KINEMATIC AND MUSCULAR STRATEGIES OF THE LOWER BACK DURING BACKWARD SOMERSAULT LANDING IN GYMNASTICS

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The purpose of this study was to investigate the kinematics and muscle activity of the lower limbs and lumbar spine during the landing of a jump in female gymnasts. Sixteen adult gymnasts performed round-offs followed by a back somersault. Lumbar, hip, and knee joint angles at peak GRF and EMG activity of 4 lumbar spine muscles were recorded. The study reveals a large heterogeneity in the kinematic and muscular strategies used by the gymnasts. A more detailed investigation is required to gain a better understanding of the motor behaviors observed, with a view to potentially improving individualized monitoring during the season and reducing the incidence of injury.

KEYWORDS: Lumbar, Lower limb, EMG, Injury.

INTRODUCTION: Gymnastics is a sport with high risk of injury, both in training and competition (Trikha et al. 2023; Desai et al. 2019). According to Campbell et al. (2019), female gymnasts (28.0%) are more prone to injuries than male gymnasts (24.1%). In addition, due to the nature of the equipment used, the female gymnasts are more prone to lower limb injuries (ankle and foot: 19.9%, knee and hip: 14.2%) and trunk injuries (11.17%) (Trikha et al. 2023; Desai et al. 2019). Cruciate ligament rupture and lumbar pain are the most common complaints (Edouard et al. 2018). Although there is a lack of literature on the relationship between the latter and gymnastics, we know that jump landing is a traumatic event for the lumbar spine (Sweeney et al. 2019). The impact at landing represents 18 to 30 times athletes' body mass after a jump (Makovitch et al. 2020, Schäfer et al. 2023), which may exceed the tolerance threshold of the affected structures. Inadequate dissipation of external mechanical forces by the musculoskeletal system during impact can increase the risk of injury (Standing et al. 2015). Jump landing studies have suggested that active knee and hip flexion may reduce the impact load (Blackburn et al. 2008). However, the scoring code of the International Gymnastics Federation only allows slight knee and hip flexion, which limits landing strategies (Straker et al. 2021). Although these rules are evolving to allow more knee and hip flexion, the impact load remains significant (Makovitch et al. 2020). Furthermore, Eyssartier et al. (2023) reported that gymnasts exhibit a lumbar posture of extreme flexion or extension at impact, which places the lumbar spine in a risky position relative to the direction of the impact. More, this lumbar flexion posture, while providing better load distribution, also places significant stress on the lumbar muscles and surrounding structures (Mörl et al. 2020). In flexion, the stretching of the erector spinae muscles increases the pressure on the lumbar discs, increasing the risk of injury (Mörl et al. 2020). Therefore, the purpose of this study was to (1) estimate the lower limb and lumbar spine kinematics during landing by female gymnasts and (2) explore the muscle activation strategies used.

METHODS: Sixteen female gymnasts, with a mean age of 22.2 ± 6.7 years, a height of 161.3 ± 4.2 cm, and a body mass of 57.5 ± 7.3 kg, participated in this study. Only gymnasts of inter-regional level and above, with no history of musculoskeletal injury in the past six weeks, were included. All participants provided informed consent for participation.

Task: The task consisted of performing a run-up to round-off and back somersault five times. The landing was executed with the feet together. Participants were instructed to go as high as possible and land without any extra steps. A five-minute warm-up on an ergocycle at a moderate pace was undergone by all participants, followed by a gymnastic warm-up on the jumping track.

Material and data collection: The run-up and round-off were executed on a tumbling Airtrack™ and the back somersault was landed on a pile of two standard competition gymnastic mats of 20 cm and 10 cm thickness (GYMNOVA®).

Participants were equipped with 47 reflective markers located according to the model of Muller et al. 2019 and 4 Electromyography (EMG) sensors (2100 Hz, DelsysTrigno®) were placed with double-sided tape and taping strip. These electrodes were positioned bilaterally on the longissimus (LG), and the multifidus (MF) muscles following SENIAM recommendations.

The 3D kinematics were collected using a 23-camera motion capture system (300 Hz, Qualisys Oqus 700+, Göteborg, Sweden), and ground reaction forces (GRF) were measured by two force plates under the landing mats (2100 Hz, ATMI, Watertown, United States). All data were time-synchronized and collected using Qualisys Track Manager® software.

Data analysis: Inverse kinematics was performed on the motion capture data using the Matlab® CusToM toolbox (Muller et al. 2019) to obtain a time-history of joint angles. This model accounts for the lumbar angle between all the lumbar vertebrae and the sacrum. The EMGs were filtered using a second-order Butterworth filter and a 20-450 Hz bandpass filter. They were then normalized to the EMGs from a submaximal test, the Sorensen test (Bivia-Roig et al. 2019). The period of interest analyzed in this study extends from the initial landing contact to the lumbar flexion peak that follows. The initial contact is determined from motion capture data. Muscle activation amplitude was determined by Root Mean Square (RMS). In addition, the GRF peak time was extracted from the force platform data to determine when the external forces applied to the body were maximal. However, since the amplitude of the GRF peaks cannot be used here due to the use of landing mats on the platforms, we will characterize the loads applied to the gymnasts by the velocity of the center of mass at impact (Figure 1). Mean (standard deviation) and coefficient of variation, which represents the dispersion of the data over a score ranging from 0 to 1, were calculated for knee, hip and lumbar flexion angles at GRF peak moment (Table 1). In this study, we used a Spearman correlation test to examine the relationship between kinematic and muscular data.

RESULTS: Some of the jumps caused electrodes detachment, so some data is missing (e.g. Figure 1, participant 12). The kinematic data showed greater interindividual variability for the angle of lumbar flexion, ranging from 3.7° in participant 5 to 35.6° in participant 1. The coefficient of variation was estimated to be 0.5. Smaller inter-individual differences were found for the hip and knee, averaged over the 5 jumps performed (see Table 1), with a calculated coefficient of variation of 0.3 and 0.2, respectively. In addition, some participants showed significant intra-individual variability between the 5 jumps performed, especially for hip flexion in participant 10 (standard deviation: 12.4°). Regarding muscle activation amplitudes, we again observed significant inter-individual variability between certain participants (Figure 1, participant 5 vs. participant 13). No correlation was found between kinematic, muscular and impact velocity data.

Table 1: Mean (standard deviation) for five landings of lumbar, hip and knee flexion angle at GRF peak.

Participant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Lumbar (°)	35.6 *(1.6)*	20.1 *(2.3)*	21.6 *(2.1)*	30.2 *(2.1)*	3.7 *(3)*	7.9 *(5.2)*	19.6 *(4.5)*	17.1 *(2.4)*	34.9 *(2.5)*	7.9 *(2.6)*	14.6 *(3.2)*	20.8 *(4.7)*	24.1 *(5.2)*	9.5 *(3.4)*	33 *(1.5)*	25.3 *(4.6)*
Hip (°)	41 *(3.2)*	57.6 *(2.3)*	36.9 *(2.3)*	71.8 *(5.2)*	51.7 *(5.8)*	45.9 *(6.9)*	43.8 *(7)*	41.1 *(3.5)*	37.3 *(5.5)*	31.5 *(12.4)*	61.1 *(4.1)*	46.1 *(5.7)*	29.4 *(9.4)*	38.5 *(4.3)*	31.3 *(4.1)*	52.6 *(4.6)*
Knee (°)	31.7 *(3)*	36.6 *(3.6)*	37.9 *(2.4)*	36.7 *(4.4)*	45.2 *(6.9)*	37.8 *(5.2)*	48.6 *(2.7)*	44.4 *(5.9)*	45.5 *(5)*	43.7 *(4.8)*	32.8 *(4.4)*	31.1 *(3.9)*	46.6 *(2)*	34.9 *(7.9)*	29.6 *(2.2)*	31.5 *(5.6)*

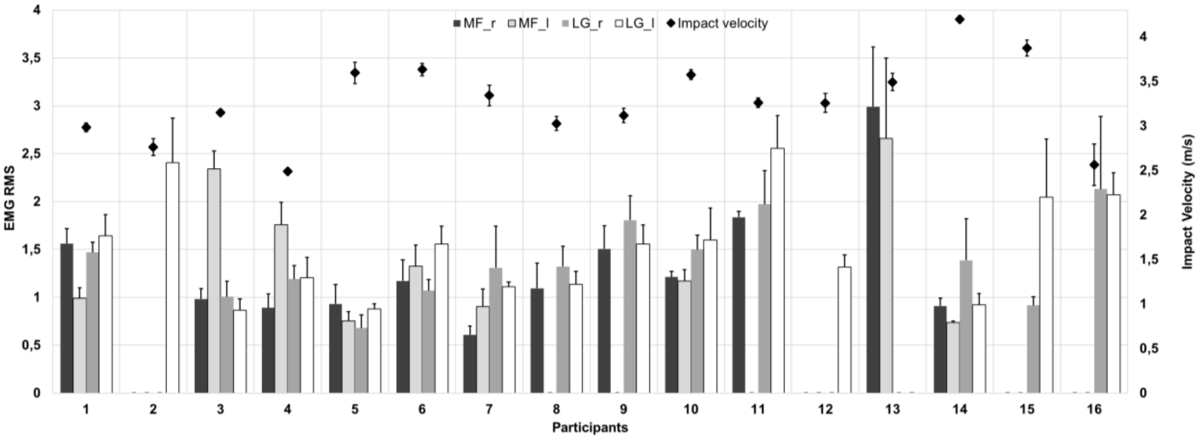

Figure 1: Muscle activation amplitude from impact to peak lumbar flexion and mean impact velocity. Mean RMS and standard deviation of right and left multifidus (MF_r, MF_l) and longissimus (LG_r, LG_l). The right axis of the graph shows the mean and standard deviation of impact velocity.

DISCUSSION: The lack of correlation between kinematic and muscular variables, as well as the variability in mean lumbar spine and hip flexion angles per participant (Table 1), suggests heterogeneity in the choice of strategies for the same type of landing. The risk characterization of a gymnastic jump landing in relation to other types of landings is complex and does not seem to be limited to the parameters studied here. Indeed, while Sonvico et al. 2019 recommend flexing the joints of the lower limbs and trunk to distribute the impact load and thus minimize the risk of injury, Wade et al. 2012 note that significant lumbar flexion decreases lumbar muscle activity, which increases the risk of mechanical stress on vertebral structures (Eyssartier et al. 2023; Mörl et al. 2020). It would be relevant to link the kinematic and muscular characteristics observed with a follow-up of the athlete's injuries during the season to identify potential injury mechanisms, particularly in the lumbar spine.

CONCLUSION: Based on the results obtained, we were able to identify a high degree of inter-individual variability in the lower limb and lumbar motor strategies implemented by the gymnasts. More detailed analyses are needed to understand these strategies, by studying the preparation phase of the landing. This variability also highlights the difficulties in identifying injury mechanisms. In addition, the implementation of an individualized assessment of landing strategy and the follow-up of injuries over the course of gymnastics seasons would help to identify these injury mechanisms.

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