DO GYMNASTS EXPERIENCE SYMMETRICAL LIMB LOADING WHEN PERFORMING FOUNDATION GYMNASTICS SKILLS?

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Uneven asymmetrical landings in artistic gymnastics is considered a risk factor for injury. The aim of this research was to investigate if gymnasts experience asymmetrical upper and lower limb loading when performing foundation gymnastics skills on floor. Sixteen competitive level gymnasts (male= 8, female= 8) performed seven different gymnastics skills while wearing four inertial measurement units located bilaterally on the distal forearm and tibias. Every gymnastics skill showed significant inter-limb asymmetry (range z= -5.8, -6.0, $p<0.001$) and every gymnast demonstrated intra-limb variability for at least one gymnastics skill. However, the level of asymmetry observed varied between skills and also gymnasts, meaning individual screening is needed to identify gymnasts, limbs and skills that may be at a higher risk for injury.

KEY WORDS: IMU, asymmetry, accelerometer, gymnastics

INTRODUCTION: High rates of injury are being reported across all competitive levels in artistic gymnastics (Campbell, Bradshaw, Ball, Pease, & Spratford, 2019). Injury is therefore a major issue facing competitive artistic gymnasts. It has been hypothesised that high training loads during training and competition contribute to the increased rates of injury observed in gymnastics (Sands, 2000). Uneven landings have also been shown to increase the already high loading occurring during landing, with previous research reporting that gymnasts experience up to 14.4 BW when performing tumbling skills on floor (Panzer, Wood, Bates, & Mason, 1987), however this can increase up to 18.0 BW through one leg if the landing is uneven (Panzer, Wood, Bates, & Mason, 1988). Gymnastics training is also highly repetitive in nature, with gymnasts training up to 36 hours/week and performing countless repetitions of skills (Caine and Harringe, 2013; Sands, 2000). While a certain level of musculoskeletal loading is required to develop positive training adaptations, the repetitive nature and the high magnitude of loading, in combination with uneven or asymmetrical landings, could substantially increase injury risk for overloaded limbs (Moresi, Bradshaw, Thomas, Greene, & Braybon, 2013).

Asymmetry is described as the difference between kinematic and kinetic variables of the left and right limbs during jumping and/or landing tasks (Zifchock, Davis, & Hamill, 2006). Gymnasts with limb asymmetries of >10% are thought to be at a higher risk of injury (Lilley, Bradshaw, & Rice, 2007; Moresi, Bradshaw, et al., 2013). Few studies however have investigated limb asymmetry during landings tasks in gymnasts. Lilley, et al. (2007) reported that 87% of junior national level competitive gymnasts demonstrated asymmetry between lower limbs when performing drop landing and rebound tasks from three different heights (on average the 'high' leg experienced 3.5 ± 0.7 BW greater load than the 'low' leg). While performing similar tasks, Moresi, Bradshaw, et al. (2013) also reported that 40-45% of pre-junior international level competitive gymnasts displayed lower limb asymmetry. Further

supporting evidence is provided from Pajek, Hedbávný, Kalichová, & Čuk (2016) who reported that while many skills in gymnastics either take-off or land on a single leg, there is evidence to suggest that functional asymmetry exists even when gymnasts are performing skills that involve bilateral landings. Only one paper has examined limb asymmetry when performing gymnastics skills. Exell, Robinson, & Irwin (2016) reported all gymnasts experienced upper limb asymmetries when performing a front handspring (a foundation floor tumbling skill) which appeared to be related to the lead leg. Considering limb asymmetry increases loading through limbs, and the association between high loading and injury, more research should focus on assessing the limb asymmetries present when performing gymnastics skills in both the upper and lower limbs. This could assist in early identification and intervention, potentially reducing injury risk in young gymnasts (Lilley, et al., 2007).
The aim of this study was (1) to use inertial measurement units (IMUs) to investigate if gymnasts experience asymmetrical upper and lower limb loading when performing foundation gymnastics skills on the floor apparatus, (2) whether there is a relationship between the gymnasts lead limb and the limb that experiences the highest load, and (3) to determine if gymnasts experience intra-limb loading variability.

METHODS: Participants: Sixteen healthy competitive level gymnasts (male, n= 8; female, n= 8) from local gymnastics clubs agreed to participate in this study (age= 14.1 ± 3.6 years, height= 154.1 ± 12.8 cm, body mass= 46.0 ± 13.4 kg, training age= 9.8 ± 4.7 years, current gymnastics level= National Level 5 - Senior International). Participants were excluded if they were injured or did not provide informed consent. For participants under the age of 18 years, consent was obtained from their parent or guardian, and assent from the participant. Ethics approval was obtained from the University of Canberra and the Australian Institute of Sport Human Research Ethics Committees.

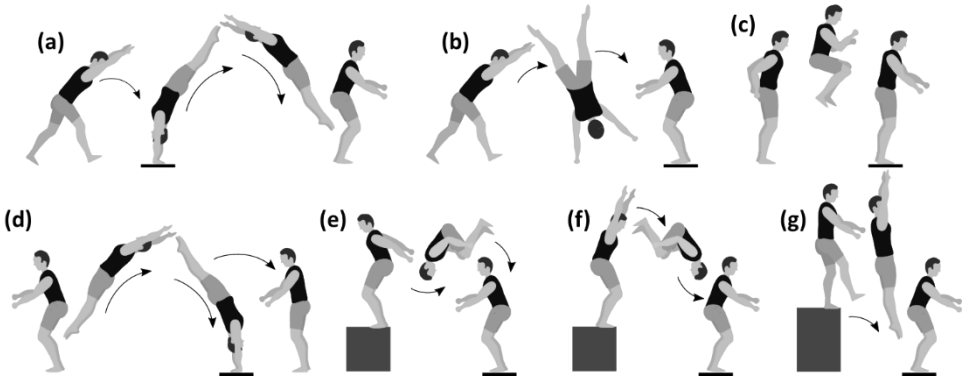

Figure 1: Foundation gymnastics skills tested; (a) front handspring, (b) round-off, (c) tuck jump, (d) back handspring, (e) back salto from a box (90 cm), (f) front salto from a box (90 cm), and (g) drop landing from box (125 cm). For the front handspring and the back handspring, the hand contacts were of interest, whereas for all the other skills, the foot contact was analysed. The ground contact that was analysed for each skill is underlined.

Procedure: Data collection took place at the Australian Institute of Sport in the Biomechanics Indoor Testing Laboratory. Participants completed a self-selected warm-up prior to performing seven foundation floor gymnastics skills that are regularly performed in training, as illustrated in Figure 1. Participants wore four IMUs (3-axis, 500Hz; IMeasureU, Auckland, New Zealand) in the following anatomical locations; bilaterally on the distal tibia (intersection of the middle and distal thirds of the antero-medial aspect of the tibia; Moresi, O'Meara, & Graham, 2013; Sheerin, Besier, Reid, & Hume, 2016) and bilaterally on the distal forearm (intersection of the third and last distal quarters of the dorsal aspect of the forearm). For the front handspring and back handspring skills, the hand contact was analysed (Figure 1), whereas for the rest of the skills the foot contacts were analysed. The IMUs were secured in position using a combination of double-sided toupee tape (Creative hair products, Melbourne, Australia) and Fixomull (BSN Medical, Hamburg, Germany). VICON Nexus software (version 2.7.0; VICON, Oxford, UK) was used to collect synchronised IMU acceleration data.

All skills were performed barefoot and each participant performed three successful (gymnast performs skill without falling) trials of each skill. Rest between each block of skills was guided by the participant. The gymnastics skills were performed in a blocked order which was randomised between participants. The lead limb for each trial was noted during data collection. For safety reasons and to increase task representation and ecological validity, the testing area was covered by matting regularly used in gymnastics training centres (10 cm depth; Acromat, Adelaide, Australia).

Data analysis and statistical analysis: Peak resultant acceleration (PRA) for both limbs during contact was exported from VICON Nexus software using a custom Python script. The highest load limb was then identified for each trial. For each skill this measure was then averaged across the three trials and identified as either all right (across all trials the right limb experienced the highest load), all left (for all trials the left limb experienced the highest load), mainly right (2 out of 3 trials where the right limb experienced the highest loading), or mainly left limb (2 out of 3 trials the left limb experienced the highest loading). The PRA data for every trial was then sorted into highest and lowest values (regardless of which limb this occurred in) to remove negative values and provide a clearer indication of any asymmetries present between limbs. The symmetry index (SI) was then calculated to assess each gymnast's functional symmetry using the following equation adapted from Zifchock, et al. (2006); $SI=(PRA_R – PRA_L)/(0.5 \times (PRA_R + PRA_L)*100)$, where PRA_R refers to the right limb and PRA_L the left limb. A coefficient of variation (CV) was then also calculated for each gymnasts SI.

SPSS software (v19, IBM Statistics, Chicago, USA) was used for all statistical analyses with statistical significance set at an alpha level of 0.05. Data was tested for normality using plots (e.g. histogram plots, Q-Q plots etc.), tests for skewness and kurtosis, and the Shapiro-Wilk test (Peat and Barton, 2005). The data was not normally distributed, therefore Wilcoxon Signed Rank tests were performed between the highest and lowest limb PRA for all gymnastics skills (Aim 1). A Spearman rank correlation test was used to determine if there was a relationship between the gymnasts lead limb and the highest load limb for gymnastics skills where gymnasts take-off on one limb (e.g. front handspring, drop landing and round-off; Aim 2). Descriptive statistics were calculated including mean ± standard deviations (SD), median and inter-quartile ranges (IQR) for PRA of the high and low loading limbs for each skill, as well as percentages provided for intra-limb variability for all gymnastics skills (Aim 3).

RESULTS AND DISCUSSION: The peak loads (PRA) and symmetry observed during the seven foundation skills on floor apparatus are summarised in Table 1. For all gymnastics skills, one limb experienced significantly higher load than the other, indicating that asymmetrical inter-limb loading exists for all of the gymnastics skills tested. However, only the back handspring, front handspring and tuck jump had a SI>10%, indicating that gymnasts performing these skills may be at a higher risk for injury because of the highly asymmetrical nature of the landings that occur when performing these skills.

Table 1: High loading limb and low loading limb

	Load (Mean ± SD; g)		Load (Median [IQR]; g)		z-score	SI (Mean; %)	CV (Mean; %)
	High Limb	Low Limb	High Limb	Low Limb			
Back Handspring	16.3 ± 2.7	13.8 ± 2.9	16.3 [2.5]	13.6 [4.7]	-6.03*	17.4	67.9
Back Salto	24.9 ± 1.3	23.7 ± 1.2	24.8 [2.2]	23.3 [1.2]	-5.84*	5.0	59.5
Drop Landing	24.3 ± 1.3	23.1 ± 1.1	23.6 [1.6]	22.9 [0.8]	-6.03*	5.0	61.9
Front Handspring	11.2 ± 2.2	8.9 ± 1.8	11.4 [3.0]	8.8 [2.3]	-6.03*	22.3	45.6
Front Salto	23.7 ± 3.9	22.1 ± 3.6	24.3 [2.5]	23.0 [2.0]	-6.03*	7.0	51.1
Round Off	22.9 ± 2.0	21.2 ± 1.9	22.9 [1.0]	21.5 [2.4]	-6.03*	7.7	45.0
Tuck Jump	16.2 ± 4.4	13.5 ± 4.0	17.2 [6.1]	13.5 [5.9]	-6.03*	18.8	43.5

* $p<0.001$

For the skills that begin with a one-leg take-off (front handspring, drop landing and round-off), the association between the high load limb and the leading limb was assessed. No association between the high load limb and the leading limb was identified for any of the skills; front

handspring (r_s= 0.08, p= 0.61), drop landing (r_s= 0.02, p=0.87), or round-off (r_s= 0.15, p= 0.31). These results differ from previous research, where it has been reported that the upper limb asymmetries experienced during a front handspring were related to the lead limb (Exell, et al., 2016).

Table 2 presents the high limb loading patterns present when performing all gymnastics skills. These results show that there was variability within and between gymnasts, with only a small percentage of gymnasts consistently landing with a similar pattern (either all right or all left). This indicates that variable intra-limb loads during landings in gymnastics are present, however it is highly individualised for each skill and gymnast. Individualised screening may need to take place to identify gymnasts who may be at a higher risk of injury due to continuous asymmetrical landings, where one limb continually sustains the higher load.

Table 2: Percentage of gymnasts who displayed consistent limb (all right or all left) or inconsistent (mainly right or mainly left) high limb loading patterns.

	Back Handspring (%)	Back Salto (%)	Drop Landing (%)	Front Handspring (%)	Front Salto (%)	Round Off (%)	Tuck Jump (%)
All Right	25.0	6.7	6.3	12.5	18.8	31.3	12.5
All Left	37.5	33.3	62.5	37.5	18.8	12.5	6.3
Mainly Right	12.5	26.7	18.8	18.8	37.5	37.5	50.0
Mainly Left	25.0	33.3	12.5	31.3	25.0	18.8	31.3

CONCLUSION: Competitive artistic gymnast's experience significant limb loading asymmetries when performing foundation floor skills. This is important knowledge for coaches and sports practitioners, considering the potential association between uneven/asymmetrical loading and injury. It also emphasises that gymnasts have individualised responses, indicating that screening at the individual level is needed to accurately identify gymnasts and limbs that are at a higher risk for injury.

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Acknowledgements

The research team would like to thank the coaches and gymnasts for their support of this project.