# KINETIC STRATEGIES OF GYMNASTICS LANDINGS

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Organisation and magnitude of lower limb kinetics during landing can contribute to knowledge of injury. Our aim was to quantify leg stiffness and temporal organisation of joint moments of two different landing styles. Four female gymnasts performed 20 landings in the women's and men's landing style. Synchronised kinematic (250 Hz) and kinetic (1000 Hz) data were used to describe the leg and joint stiffness, and the sequencing of the peak joint moments. Leg stiffness demonstrated lower variability compared to the associated joint level, suggesting joint level control. Group relative timing of the lower extremity joint moments presented distal-proximal sequencing, although individuals presented a variety of landing strategies. This study highlights the individualised signature strategies in landing, and consequently the importance of a single-subject design when examining injury risk.

**KEYWORDS:** stiffness, injury risk, coaching, kinetic sequencing

**INTRODUCTION:** Stress fractures have been recognised as a prevalent injury affecting female athletes' participation in sport. In particular, women's collegiate gymnastics has reported the second highest stress fracture rate per 1000 exposure hours (25.58/100 000 AEs) across 25 NCAA sports with 73% of these types of injuries presenting in the lower extremity (Rizzone et al., 2017). Given that stress fractures are suggested to occur as a result of repetitive submaximal loading, it is logical that these types of injuries emerge due to the high frequency of impact landings performed during the floor exercise (Rizzone et al., 2017). The successful performance of a landing in gymnastics is governed by a similar set of objectives for both men and women; however, with one variation. Female artistic gymnasts are expected to land with their feet together ($W_{LS}$), whilst males are able to land with their feet apart and accrue no penalty, provided they are able to tap their heels together without lifting the front of the feet ($M_{LS}$) upon completion (FIG 1 i;ii). Previous research has investigated this problem with Bradshaw et al. (2016) identifying a reduced impact force in young, elite female gymnasts performing backward somersaults when landing with their feet shoulder width apart. Whilst Straker et al. (2021) found no significant reductions in external kinetics at a group level, they did report a greater range of motion (ROM) at the knee and hip in female, collegiate gymnasts when performing a drop landing using the $M_{LS}$. Interestingly, both studies identified a clear need for individual analyses, with participants demonstrating signature strategies to meet the specific task demands (Irwin & Kerwin, 2009). In order to investigate this further, leg and joint stiffness may provide insight into potential injury risk (Butler et al., 2003). Additionally, an investigation into the sequencing of joint kinetics may provide further understanding into the task specific coordination and control of individual gymnasts during a closed chain movement (Newell & Irwin, 2021). Therefore, the aim of this study was to quantify the differences in lower-limb stiffness and task specific temporal organisation of the joint kinetics in female, collegiate gymnasts when performing the $M_{LS}$ or $W_{LS}$. This research will help coaches understand movement forms and provide information on injury risk during landing technique.

**METHODS:** An individual-orientated analysis was used, where four gymnasts (age: 20.6 ± 1.6 years, height: 1.67 ± 0.07 m, mass: 65.8 ± 9.4 kg) were recruited via purposeful sampling from the University gymnastics team. All participants were required to be training at least three times per week and have no known lower limb injuries or neurological conditions which would affect the execution of the landings. Ethical approval was gained from the University ethics committee, and voluntary, informed consent was collected from each gymnast prior to the data collection.

Each gymnast performed a self-selected warm-up before performing 20 randomised drop landings, either using the $M_{LS}$ (n = 10) or $W_{LS}$ (n = 10) from a 0.72 m height onto two independent gymnastics mats.

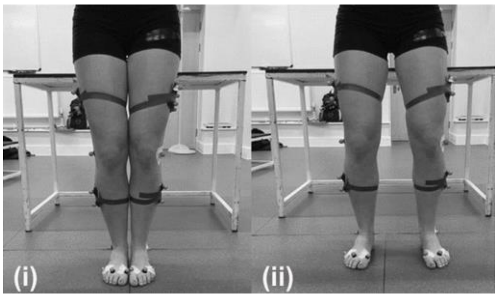


**Figure 1. Two landing styles – (i) $W_{LS}$ (with feet together) and (ii) $M_{LS}$ (feet apart as long as the heels can tap together, without raising the front of the feet upon completion of the landing movement).**

These were affixed to two, independent force plates (9827CA, Kistler, 1000 Hz) and were synchronised with a 13 camera Vicon Vantage (250 Hz) system to simultaneously collect the kinetic and kinematic data. Sixty-nine retroreflective markers and clusters were positioned on the body in accordance with a modified, full-body six degrees of freedom marker set. Participants were then asked to execute the landing manoeuvre as if they were in a competition, and only alter the foot position when instructed by the researcher. The marker trajectories were gap-filled in Vicon Nexus (v2.9.2, Oxford Metrics Ltd.), and transferred into Visual3D (C-motion Rockville, MD, USA). The coordinate and force plate data were low pass filtered using a fourth order Butterworth filter, with cut-off frequencies of 11 Hz and 50 Hz, respectively. The local coordinate system was defined using the standing calibration trial, with the *landing phase* defined as the instant of touchdown (TD) (10 N threshold) until the lowest vertical position of the models' centre of mass (COM) and normalised to 100% movement time using a cubic spline. The variables chosen for analysis were leg stiffness ($k_{leg}$), joint stiffness ($k_{joint}$), and the relative timing of the peak ankle, knee, and hip joint moments ($JM_{time}$). $K_{leg}$ and $k_{joint}$ were calculated using methods previously reported by Ward et al. (2019). The ground reaction force and moment data were normalised to the bodyweight, and the change in vertical displacement of the COM was defined relative to height. Means, standard deviations were calculated for all variables, and the coefficient of variation for the stiffness. A paired t-test was used to determine significant differences between conditions with the level of significance set at ($p \leq 0.05$). Hedges g was used to determine the measure of these associations with the effect size (ES) interpreted as small (0.2-0.5), medium, (0.51-0.8) and large (> 0.8).

**RESULTS:** Group and individual right leg stiffness (mean ± SD) and the coefficient of variation (CV%) for the $W_{LS}$ and $M_{LS}$ are presented in Table 1. No significant differences were reported at the group level with negligible effects (0.14 and 0.15), but P1 and P2 exhibited significant

**Table 1. Mean (SD) group and individual absolute and normalised leg stiffness of the right leg when performing the $W_{LS}$ and $M_{LS}$.**

| | Absolute Leg Stiffness (BW/m) | | | | Normalised Leg Stiffness (BW/ht) | | | |
|---|---|---|---|---|---|---|---|---|
| | $W_{LS}$ | CV (%) | $M_{LS}$ | CV (%) | $W_{LS}$ | CV (%) | $M_{LS}$ | CV (%) |
| GROUP | 20.1 (4.5) | 22.22 | 19.4 (4.4) | 22.4 | 33.4 (7.4) | 22.05 | 32.2 (6.6) | 20.57 |
| P1 | 17.87 (2.26)* | 12.65 | 14.86 (1.39) | 9.37 | 31.45 (3.98)* | 12.65 | 26.15 (2.45) | 9.37 |
| P2 | 18.11 (4.96)* | 27.41 | 23.31 (3.36) | 14.39 | 29.34 (8.04)* | 27.41 | 37.77 (5.44) | 14.39 |
| P4 | 22.72 (5.28) | 23.24 | 19.35 (3.95) | 20.43 | 38.40 (8.92) | 23.24 | 32.71 (6.68) | 20.43 |
| P7 | 21.30 (3.10) | 14.57 | 19.75 (3.64) | 18.43 | 34.08 (4.97) | 14.57 | 31.60 (5.82) | 18.43 |

Notes: P, participant, $W_{LS}$, women's landing strategy, $M_{LS}$, men's landing strategy, CV, coefficient of variation. Significant differences in strategy are denoted by a *.

differences in leg stiffness ($p \leq 0.05$). Group and individual right ankle, knee, and hip joint stiffness (mean ± SD) and the coefficient of variation for the $W_{LS}$ and $M_{LS}$ are presented in Table 2. No significant differences were reported at the group level, however the hip (0.31) and ankle (0.55) demonstrated small and medium effect sizes respectively. P4 demonstrated a significant reduction ($p \leq 0.05$) in ankle joint stiffness when performing the $M_{LS}$.

**Table 2. Mean (SD) group and individual ankle, knee and hip joint stiffness of the right leg when performing the $W_{LS}$ and $M_{LS}$.**

| | Ankle Joint Stiffness (BW/°) | | | | Knee Joint Stiffness (BW/°) | | | | Hip Joint Stiffness (BW/°) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $W_{LS}$ | CV(%) | $M_{LS}$ | CV(%) | $W_{LS}$ | CV(%) | $M_{LS}$ | CV(%) | $W_{LS}$ | CV(%) | $M_{LS}$ | CV(%) |
| **GROUP** | 0.04 (0.02) | 45.15 | 0.03 (0.01) | 38.72 | 0.09 (0.04) | 46.06 | 0.09 (0.04) | 45.16 | 0.08 (0.06) | 71.38 | 0.06 (0.05) | 77.82 |
| **P1** | 0.04 (0.00) | 12.42 | 0.04 (0.00) | 11.37 | 0.08 (0.01) | 18.10 | 0.07 (0.02) | 22.93 | 0.07 (0.02) | 32.71 | 0.05 (0.02) | 29.67 |
| **P2** | 0.05 (0.02) | 42.00 | 0.04 (0.00) | 11.05 | 0.05 (0.03) | 66.29 | 0.06 (0.03) | 56.24 | 0.05 (0.02) | 50.16 | 0.03 (0.02) | 52.13 |
| **P4** | 0.02 (0.01)* | 49.48 | 0.01 (0.00) | 17.56 | 0.13 (0.02) | 17.85 | 0.14 (0.03) | 18.74 | 0.04 (0.06) | 128.21 | 0.02 (0.02) | 67.7 |
| **P7** | 0.03 (0.01) | 18.14 | 0.03 (0.00) | 18.04 | 0.09 (0.03) | 39.58 | 0.08 (0.02) | 29.13 | 0.15 (0.01) | 8.22 | 0.14 (0.01) | 10.7 |

Notes: P, participant, $W_{LS}$, women's landing strategy, $M_{LS}$, men's landing strategy, CV, coefficient of variation. Significant differences in strategy are denoted by a *.

The relative timings (mean ± SD) and sequencing of the peak joint moments (ankle, knee, and hip) are presented in Figure 2. The timing of the peak knee joint moment for P1 was found to occur significantly earlier ($p \leq 0.05$) when performing the $M_{LS}$.

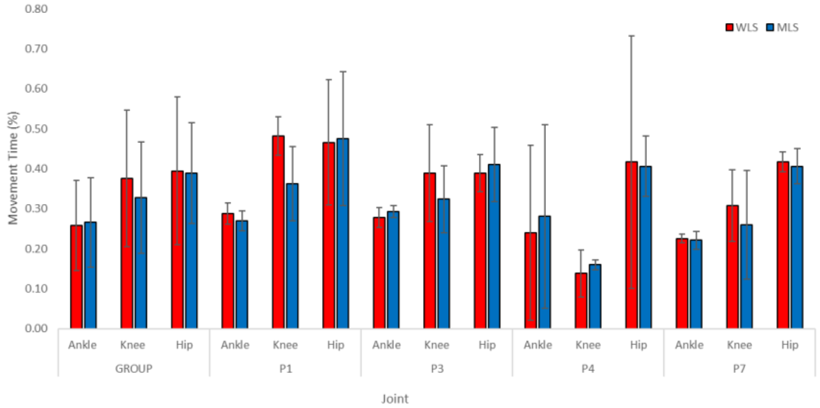


**Figure 2. The relative timings of peak joint moments (normalised to 100% movement time) when performing the $W_{LS}$ compared to the $M_{LS}$. * Denotes a significant difference ($p \leq 0.05$) between the two landing styles.**

**DISCUSSION:** The aim of this study was to quantify the differences in lower-limb stiffness and task specific temporal organisation of the joint kinetics in female, collegiate gymnasts when performing the $M_{LS}$ or $W_{LS}$. No significant group differences in $k_{leg}$ were observed at a group level, however, this can be explained through the differing individual responses. P1 exhibited a significantly reduced $k_{leg}$ when performing the $M_{LS}$ whilst P2 showed a significantly increased $k_{leg}$ when performing the $M_{LS}$, highlighting the importance of an individual-orientated analysis. Previous retrospective studies have suggested an increased stiffness to be associated with bony injuries, for example stress fractures (Butler et al., 2003). Therefore, P1 could have a higher potential for developing stress fractures when performing the $W_{LS}$, whilst the opposing conclusion would be applied to P2. No significant group differences were identified in $k_{joint}$ between the landing styles, with only P4 exhibiting significantly reduced ankle stiffness when performing the $M_{LS}$. A reduction in joint stiffness has been suggested to allow for excessive joint motion (Butler et al., 2003), increasing the risk of soft tissue injury. The lack of significant differences in $k_{leg}$ between landing styles could be due to the large intra- and inter-individual variation at the three joints. Similar results were found in female dancers during landings, where neither the ankle, knee nor hip stiffness values significantly contributed to variance in $k_{leg}$ (Ward et al., 2019). Previous research has also recognised gymnasts tending to exhibit signature movement patterns, with one explanation being the highly constrained tasks in gymnastics by the apparatus and the rules (Irwin & Kerwin, 2005; Irwin et al., 2021). The constrained techniques performed in gymnastics has been suggested to require the gymnasts to be consistent at a macroscopic level (Irwin et al., 2021), which is supported by a larger coordination flexibility at joint level allowing adaptation to varying tasks. According to Nordin & Dufek (2019) a reduction in intra-individual (between trial) movement variability may inhibit their capacity to adapt during repetitive loading and therefore increasing the risk of injury. In terms of the relative $JM_{time,}$ Figure 2 indicates a subject specific signature to the organisation of these peak kinetics. The relative $JM_{time}$ suggests a distal-proximal sequencing at the group level, however when analysed individually not all participants reached their peak joint moments sequentially. This finding supports the observations regarding closed chain joint actions, described in Newell and Irwin (2021) and brings new evidence of task and subject specific coordinative structures. Implications around this sequencing may provide insight into difference in load distribution and warrants future examination.

**CONCLUSION:** The large prevalence of lower extremity overuse injuries in female gymnasts warrants investigation into the biomechanical differences when performing either landing style. A key finding of this study was the consistency observed in total leg stiffness compared to the individual joints within each subject, suggesting a joint level control strategy. In terms of sequencing of the joint kinetics, the inter-subject variation highlights the individual signature of temporal organisation. Difficulties arise in attempting to create a generalised rule change for all with such individual responses. Building on the current research an examination of the associations between task demand, intra-individual variability, and the potential for overuse injury with an individual-oriented analyses should be applied.

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