THE EFFECT OF CHANGES IN FUNDAMENTAL SKILL COMPLEXITY ON UPPER LIMB LOADING IN FEMALE GYMNASTICS

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The aim of this study was to investigate if changes in elbow and wrist joints loading occurred as a function of (a) different hand placement and (b) fundamental skills difficulty level in female gymnastics. Ten female gymnasts performed 54 successful trials of round-off skills (cartwheel [18], round-off [18], round-off to back handspring [18]), with three different hand positions (parallel, T-shape and reverse). Kinematic and kinetic data were collected for each trial. A two-way repeated measures ANOVA was used to analyze the injury risk factors. Results suggested that the T- shape technique during different levels of round-off skills decreases mechanical load (peak vertical ground reaction forces and joint kinetics at the elbow and wrist) and may represent safer technique for young female gymnasts.

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

INTRODUCTION: In gymnastics, the cartwheel (CW), round-off (RO) and round-off followed by back hand spring (RO-BH) are in this sequence the earliest fundamental skills learned during training process (Mitchell, Davis & Lopez, 2002), and are performed tens even hundreds, of times a day on beam or floor. Previous research demonstrated that during these skills upper extremity, especially wrist and elbow joint, have to deal with large impact forces across different level, age and sex of gymnasts (Farana, Jandacka, Uchytil, Zahradnik & Irwin, 2014; Farana, Jandacka, Uchytil, Zahradnik & Irwin, 2017; and Farana, Exell, Strutzenberger & Irwin 2018; Farana, Strutzenberger, Exell, Skypala, Wiltshire, & Irwin 2019). These studies have investigated injury risk factors associated with the choice of hand placement (technique) in RO family skills performed by elite and young female and male gymnasts. According to results of these studies the T-shape hand position leads to lower peak ground reaction forces, lower elbow internal adduction moment and decreased axial compression force on the wrist joint, when compared to parallel and reverse hand positions. This indicates that the T-shape hand position may represent a safer technique for the RO skill; therefore, it should be studied from different approaches. The process of gymnastics training is typical in increases difficulty of skill levels as the gymnast develops. The increase in skill difficulty may lead to a greater biomechanical load (e.g. Fujihara & Gervais, 2012), however this was not been investigated during round-off skills. From this point of view, the right choice of skill technique could be a significant factor in the reduction of upper limbs stress. There is a need for effective and efficient skill development pathways to be identified that will not only improve performance but also reduce the risk of overtraining-related injury (Irwin, Hanton & Kerwin, 2005). Knowledge of the load differences effected by increasing skill difficulty and its technique may help reduce mechanical load in development of fundamental gymnastics skills. Therefore, the aim of this study was to investigate if changes in elbow and wrist joints loading existed as functions of (a) different hand placement and (b) fundamental skills difficulty level in female gymnastics.

METHODS:

Participant & Protocol: Ten young active female gymnasts from Czech Republic, with more than 5 years' experience with systematic training and competitive gymnastics, participated in this study (age: 12.1±1.6 years; height: 147.5±12.8 cm; mass: 35.4±9.0 kg). During their career, they had no injuries, which could affect the measurement results. Informed consent 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 6 trials for each condition of RO family skills (CW – RO – RO-BH) from a hurdle step with “parallel”, “T-shape” and “reverse” hand positions (Figure 1) and in different level of difficulty (cartwheel, round-off and round-off to back handspring). All trials were performed in a random order and separated by a one-minute rest period.

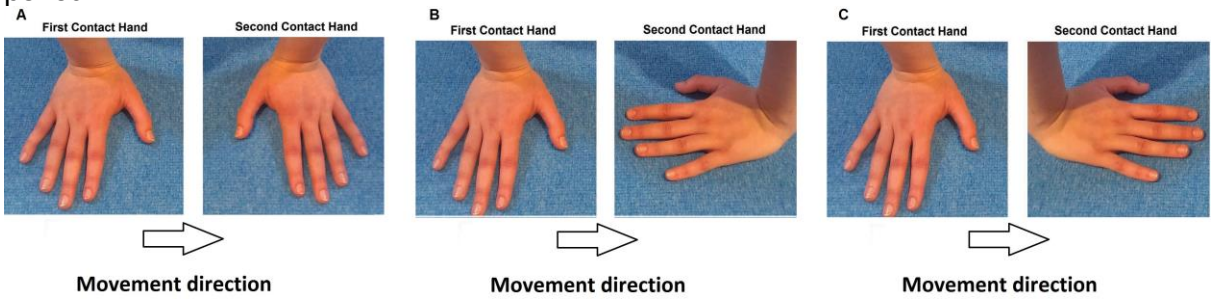

Figure 1: Round-off hand positions (A) Parallel, (B) T-shape and (C) Reverse.

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. Approach velocity of hurdle step has been set on 2.5-3.0 m/s and checked by photocells.

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 techniques. Based on previous studies (Farana et al., 2014 and 2017) key injury risk variables included peak vertical ground reaction force (VGRF), elbow joint internal adduction moment (+ adduction / – abduction), elbow and wrist joint axial compression 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. Two-way repeated measure ANOVA (technique × skill difficulty) determined significant differences between each hand position. The significance level was set at $p < 0.05$.

RESULTS: Descriptive statistics with means and standard deviations for the three techniques (parallel, reverse and T-shape) and three difficulty levels (CW, RO, RO-BH) are present in Table 1.

Table 1: Descriptive statistics of VGRF, elbow and wrist joints kinetic measures mean (standard deviation).

Measures	Parallel			Reverse			T-Shape		
	CW	RO	RO-BH	CW	RO	RO-BH	CW	RO	RO-BH
Ground reaction forces									
Peak VGRF (BW)	0.68 (0.19)	0.90 (0.21)	0.88 (0.24)	0.67 (0.20)	0.87 (0.16)	0.85 (0.24)	0.60 (0.15)	0.70 (0.19)	0.80 (0.26)
Elbow adduction moment (Nm/kg)	0.23 (0.13)	0.32 (0.14)	0.31 (0.17)	0.28 (0.16)	0.39 (0.15)	0.35 (0.13)	0.09 (0.09)	0.12 (0.08)	0.16 (0.12)
Elbow compression force (N/kg)	5.31 (1.26)	6.59 (2.00)	6.48 (2.22)	5.38 (1.63)	6.39 (1.62)	6.29 (2.08)	4.67 (0.84)	5.04 (1.29)	5.77 (1.97)
Wrist compression force (N/kg)	6.25 (1.40)	7.79 (2.00)	7.60 (2.27)	6.15 (1.78)	7.47 (1.52)	7.31 (2.21)	5.41 (1.02)	5.97 (1.45)	6.86 (2.07)

Notes: VGRF, vertical ground reaction force; BW, body weight; Nm/kg, Newton-meter per kilogram; N/kg, Newton per kilogram

For the RO skills, significant main effects for technique were found for peak VGRF (p=0.000, η2=0.683), for peak elbow compression forces (p=0.025, η2=0.370), for peak wrist compression forces (p=0.019, η2=0.391), and for peak elbow internal adduction moment of force (p=0.000, η2=0.863). A significant main effects of skill difficulty level were observed for peak VGRF (p=0.001, η2=0.584), for peak elbow compression forces (p=0.016, η2=0.403), for peak wrist compression forces (p=0.004, η2=0.498), for peak elbow internal adduction moment of force (p=0.022, η2=0.381). An interaction effects were found for peak VGRF (p=0.022, η2=0.293), for peak elbow compression forces (p=0.018, η2=0.303), for peak wrist compression forces (p=0.002, η2=0.413) and for peak elbow joint internal adduction moment (p=0.006, η2=0.352). Subsequent pairwise comparisons for peak VGRF between techniques found significant differences between parallel technique and T-Shape technique (p=0.000), and between reverse technique and T-shape technique (p=0.004). Comparing RO skills difficulty level demonstrated that the CW skill elicited significantly lower peak values of VGRF to the RO skill (p=0.009) and RO-BH (p=0.007). Significant differences were found for peak elbow compression force between parallel hand position and T-Shape hand position (p=0.041). Significant differences were found for peak wrist compression force between parallel and T-Shape hand position (p=0.021). Comparing RO skills difficulty level showed that the CW skill elicited significantly lower peak values of wrist compression forces compared to the RO (p = 0.028). Significant differences were found for T-shape technique peak values of internal adduction moments compared to the parallel (p = 0.027) and reverse (p=0.000) techniques.

DISCUSSION: The aim of this study was to investigate if changes in elbow and wrist joints loading existed as functions of (a) different techniques and (b) fundamental skills difficulty level in female gymnastics. In previous study, Farana et al. (2018) speculated that the increase in skill difficulty level, i.e. CW to RO, might influence the mechanical demands placed on the performer and consequently the mechanical load placed on the wrist and elbow joint. The results of the current study showed that mechanical load placed on the wrist and elbow joint increased as a function of difficulty level in the RO, were we confident that approach velocity was not a cofounding factor as this was shown to be the same for all skills and gymnasts. Additionally, it was observed that as the difficulty level of the RO increased the peak VGRFs of the second contact hand was lowest in the T-shape technique (Table 1). These finding are in accordance with previous studies on elite and young female gymnasts (Farana et al., 2014; Farana et al., 2018), which highlighted that the T-shape hand position reduced peak VGRF of the second contact hand compared to other techniques of these fundamental skills, and may reduce injury potential during skill development. Significant decrease in elbow internal adduction moment of force and elbow compression forces were observed between techniques and across skill level difficulty (Table 1). These results showed that T-shape technique elicited lowest valgus stress accompanied by compression force placed on elbow joint across different levels of RO skills complexity. Koh et al. (1992) have previously highlighted combination of these factors during back handspring as high risk for elbow joint injury. Similarly, current findings show a significant decrease in wrist compression forces between techniques and across skill difficulty. These results are in accordance with previous studies and adds the dependence of difficulty level as new knowledge. Further recommend the use of T-shape technique in training and skills development to reduce elbow joint and wrist injury risk factors of young gymnasts. Although current research is focused on the floor event, in vaulting the horizontal velocity has been reported nearly twice as high during Tsukahara a Yurchenko vaults as in the current study on the floor (Schärer, Lehmann, Naundorf, Taube & Hübner, 2019). This tends to suggest that transfer of these results onto vault should be treated with caution in terms of increase mechanical load with increase in approach speed.

CONCLUSION: Results of the current study showed that an increase in RO skills difficulty level significantly influences mechanical load on upper extremity despite of fixed range of approach velocity. Decreases in mechanical load, including VGRF, internal adduction moment of force, elbow and wrist compression forces further inform that the T-shape hand position represent a potentially safer technique for skill development particularly for young female gymnasts.

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