UPPER LIMB JOINT COORDINATION DURING ROUND-OFF IN FEMALE GYMNASTICS

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The aims of this study were to integrate the analysis of the elbow joint loading kinetics with the coordination and coordination variability across three round-off (RO) techniques (‘Parallel’, ‘Reverse’, ‘T-shape’). Twelve young female gymnasts performed 6 RO trials in each technique. Kinematic and kinetic data were collected for each trial. Statistical parametric mapping of mean elbow joint ad/abduction moments was performed to compare differences between techniques. Modified vector coding technique were used to asses coordination patterns and coordination variability (CAV). Results indicated that the combination of anti-phase coordination and lower coordination variability using ‘Reverse’ technique may explain the mechanism which leads to increased elbow adduction moment and could result in overuse elbow injury.

KEY WORDS: technique, core skill, variability, elbow joint, wrist joint

INTRODUCTION: Technique selection in gymnastics plays an important role to inform performance enhancement or injury prevention. RO represents a core skill in gymnastics and it’s performed multiple times during training sessions (Daly et al., 1999). Previous research has investigated differences between three specific techniques during the round-off (RO) skill related to in injury potential (Farana et al., 2015, 2019) and highlighted an increased elbow adduction moment as the injury risk factor at the elbow joint. Similar results were reported by Brtva et al. (2021), which investigated differences in performance related variables. Results from these studies suggest, that the joint kinetics of ‘Reverse’ technique are exposing the gymnasts to potentially greater injury mechanisms. Limited research exists focusing on the interaction of the elbow adduction moment and the coordinative structures that emerge with different round off techniques. Bringing together the paradigms of Newtonian mechanics and dynamical systems provides better insight into the state of a system by assessing the complex interactions between joint coordination and kinetics (Bernstein, 1967; Newell, 1986). Modified vector coding can be used to calculate the vector orientation between adjacent data points on an angle-angle plot relative to the right horizontal (Needham et al., 2014). Vector coding technique provides insights into movement organization during the RO skills, and in combination with joint kinetics may help to understand underlying loading mechanisms and the implications to injury. It has been suggested that reduced coordination variability leads to repeated loading and consequently an increased injury potential (Hamill et al., 1999). Currently, there is limited evidence about movement organization (i.e. coordination and coordination variability) and the interacting kinetics. This knowledge would enhance the understanding of patterns of coordination that may assist in the characterization of efficient, effective and safe skill techniques. Therefore, the aims of this study were to intergrade the analysis of the elbow joint loading kinetics with the coordination and coordination variability across three RO techniques. These findings provide useful information about potential injury risk mechanisms, which could be used by coaches to inform technique selection.

METHODS: Participant & Protocol: Twelve young female gymnasts from the Czech Republic, with more than 5 years of experience with systematic training and competitive gymnastics, participated in this study (age: 11.2±1.5 years; height: 142.0±12.3 cm; mass: 33.5±14.0 kg). Following 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. They had no upper limb injuries during their career, which could affect the measurement results. After a self-selected warm-up and practice, the gymnasts performed 6 RO trials from a hurdle step in each technique "Parallel", "T-shape" and "Reverse" hand positions (see Brtva et al., 2021). All trials were performed in random order and separated by a one-minute rest period.

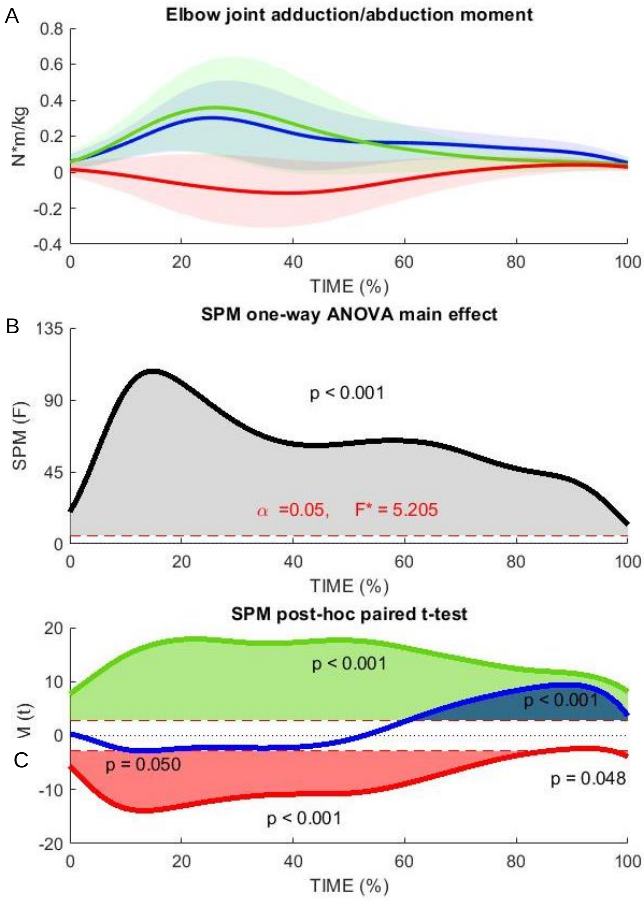

Figure 1: A) Second-hand elbow joint adduction/abduction moments – Parallel (blue), T-shape (red), Reverse (green). B) SPM one-way ANOVA main effect. C) SPM post-hoc paired t-tests – Parallel vs. Reverse (blue), T-shape vs. Reverse (red), and T-shape vs. Parallel (green).

Data Collection: Data were collected using 10 infrared cameras (Qualisys, 240Hz) synchronized with 2 force plates (Kistler, 1200Hz). Based on C-motion Company (Rockville, MD, USA) recommendations, retroreflective markers and clusters were attached to the gymnasts' upper limbs (Brtva et al., 2021). Approach velocity of the 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. Data were normalized for contact time (0-100%). 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. The dependent variable was elbow joint abduction/adduction moment (M_{elbow}). Means and standard deviations (M ± SD) were calculated for all techniques. A curve analysis, one-dimensional statistical parametric mapping (SPM; Pataky, 2010) of mean elbow joint adduction/abduction moment was performed to compare differences between the three techniques. One-way ANOVA SPM was used to detect main effect of hand positions. To compare differences between hand positions, post-hoc analysis using SPM paired t-test. The significance level was set at $p < 0.05$. Statistical analysis was conducted in the Matlab (R2021a, The Mathworks Inc, Natick, USA; open-source package www.spm1d.org). Modified vector coding technique (Needham et al., 2020) were used to asses coordination patterns and coordination variability (CAV) for each technique. Elbow and wrist internal/external rotation couplings were selected for this analysis. The coordination patterns were divided into four bins – in-phase proximal dominancy (IPPD), in-phase distal dominancy (IPDD), anti-phase distal dominancy (APDD), and anti-phase proximal dominancy (APPD).

RESULTS & DISCUSSION: Results of the SPM analysis for M_{elbow} are presented in Figure 1. We found a main effect during the whole contact phase (p<0.001, 0-100%; Figure 1B). Post-hoc SPM paired t-test (Figure 1C) revealed the M_{elbow} was significantly different during the contact phase between T-shape and Parallel techniques (0-100%, p<0.001). M_{elbow} was also found to be different between the T-shape and Reverse (0-84%, p<0.001; 97-100%, p=0.048) and Parallel and Reverse (11-14%, p<0.001; 62-100%, p<0.001) techniques. Kinetic profiles showed M_{elbow} peaks ranged from 25-35% approx. across all techniques suggesting the end of the loading phase. During this period of elbow joint loading the coordination between Elbow-Wrist rotation in Parallel and Reverse techniques demonstrated anti-phase pattern (Figure 2). In contrast, the T-shape technique revealed generally in-phase coordination pattern. These coordination patterns may help to explain differences and underlying mechanism found in M_{elbow}. T-shape technique elicited the lowest M_{elbow} which correspond to the in-phase coordination pattern of the wrist and elbow joints during loading phase. In contrast the Parallel and Reverse technique showed an increased internal adduction moment at the elbow joint and an anti-phase coordination pattern. The interaction between the between the coordinative structure and the elbow loading may be a key injury risk factor (Hamill et al., 1999). The variability of the coordination pattern was observed to change between techniques, with the Parallel and T-shape techniques (Figure 2) showing higher levels of variability. High levels of coordination variability have been shown to play an important role in reducing injury risk (Hamill et al., 1999). In contrast, the Reverse technique showed the lowest variability and as such may have an increased risk of elbow overuse injury. Using the Reverse technique had been previously been identified as RO technique, with increased injury risk due to increased adduction moments and also elbow compression forces (Farana et al., 2018; Brtva et al., 2021). A combination of joint kinetic and coordination analysis provides novel insights into the relationship between mechanical loading and the control of human movement, and explains the mechanism resulting in increased load. The limitations of this study rest with the lack of further statistical analysis of relationships between increased moments and coordination phases. Vector coding technique using group means may also hide subtle differences of individuals or between trials (Needham et al., 2020).

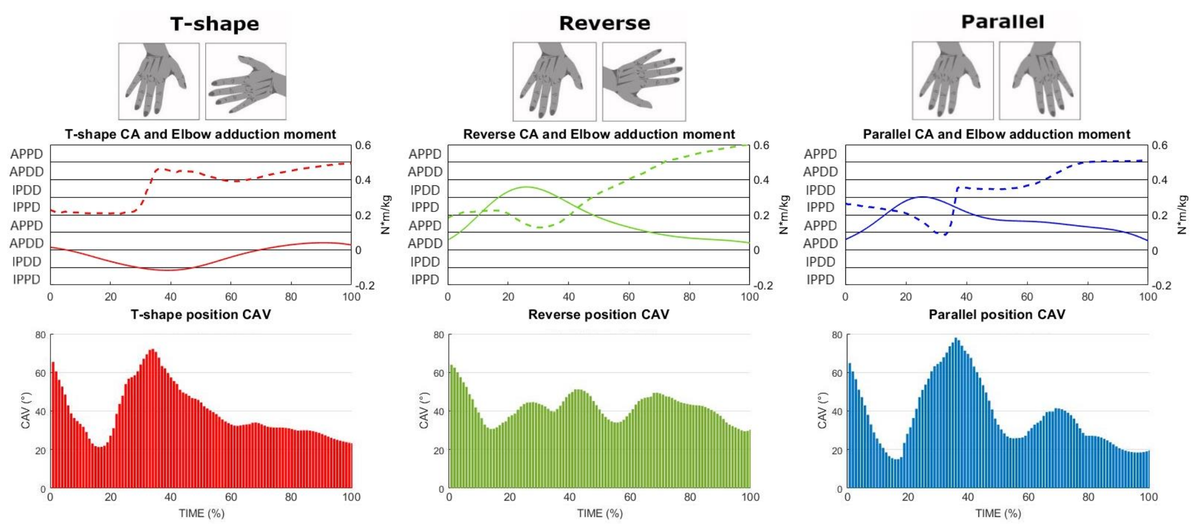

Figure 2: TOP - Coupling angle plots (dash line) and elbow joint ad/abduction moment (solid line) of round-off techniques –T-shape (red), Reverse (green), Parallel (blue). BOTTOM - Coordination variability (CAV) of round-off techniques.

CONCLUSION: Elbow joint adduction/abduction moment analysis revealed that the T-shape technique elicited the lowest values during loading, which could be associated with the in-phase coordination pattern between the wrist and elbow joint rotation during RO skill. In contrast, the Parallel and Reverse techniques revealed anti-phase coordination. Coordination variability was higher using T-shape and Parallel techniques compared to Reverse suggesting a higher injury risk in the reverse technique. Understanding the coordination structure and its variability in combination with joint loading characteristics provide a useful mechanics to understand injury risk potential.

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