TECHNIQUE SELECTION DURING LANDINGS IN ARTISTIC GYMNASTICS

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This study aimed to quantify the mechanical characteristics of two landing techniques performed by artistic gymnasts. Seven senior female artistic gymnasts performed 20 drop landings with different foot positions: feet together (women's technique) or hip width apart (men's technique). Synchronised 3D kinematic (250 Hz) and kinetic data (1000 Hz) were collected for each trial and biomechanical variables associated with lower extremity injury during landing were analysed. Significant differences ($\alpha < 0.05$) in ankle dorsiflexion and inversion at peak vertical ground reaction force (F_{PeakZ}) were identified between techniques. The findings suggest the female landing style to be associated with increased F_{PeakZ}, loading rate and reduced knee flexion. Whereas the male landing style was reported to exhibit significantly increased ankle inversion angles and reduced ankle dorsiflexion angles at F_{PeakZ}. Results suggest that both strategies present characteristics associated with increased risk of differing injuries

KEYWORDS: Injury prevention, technique selection

INTRODUCTION: Lower extremity injuries are the most frequently reported injuries within women's artistic gymnastics (WAG) (Kerr *et al.*, 2015), with ankle and knee sprains being the most commonly reported anatomical sites of acute injury (Kerr *et al.,* 2015). This is unsurprising due to the frequency of landings performed (Kirialanis *et al.*, 2003) and the magnitude of load the body must attenuate when landing often complex aerial rotations (Gittoes, Irwin & Kerwin, 2013). Changes in rules have been driven by safety; leading to injury prevention measures such as safety mats, but also to technique changes such as landing foot placement driven by judging criteria (Sands, 2000; FIG., 2016). The lower extremity injury rate still remains considerably high compared to their male counterpart (Kolt & Caine, 2010).

Artistic gymnastics is divided into the men's (MAG) and women's (WAG) competition; both governed under two individual rulebooks (code of points [CoP]) (FIG., 2016a; 2016b). Both codes provide information regarding how skills should be executed and evaluated against *'aesthetic'* movement patterns (Gittoes, Irwin & Kerwin, 2013). When performing a landing, the men and women are assessed differently as to what constitutes as a safe, aesthetic, successful movement. The landing criteria in both codes requires male and female gymnasts to land skills using a double-footed, balanced technique with limited flexion of the trunk and lower extremities (FIG 2016a; 2016b). The only discrepancies that emerge are the deviation of the legs when first landing to completing the movement. In the women's competition any deviation of the legs apart is considered a fault and awarded a 0.1 penalty per instant of the fault (FIG., 2016a). Whilst in the men's competition the gymnasts are able to land skills with their legs up to hip width apart (so as to allow a heel tap at the termination of the movement) without penalisation (FIG., 2016b). Currently the available reasoning for these discrepancies are for *'safety reasons'* within the men's competition (FIG., 2016b, p. 31). These differences are further compounded by differences across national governing bodies. For example, USA Gymnastics allow for female artistic gymnasts competing against the junior Olympic or Xcel code of points to land with their feet up to hip width apart with no deduction (identical to the FIG MAG code of points). Therefore, the aim of this study was to quantify the differences in the lower limb biophysical demands during landings in female gymnasts, with differing task constraints (landing stance). With disparity in the codes, this study may provide empirical evidence to better develop knowledge that may reduce the risk of injury. It was hypothesised that landing mechanics are affected by the landing strategy (male vs female style) during a drop landing (H1).

METHODS: Seven, national level, female, artistic gymnasts (age: 20.5 ± 1.2 years, height: 1.60 ± 0.10 m and mass: 60.5 ± 10.2 kg) were recruited from the University gymnastics team. All participants were required to be actively training at least three times per week, free from musculoskeletal injuries and neurological conditions which would impair the execution of the landing task. Ethical approval was granted by the university's ethics committee and informed consent was obtained from each participant. Each participant performed a self-selected warm-up before performing ten randomised trials of each drop landing condition (Figure 1) from a 0.72 m platform (to replicate typical velocities during gymnastics landings) onto two customised landing mats affixed to either force plate (mat dimensions).
Synchronised kinematic (13 Vicon Vantage cameras, 250 Hz) and kinetic (two Kistler 9827CA force plates, 1000 Hz) data were collected for each trial. Sixty-nine retroreflective markers and clusters were attached to the body in accordance with a modified full body six degrees of freedom marker set.

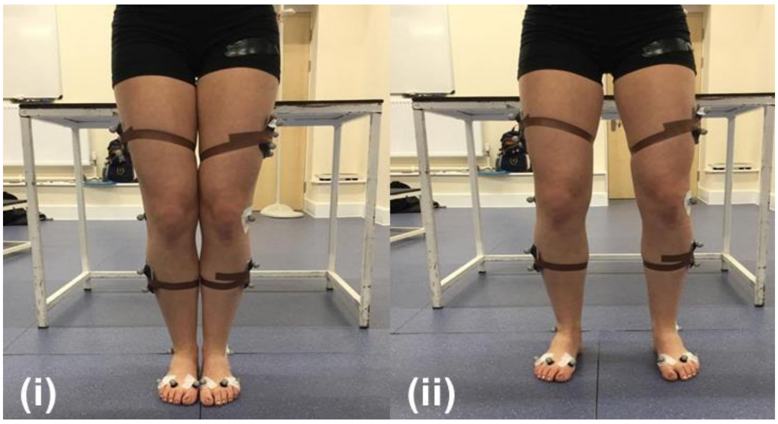

Figure 1. Two landing conditions – (i) feet together [WAG] and (ii) feet apart which would allow for a heel tap without raising or moving the front of the feet [MAG].

Data were processed using Visual 3D (C-motion, Rockville, MD, USA), where the local coordinate system was defined using a standing calibration trial. All analyses were focused during the landing phase; defined from the moment of touchdown till the performer returned to a standing position (typical of a competitive, gymnastics landing). The variables of interest were those associated with increased injury risk.
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. Means and standard deviations were calculated for all measured variables. The Wilcoxon signed-rank test ascertained significant differences between conditions with the level of significance set at ($p<0.05$), with the sum of those ranks to calculate 95% confidence intervals ($\alpha = 0.05$). Hedges g was used to determine the measure of these associations, with the effect size (ES) interpreted as small (d=0.2-0.5), medium (d=0.51-0.8) and large (d>0.8) (Hedges, 1981). The results for the dominant leg are reported, with the exception of symmetry angle (Zifchock *et al.*, 2008) used to quantify inter-limb symmetry.

RESULTS: Descriptive statistics (mean ± SD), effect sizes (ES) and 95% confidence intervals (95% CI) between the two techniques are presented in Table 1. The observations from these results highlighted differences in both kinematic and kinetic measures when performing each style of landing. The relative time of F_{PeakZ} (%MT), dorsiflexion and inversion displacement at F_{PeakZ} (°), were reported as statistically significant ($\alpha < 0.05$) between groups.

Table 1. Comparison of external force, joint angular kinematic and kinetics at the ankle and knee with effect sizes and confidence intervals.

Variable	WAG style	MAG style	ES	95% CI	SA (%)	
External Force					WAG	MAG
F_{PeakZ} (BW)	3.2 (0.3)	3.1 (0.2)	0.4	-0.02 – 1.11	4	4
Relative time of F_{PeakZ} (% MT)	4.3 (1.6)	5.0 (1.9)	0.4	0.22 – 1.55*	2	1
Loading rate (BW/s)	70.1(21.4)	68.4(18.6)	0.1	-20.9 – 13.8	4	6
Ankle						
Dorsiflexion at F_{PeakZ} (°)	4.3 (8.7)	2.7 (6.4)	0.2	12.7 – 23.9*	7	7
T_{dors} (% MT)	28.8 (22.5)	35.9 (24.5)	0.3	-5.87 – 9.27	2	1
Inversion at F_{PeakZ} (°)	4.5 (8.5)	7.5 (10.0)	0.3	1.05 – 5.99*	6	1
$M_{Peak\ plantar\ flexion}$ (Nm/kg)	1.4 (0.5)	1.4 (0.5)	0.0	-0.18 – 0.12	0	0
Peak power (W/kg)	28.4 (7.1)	30.4 (6.9)	0.3	-4.59 – 1.74	0	3
Knee						
Flexion at F_{PeakZ} (°)	41.7 (8.0)	43.1 (5.9)	0.2	-1.25 – 8.59	2	2
T_{flex} (% MT)	15.0 (7.6)	19.4 (9.0)	0.5	-0.06 – 8.33	3	1
Adduction at F_{PeakZ} (°)	2.7 (4.9)	1.4 (5.7)	0.2	-4.15 – 1.65	20	20
M_{ext} (Nm/kg)	2.4 (0.6)	2.4 (0.5)	0.0	-0.18 – 0.12	4	3
Peak power (W/kg)	33.1 (9.1)	32.1 (8.6)	0.1	-4.89 – 4.09	6	5

Notes: F_{PeakZ}, peak vertical ground reaction force; BW, bodyweight; BW/s, bodyweights per second; Nm/kg, Newton-metre per kilogram; W/kg, watts per kilogram; %MT, percentage of movement time; SA, symmetry angle; WAG, the women's style of landing; MAG, men's style of landing; M_{ext}, extensor moment,; T_{flex}, relative time of peak flexion, T_{add} relative time of peak adduction; T_{dors}, relative time of peak dorsiflexion; M_{Peak}, peak moment, *; denotes significance between groups ($\alpha < 0.05$).

DISCUSSION: The aim of the study was to quantify the mechanical differences of the lower extremity of female artistic gymnasts when performing a WAG or MAG style landing. Discrepancies between male and female landing criteria, stipulated by the international gymnastics governing body (FIG), may cause differences in the task demand to achieve the same goal of landing successfully. These differences are compounded by other national governing bodies providing their own rules (USA Gymnastics, NCAA), regarding landing stance width and an extra step following touchdown.

The combination of larger ground reaction forces and differences in joint kinematics and kinetics provided insight into the potential injury risk. Similar to previous research (Slater *et al.,* 2015), the habitual WAG style of landing exhibited reduced knee flexion with greater F_{PeakZ} and loading rates compared with the MAG technique. Additionally the time to reach F_{PeakZ} was significantly longer (+15%) when utilising the men's style of landing, suggesting the increased landing time may reduce F_{PeakZ} and therefore reduce injury risk (Slater *et al.,* 2015).

Although the MAG style of landing presented reduced ground reaction forces and increased knee flexion associated with a reduced injury risk, this strategy did however demonstrate significantly increased ankle inversion (+50%) at F_{PeakZ} and reduced ankle dorsiflexion at $F_{PeakZ.}$ (-46%). The combination of these positions during landing from a vertical drop jump has been suggested as a mechanism contributing to the likelihood of a lateral ankle sprain (Hopper *et al.,* 1999). The reduced ankle inversion could be explained as a result of the WAG landing strategy utilised. When performing the female style of landing (with no leg separation), one leg could effectively act as a brace for the other, supporting the prevention of the ankle inverting. An alternative explanation for these results could be proposed through the gymnasts' lack of familiarity when performing the male style of landing, as this would not be a movement habitually practised by British, female gymnasts.

No significant differences were identified in peak moment or peak ankle and knee powers, suggesting energy dissipation of the contributing muscles not to be affected by either landing strategy (Zhang *et al.,* 2000). Similarly there were little discrepancies regarding inter-limb symmetry (SA < 10%) in either technique, excluding knee adduction at F_{PeakZ} (SA = 20%). The asymmetry of knee adduction at F_{PeakZ} may further increase the risk of injury due to the unbalanced distribution of force absorption during landing (Čuk & Marinšek, 2013). Not including this result, the other measures displayed reduced inter-limb asymmetry. This would be in accordance with the expectation of symmetrical movement patterns described in the code of points (FIG., 2016a; 2016b). The results ascertained between techniques perhaps indicates that both strategies present characteristics associated with increased risk of differing injuries. Therefore further research is warranted before an appropriate recommendation regarding the selection of a suitable landing technique to reduce the risk of injury could be made.

CONCLUSION: The need to have parity between codes in gymnastics is twofold. First, the codes underwent a dramatic change after the 2004 Olympic Games, artistic gymnastics has attempted to become more transparent when assessing performers. This study has identified potential discrepancies between sexes which may be exposing either to increased injury risks. A closer examination of the landing strategy performed by male gymnasts and an increase in task complexity would provide further evidence of the impact of landing techniques.

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