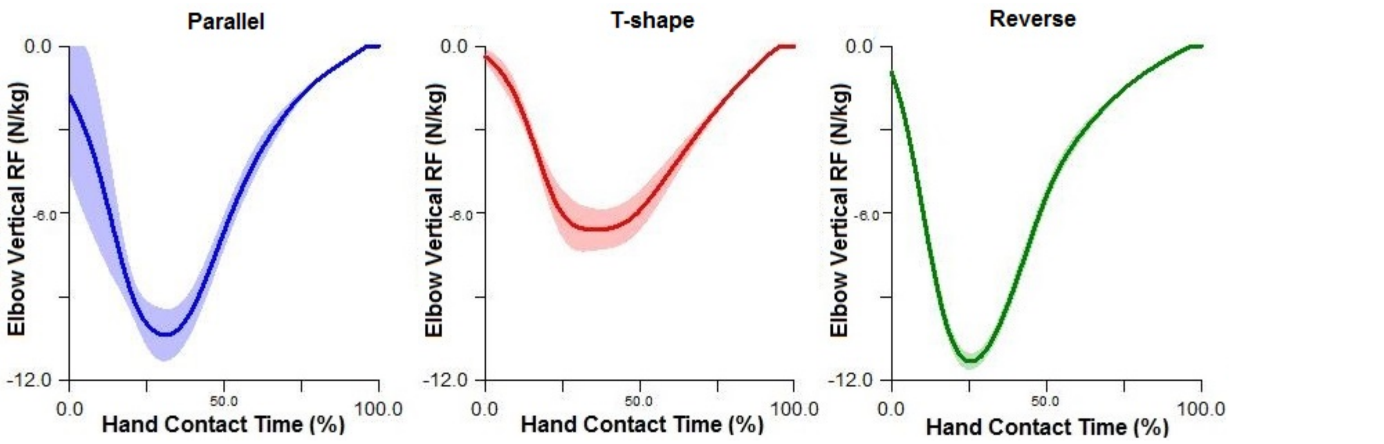

Figure 6. Elbow joint vertical reaction force profiles of the second contact hand in parallel (blue), T-shape (red) and reverse (green) techniques.

Table 1
Ground reaction forces, loading rates of ground reaction forces, elbow joint kinematics and kinetics of 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)	1.48 ± 0.07	1.36 ± 0.11	1.49 ± 0.05	**1.3**	0.2	**1.5**
Peak APGRF (BW)	-0.42 ± 0.03	-0.31 ± 0.03	-0.52 ± 0.06	**3.7**	**2.1**	**4.4**
Peak RGRF (BW)	1.54 ± 0.07	1.39 ± 0.12	1.55 ± 0.07	**1.5**	0.1	**1.6**
Loading rate VGRF (BW/s)	37.06 ± 2.19	33.38 ± 4.59	46.77 ± 2.68	1.0	**3.6**	**4.0**
Loading rate APGRF (BW/s)	-8.45 ± 2.20	-5.63 ± 0.42	-17.78 ± 2.15	**1.8**	**4.3**	**7.8**
Loading rate RGRF (BW/s)	36.07 ± 2.51	32.71 ± 3.10	48.74 ± 3.51	1.2	**4.8**	**4.2**
Elbow ab/adduction angle (°)	-2.84 ± 1.53	3.55 ± 0.51	-5.77 ± 1.56	**5.6**	**1.9**	**8.0**
Elbow adduction moment (Nm/kg)	1.11 ± 0.12	0.10 ± 0.03	1.06 ± 0.05	**11.5**	0.5	**23.3**
Elbow vertical reaction force (N/kg)	-10.39 ± 0.73	-6.63 ± 0.60	-11.33 ± 0.21	**5.6**	**1.8**	**10.5**

Notes: VGRF, vertical ground reaction force; APGRF, anterior-posterior ground reaction force; RGRF, resultant ground reaction force; BW, body weight; BW/s, body weight per second; °, degrees; Nm/kg, Newton meter per kilogram; N/kg, Newton per kilogram; ES, effect size; P, parallel technique; T, T-shape technique; R, reverse technique.

Very large ESs were observed for VGRF loading rates between parallel and T-shape technique (ES = 3.6, very large), and between T-shape and reverse technique (ES = 4.0, very large). In addition large to nearly perfect ESs were found for APGRF loading rates between parallel and T-shape technique (ES = 1.8, large), between parallel and reverse technique (ES = 4.3, nearly perfect), and between T-shape and reverse technique (ES = 7.8, nearly perfect). RGRF loading rates displayed nearly perfect ESs between parallel and reverse technique (ES = 4.8, nearly perfect), and between T-shape and reverse technique (ES = 4.2, nearly perfect).

As for elbow joint kinematics large to nearly perfect ESs were found for abduction angle between parallel and T-shape technique (ES = 5.6, nearly perfect), between parallel and reverse (ES = 1.9, large), and between T-shape and reverse technique (ES = 8.0, nearly perfect). In addition, nearly perfect ESs were observed for internal adduction moment between parallel and T-shape technique (ES = 11.5, nearly perfect), and between T-shape and reverse technique (ES = 23.3, nearly perfect). The highest magnitude of elbow internal adduction moment was observed in the parallel technique (Figure 5 and Table 1).

Elbow joint vertical reaction force displayed large to nearly perfect ESs between parallel and T-shape technique (ES = 5.6, nearly perfect), between parallel and reverse technique (ES = 1.8, large), and between T-shape and reverse technique (ES = 10.5, nearly perfect). The highest magnitude of elbow joint reaction force was observed in the reverse technique (Figure 6 and Table 1).

DISCUSSION

Building on previous research by Farana et al. (2013, 2014) which focused on female gymnastics, this study aimed to investigate key injury risk factors including impact forces, elbow joint kinetics, and kinematics during round-off skills with three different hand positions in male artistic gymnastics.

Previously, Seeley and Bressel (2005) highlighted that, during the round-off phase of the Yurchenko vault, the hands produce high peak reaction forces which may be responsible for upper-extremity injuries. In the current study, peak VGRF, peak APGRF, and peak RGRF of the second hand were higher in the parallel and reverse techniques compared with the T-shape technique. As shows Figure 4 and Table 1, highest magnitude of RGRF was observed in the reverse technique. A typical “braking” (i.e., high negative peak) occurs in the first part of the round-off in the anterior-posterior direction (Table 1). Table 1 shows that highest magnitude of these “braking” forces were observed in the parallel and reverse techniques compared with the T-shape technique. From an injury prospective these observations concur with the comments of Whiting and Zernicke (2008) who stated that peak forces are among the most fundamental injury risk factors. Moreover, these observations suggest that the T-shape technique may provide a technique of the round-off that reduces the risk of bio-physical overload and consequently reduces the risk of injury (Farana et al., 2014). Interestingly, the reverse technique also shows the highest second peak of RGRF which may be useful from performance perspective, when the second peak shows take-off force from the ground. Therefore, the reverse technique is more often use by male gymnasts especially for vault performance, when explosive take-off from the vaulting table is required to increase post-flight time (e.g., Takei, Dunn, & Blucker, 2003; Lim, 2004). From the vault performance perspective, an increase in post-flight time provides gymnasts the capacity to complete more complex skills, increase the vault difficulty and potential for achieving a higher score (Bradshaw et al., 2010). However, from an injury perspective this position should be used with caution.

Previous studies highlighted an important role of a forearm rotation on the elbow joint loading during the RO in female gymnast (Farana et al., 2014; Farana et al., 2015). In the current study a significantly greater peak internal adduction moment was found in the round-off with parallel and reverse hand position compared with the T-shape hand position (Figure 5). These findings are in accordance with Farana et al. (2013) and Farana et al. (2014) research who found significantly lower magnitudes of internal adduction moment in the T-shape technique compared with parallel hand position. Moreover, evidence from previous research has identified that repetitive abduction stress placed on the elbow joint can lead to chronic elbow injuries (Hume, Reid, & Edwards, 2006). Furthermore, higher magnitudes of elbow joint vertical reaction force were observed in the parallel and reverse technique compared with the T-shape technique (Figure 6). These compression forces and sizeable adduction moments placed on the elbow joint may be responsible for chronic injuries a finding which concurs with the previous study by Koh et al. (1992). In the current study elbow abduction angle were found in the parallel and reverse technique compared with the T-shape technique (Table 1). However, magnitudes of these abduction angles were lower compared with female gymnasts (Farana et al., 2014). This could be explained from the elbow joint anatomical perspective, when larger elbow carrying angle were observed in females that in males (van Roy, Baeyens, Fauvart, Lanssiers, & Clarijs, 2005).

Conclusions from this study must be considered with the sample size in mind. This limitation reduces the wider application of these results. However, the current study has benefited from the use of elite level gymnast and shows similar trends in results as previous research by Farana et at. (2013, 2014). These initial findings provide a foundation to investigate this area further, with a larger sample, different performance levels and stages of learning to examine other factors that may influence the occurrence of injury.

CONCLUSIONS

The results of the current case study provide initial findings about three different hand positions during RO skills in male gymnastics. This study found that the T-shape hand position reduces VGRFs, APGRFs, RGFRs, loading rates of these forces and indicate a safer technique of RO skills. Specifically, differences in elbow joint reaction forces and internal adduction moments highlighted that from an injury perspective the parallel and reverse techniques may be responsible for elbow joint overloading and consequently increase potential for elbow injury. These initial results may have implications for injury and performance. When potential risk factors are identified, the process of technique selection may be more objective and safe.

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