CHANGES IN UPPER LIMB JOINT POWER DURING ROUND-OFF IN FEMALE GYMNASTICS

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The aim of the current study was to investigate joint power changes in upper limb joints during the support phase of three round-off (RO) techniques (reverse, parallel, T-shape). Twenty young female gymnasts performed 18 RO trials in three different techniques. Kinematic and kinetic data were collected for each trial. Statistical parametric mapping of mean joint power was performed to compare differences between techniques. Results demonstrated that the reverse technique had lower joint powers during the absorption and propulsion phases of the skill compared to the other techniques. The T-shape technique elicited greater wrist absorption, and elbow power generation. Wrist and elbow joint power absorption-propulsion peaks follow a distal-proximal pattern which reversed to a proximal-distal sequence of movement coordination across all techniques.

KEY WORDS: technique, round-off, motor-control, upper limb, joint power, coaching.

INTRODUCTION: In almost every gymnastics skill a gymnast tries to change the geometry of a body, either using upper or lower limbs. Performing these skills requires the gymnast to exert joint kinetics (forces and torques). In addition, these joint kinetics needs to be produced in short periods of time, as such the key mechanical variable of joint power is fundamental to success (McGinnis, 2013). Previous research has focused on the biomechanical characteristics of different RO technique in gymnastics, which represent an instrumental part of understanding these skills and in turn improving performance (Brtva et al., 2021) and reducing injury (Farana et al., 2019). Biomechanical energetic analysis can increase understanding of how the changes in technique enable us to better satisfy task demands and can explain why a given technique is safer, more successful, or quantify the mechanical demands of that technique (Williams et al., 2015). Moreover, Newell and Irwin (2021) question the generality of the long-held view in motor control that the emerging kinetic/kinematic output within both the upper and lower limb patterns of joint motion follows a proximal–distal sequential order. The proximal–distal direction has been viewed as a fundamental principle of motor control, but these authors highlighted that the proximal–distal order is prevalent in open chain expressions of arm (e.g. over arm throwing - Putnam, 1993) and leg motion actions (e.g. ball kick - Katis et al., 2005). However, the proximal–distal order is not only absent with certain task constraints, but can be reversed in its time dependency of influence on movement coordination (Newell and Irwin, 2021). Specifically, in actions where the motion of the distal segment of the arm or leg is restricted, or even not free to vary, which lead to a closed chain configuration (Steindler, 1955). This reversal order (distal-proximal) can be found in task such as drop landing (McNitt-Gray, 1993) and the stance phase of sprinting (von Lieres and Wilkau, 2017). Currently, there is lack of evidence to support these observations in fundamental gymnastic tasks which are closed chained actions. The aim of current study is to examine the joint power changes in upper limb joints during the support phase of three RO techniques, and determine the sequencing of these joint kinetics. These findings will provide useful information for coaches, scientists and clinicians.

METHODS: Participant & Protocol: Twenty young active female gymnasts from Czech Republic, with more than 5 years' experience with systematic training and competitive gymnastics, participated in this study (age: 11.2±1.5 years; height: 143.9±10.4 cm; mass: 33.6±6.9 kg). In accordance with the guidelines of the University of Ostrava Ethics and Research committee and according to Helsinki declaration, an informed consent and parental consent were obtained from each gymnast and their parents. During their career, they had no upper limb injuries, which could affect the measurement results. After a self-selected warm up and practice, the gymnasts performed 6 round-off (RO) trials from a hurdle step with “parallel”, “T-shape” and “reverse” hand positions (Figure 1). All trials were performed in a random order and separated by a one-minute rest period.

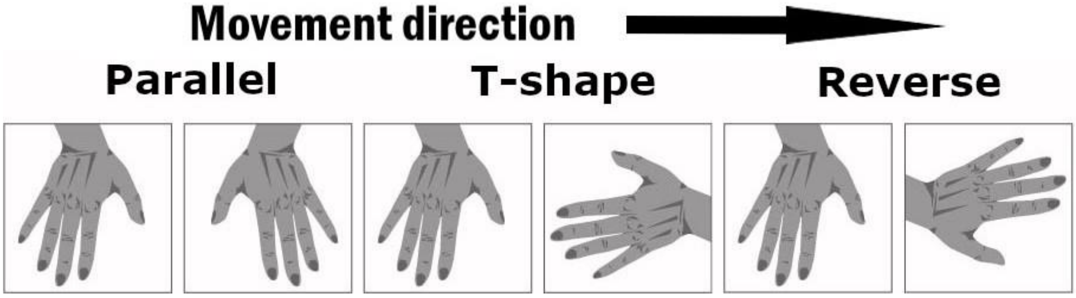

Figure 1: Round-off hand positions. Edited from Brtva et al. (2021)

Data Collection: Synchronized kinematic (10 QUALISYS cameras; 240 Hz) and kinetic (2 KISTLER force plate embedded into the floor; 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 (Farana et al., 2019). Approach velocity of hurdle step was set to 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. All analyses focused on the contact phase of the second hand during the three different techniques. 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 variables. A curve analysis, one-dimensional statistical parametric mapping (SPM; Pataky, 2010) of mean wrist and elbow joint powers was performed to compare differences between the three techniques. SPM paired t-test determined whether significant differences existed between each hand position. The significance level was set at $p < 0.05$. Statistical tests were conducted in the Matlab (R2016b, The Mathworks Inc, Natick, USA; open-source package www.spm1d.org).

RESULTS: During the second hand contact the SPM analysis (Figure 2.) revealed the joint power at the elbow was significantly different between the parallel and reverse techniques ($p<0.001$, 0-13%) and T-shape and reverse technique ($p=0.008$, 2-12%). These results highlight that the difference were early (<13%) in the initial contact phase. In addition, significant differences were found during the absorption phase between the reverse technique and parallel and T-shape ($p<0.001$, 24-47%). Similar findings were found during the propulsive phase across all techniques ($p<0.001$, 55% and 64%). For the wrist joint power, significant differences were observed early in contact phase between T-shape technique and the parallel and reverse ($p<0.001$, 0-30%). During the propulsive phase there were differences between T-shape technique and parallel and reverse ($p<0.001$, 38%-61%). In addition, there were differences between parallel and reverse technique ($p=0.021$, 40-49%). During the later stages propulsive phase differences between T-shape and reverse technique were found ($p<0.001$, 76-100%), and difference at approximately 66%-80% ($p=0.002$) and from 91% ($p=0.015$) with parallel technique were observed. Finally, differences were also found for reverse technique compared to parallel technique ($p<0.001$, 58-100%).

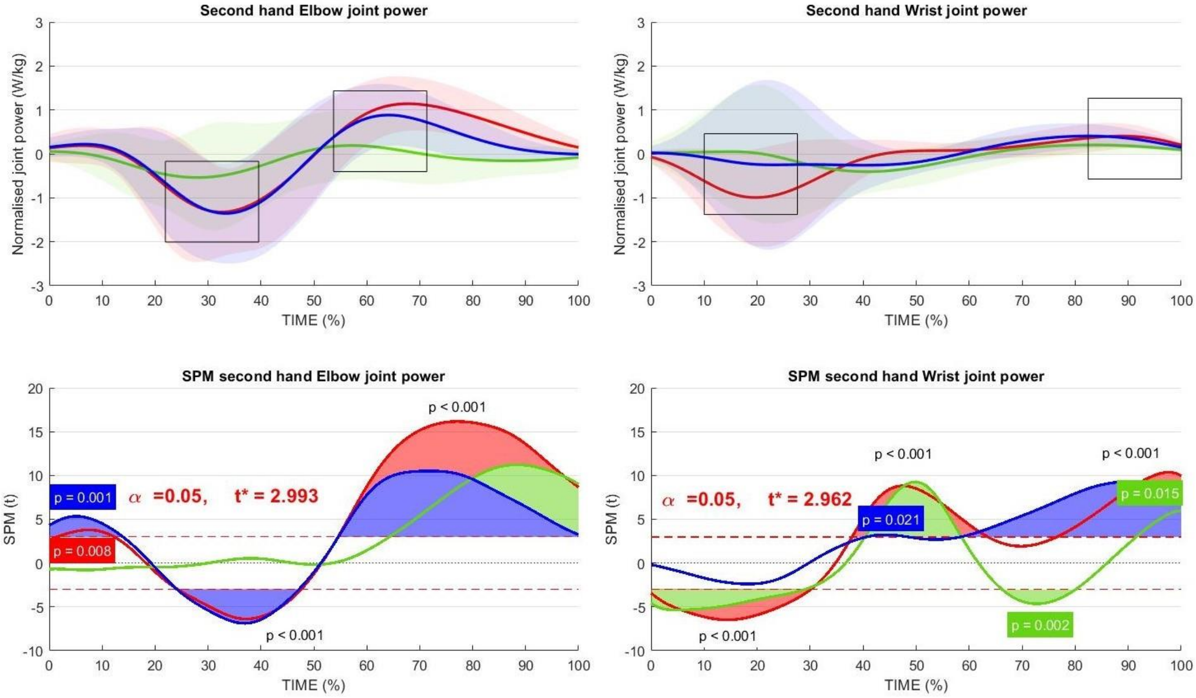

Figure 2: Up: Second hand wrist and elbow joint power means – T-shape (red), Parallel (blue), Reverse (green). Down: SPM comparison between techniques – T-shape vs. Reverse (red), Parallel vs. Reverse (blue), T-shape vs. Parallel (green).

DISCUSSION: Selecting the best technique is a challenge for coaches and gymnast and becomes more so with key skills such as the RO. Understanding the joint kinetics including joint powers provide meaningful knowledge about these skills and which techniques are more effective and safer. The aim of this study was to investigate joint power changes in upper limb joints during the support phase of the RO when performing three different techniques. During this skill, the contact phase is performed with the upper limbs and variability is limited because of the arms supporting the gymnast's body in a 'handstand' while rotating. In order to explain the joint kinetic changes an examination of the directionality of the individual joint powers was performed. Negative joint power indicates an absorption phase where the musculoskeletal demand is generally eccentric, and is followed by a positive joint power demonstrating a propulsive phase and concentric type muscle actions. The sequencing of these joint powers was also a key feature of our analysis. Observations of the joint power curves at the elbow and wrist joints showed that during the impact phase peak absorption occurred earlier in the wrist (18%) compared to the elbow (26-33%). During the propulsion phase the peak joint powers at the elbow joint occurred earlier (58-69%) compared to the wrist (86-100%) for all three techniques. This sequence indicates distal to proximal pattern of upper limb joints motion during absorption phase, and then this sequence is reversed to proximal to distal pattern during propulsion. These findings support the observations regarding closed chain arm actions, described in Newell and Irwin (2021) and brings new evidence of task specific coordinative structures. Another key observation was that the reverse technique elicited lower wrist and elbow joint powers during the absorption and propulsion phases compared to the parallel and T-shape technique. Lower wrist and elbow joint powers during the reverse technique must be considered in conjunction with the impact forces and joint stiffness reported by Farana et al. 2019. Understanding the full range of kinetic variables may suggest that the reverse technique may lead to higher mechanical load due higher joint specific compression forces and also not be able to create sufficient joint work to improve performance. Brtva et al. (2021) demonstrated that the reverse technique seems to be less effective in terms of vertical velocity transfer due to lower vertical velocity at take-off for young female gymnasts. The T-shape technique was shown to produce a greater and longer power generation at the elbow during the propulsive phase (approx. 64% through the impact phase). This finding supports speculation from Brtva et al. (2021), that the T-shape hand position during RO may help young female gymnasts to create greater vertical velocity and angular momentum at take-off. Furthermore, during the T-shape technique the wrist joint provides better absorption of impact forces. This is in accordance with findings earlier work by Farana et al. (2017) who showed that T-shape technique had lower compression forces.

CONCLUSION: Upper limb joints power analysis revealed that the T-shape technique elicited greater wrist absorption, suggesting this is a key joint for the performance of this skill and also a potential site for injury risk. The elbow joint showed the greater power production during the propulsive phase suggesting this joint is key to the performance of the latter phases and the generation of angular momentum. In contrast there was significantly lower values in power absorption and generation using reverse technique suggesting this technique is less effective. Wrist and elbow joint power absorption-generation peaks follow a distal-proximal pattern which reversed to a proximal-distal sequence of movement coordination across all techniques. These results highlight the distal-proximal coordinative structure during this closed chained arm action. This study builds on a decade of research in the RO skill, from the Ostrava Research group, and these finding contribute to making coaching and training more effective, efficient and safe, and proving a bridge between theory and practice.

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