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INTRA-LIMB VARIABILITY AND INTER-LIMB ASYMMETRY IN GYMNASTICS JUMP TESTS

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The inter-limb symmetry of loading patterns during drop landings and the first contact of rebound jumps was examined in young, talent-selected female gymnasts. Each gymnast performed three trials of each task from two box heights (72 and 107 cm) onto two Kistler force platforms. A symmetry index and coefficient of variation was calculated from the peak ground reaction forces. The loading patterns for each gymnast was categorised as either symmetrical, significant asymmetry or inconclusive asymmetry. Landing forces increased with age for the 107cm landing task. Approximately 40-45% of gymnasts displayed inter-limb asymmetry across both tasks and heights. Low incidences (12-17%) of inconclusive asymmetry were observed, where the asymmetry observed was less than the intra-limb loading variability.

KEY WORDS: force, jump, landing, symmetry index, gymnastics.

INTRODUCTION: Many gymnastics skills are characterised by closed kinetic-chain movements and fast muscle actions that often involve either a stretch-shortening (Impellizzeri, Rampinini, Maffiuletti & Marcora, 2007) or a tension-shortening action (Krug, Minow & Jassman, 2001). For this reason, physiological and biomechanical testing of gymnasts often includes functional tests such as sprinting, hopping, and jumping in order to assess their overall physical abilities and fitness levels (e.g. Sleeper, Kenyon & Casey, 2012). One purpose of these tests is to monitor individual gymnasts to identify strengths and weaknesses related to performance, as well as potential injury risk.

Uneven lower limb loading patterns during jumping and landing skills have been previously speculated to be a mechanism of injury (e.g. Ford, Myer, Smith & Hewett, 2003), and therefore an injury risk factor. A clinical and objective definition of what constitutes a significant asymmetry and therefore functional imbalance has not been well established in the literature. Most estimate higher risk limbs as those with an asymmetry of more than 10 to 20%. Due to the repetitive nature and high forces related to gymnastics loading patterns, limb asymmetry has been defined as more than a 10% difference (Lilley, Bradshaw & Rice, 2007). Based on that definition, they reported that at the non-elite competitive level of gymnastics, less than 15% of the gymnasts tested had functionally symmetrical landings. More recent data from Bradshaw (2010) that used the same criteria revealed a slightly more favourable result with 44% of elite Australian gymnasts displaying functionally symmetrical drop landings and much lower overall levels of asymmetry. However neither study accounted for the variability of the intra-limb loading patterns. An alternative asymmetry definition is when the inter-limb difference is greater than the intra-limb variability (Giakis & Baltzopoulos, 1997). The purpose of the current study was to examine the intra- and inter-limb loading patterns of talent-selected gymnasts during drop landing and rebound jumping tasks.

METHODS: Forty-two gymnasts aged 10-13 years (Height = 140.9 ± 5.8 cm; Mass = 34.0 ± 4.4 kg) who were injury free at the time of testing, participated in the study. All of the gymnasts were selected to participate in a sub-junior national development camp and compete at the international development levels 5 to 10. Each gymnasts height, body mass, limb lengths (foot, humerus, radius, femur, tibia, tibia to floor), and segment widths (shoulder, hip) were

measured. The gymnasts executed three trials of drop landings and rebound jump tasks from a box height of 72 and 107 cm. The gymnasts were asked to step off the box and land onto the ground with both feet simultaneously, controlling their landing as they would in competition. For the rebound jump they were asked to contact the ground with both feet simultaneously and jump vertically as high as possible. The lead foot for both tasks was visually observed and recorded. Both tasks were completed barefoot onto two triaxial force platforms (Kistler, Switzerland, 9286A, 1000 Hz) covered with 6 cm thick carpeted gymnastics foam mats (Acromat, Mile End South, South Australia). The force/time curves for each leg were analysed using Bioware software (Kistler, Switzerland, version 5.03.0) to identify the peak vertical ground reaction forces during the landings and the first contact phase of the rebound jumps. The symmetry index (SI; Sadeghi, Allard, Prince & Labelle, 2000) was calculated for each trial and task for each gymnast as difference between the left and right peak forces (expressed in units of body weight) divided by the average of the left and right peak forces multiplied by 100. A positive SI indicated increased loading on the right leg, and a negative SI indicated increased loading on the left leg. A coefficient of variation for each limb was calculated for the peak vertical ground reaction force across the three trials to examine the intra-limb loading variability. Each gymnasts loading pattern results were categorised as either significant asymmetry, inconclusive asymmetry, or symmetrical. Symmetrical loading was defined as when the SI was 10% or less. Significant asymmetry was defined as a SI greater than 10% and the observed intra-limb variability. Inconclusive asymmetry was defined as a SI greater than 10% but less than the observed intra-limb variability.
All data was collated and analysed statistically using SPSS for Windows software (SPSS Inc., Illinois, version 20.0). An alpha level of 0.05 was set for all analyses. A one-way analysis of variance (ANOVA) was used to assess the effect of age on the dependent measures, and a frequency analysis was used to assess the limb favoured during the loading tasks, and the categorisation of the ground contacts (e.g. symmetrical).

RESULTS: Combined force measures showed gymnasts experienced ground reaction forces of approximately 8.5 BW and 11.0 BW for the 72cm and 107cm drop landings respectively (Table 1). Absolute symmetry indexes indicated similar results across both jump heights with an average SI of 14-15%. Intra-limb variability results indicated an average CV% of 10.2-13.8% (Table 1). One-way ANOVA analysis indicated a significant difference in combined force measures between age groups ($F_{3,38}$ = 4.16, p<0.05) during the 107 cm landing task. No other age differences were found although the combined force during the 72cm landing task approached significance ($F_{3,38}$ = 2.29, p=0.09).

Table 1: Loading patterns during drop landings from a box height of 72 and 107 cm. Significant age effects identified as *p<0.05.

		Land 72 cm									Land 107 cm								
Age (yrs)	N	Combined Force (BW)		Absolute Symmetry Index (%)		Right Limb Favour-ed (%)	Left Leg CV (%)		Right Leg CV (%)		Combined Force (BW)*		Absolute Symmetry Index (%)		Right Limb Favoured (%)	Left Leg CV (%)		Right Leg CV (%)	
		M	SD	M	SD		M	SD	M	SD	M	SD	M	SD		M	SD	M	SD
10	5	7.69	1.21	8.70	11.72	60.00	16.02	3.73	12.18	5.95	9.88	1.57	8.50	9.48	40.00	8.49	5.52	12.69	4.57
11	12	8.12	1.32	19.39	12.56	33.33	14.05	11.89	13.18	11.73	10.39	1.20	17.82	13.43	50.00	12.66	6.87	11.44	8.70
12	19	8.83	1.51	14.35	8.80	78.95	13.26	10.24	14.10	8.81	11.32	1.46	14.90	6.67	78.95	10.48	4.67	9.76	7.03
13	6	9.56	1.31	16.55	14.69	50.00	11.66	8.87	10.77	3.17	12.37	1.28	15.01	16.16	50.00	9.30	2.62	6.92	5.57
Group	42	8.55	1.34	14.75	11.94	55.57	13.75	8.68	12.56	7.42	10.99	1.38	14.06	11.44	54.74	10.23	4.92	10.20	6.47

Combined force measures during the rebound jumps indicated similar results to the drop landings (Table 2). Results indicated absolute symmetry indices of 11.8% and 14.8% for the 72 cm and 107 cm rebound tasks respectively. Average intra-limb CV% results ranged from 9.8-12.1% (Table 2). One-way ANOVA results indicated no statistically significant differences

between variables with age. Combined force during the 107cm rebound jump task approached but did not reach statistical significance ($F_{3,38}$ = 2.22, p=0.10).
Symmetry index percentages during both landing tasks showed 42.9% and 45.2% of athletes with a SI greater than the intra-limb CV% and 10% for the 72cm and 107cm landing heights respectively (Figure 1).

Table 2: Loading patterns during during the first contact phase of rebound jumps from a box height of 72 and 107 cm. Significant age effects identified as *p<0.05.

		Rebound 72 cm									Rebound 107 cm								
Age (yrs)	N	Combined Force (BW)		Absolute Symmetry Index (%)		Right Limb Favour-ed (%)	Left Leg CV (%)		Right Leg CV (%)		Combined Force (BW)		Absolute Symmetry Index (%)		Right Limb Favour-ed (%)	Left Leg CV (%)		Right Leg CV (%)	
		M	SD	M	SD		M	SD	M	SD	M	SD	M	SD		M	SD	M	SD
10	5	7.68	1.39	11.89	15.38	27.27	8.85	5.93	11.35	8.70	9.65	2.12	14.08	12.16	27.27	10.10	4.73	7.94	3.47
11	12	8.29	1.45	11.31	8.25	28.00	13.07	6.10	8.98	5.34	10.50	1.27	15.79	12.69	12.00	12.68	8.10	14.27	6.89
12	19	8.43	1.44	11.17	9.88	73.91	12.92	6.80	11.58	7.01	10.84	1.41	14.08	17.31	56.52	9.08	7.13	9.65	7.77
13	6	9.28	1.10	14.21	11.14	71.43	10.44	5.61	11.73	5.46	11.80	1.04	16.16	17.58	42.86	7.07	6.94	9.91	4.07
Group	42	8.44	1.41	11.75	10.05	48.48	12.10	6.31	10.87	6.45	10.74	1.49	14.84	15.31	33.33	9.82	7.20	10.80	6.90

Rebound jump tasks displayed lower percentages of asymmetry with 38.1% and 40.5% classified with lower-limb asymmetry in the 72 cm and 107 cm rebound jumps respectively. Gymnasts classified as having inconclusive asymmetry ranged from 11.9-16.7% across the jump tasks.

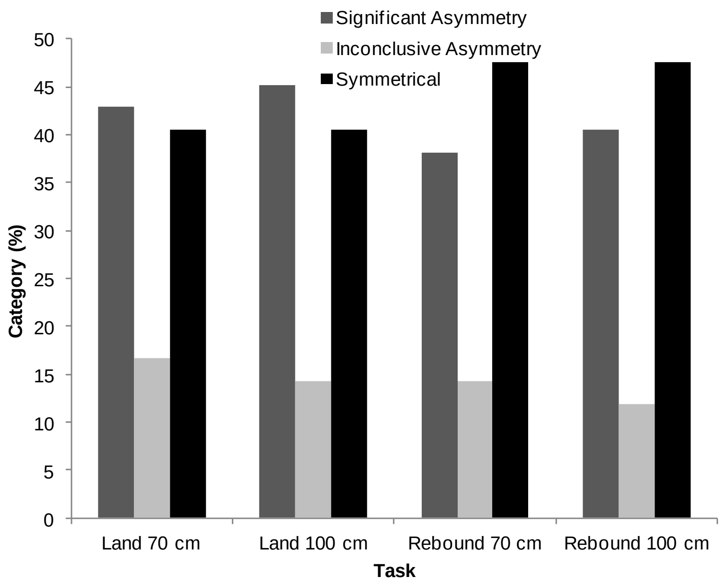

Figure 1: The frequency of symmetrical loading patterns during landings and rebound jumps.

DISCUSSION: The present study identified similar athlete asymmetry percentages (40-45%) among young talented-identified gymnasts as has been previously shown in elite gymnasts (Bradshaw, 2010). A smaller percentage of gymnasts in this cohort displayed asymmetry than has been previously reported in non-elite competitive gymnasts (Lilley et al., 2007). Of note, the present study identified an additional group of gymnasts (12-17%) with inconclusive asymmetry across the different jump tasks. In these gymnasts, although inter-limb asymmetry was identified, the SI index did not exceed the between trial intra-limb variation.
Average SI appeared to be stable across all age groups and jump types at approximately 14-15%, with the exception of the 72cm landing task (12%). The results of the present study also indicated a significant increase in combined ground reaction forces with increased age. The combination of these two factors suggest that older talent-identified athletes may become

increasingly at risk of injury due to inter-limb asymmetry; not as a result of inter-limb symmetry changes but with increased ground reaction force magnitudes where this level of asymmetry may potentially place the athlete at increased risk. A certain level of stress and strain on the musculoskeletal system is essential in adaptation to training and for positive enhancements to performance. However an overload to the musculoskeletal system can lead to negative tissue damage (Bruggemann, 2010). With increased relative limb loading due to inter-limb asymmetry, under increased force demands, subsequent acute or chronic musculoskeletal injury may occur. Early screening, identification and intervention may be beneficial in reducing potential inter-limb asymmetry - injury risk links in young gymnasts.

Although inter-limb asymmetry was identified in young, talent-selected gymnasts the underlying mechanisms remain unclear. The wider literature suggests that limb force asymmetry may be related to neural factors (sensory information) rather than differences in mechanical abilities between limbs (Simon & Ferris, 2008). Findings from the present study identified a similar absolute magnitude of asymmetry across all tasks. However, the rebound jump tasks showed a percentage increase in symmetrical gymnasts when compared with less demanding landing tasks. Increased symmetry with increased task demands appears contrary to previous findings among non-elite gymnasts which indicate a reduction in asymmetry with lower drop heights (Lilley et al., 2007). The results of the present study suggest inter-limb symmetry in this cohort of gymnasts may be more related to neural factors than strength deficits. Further research identifying absolute limb strength and SI with differing task demands in talent-identified gymnasts may provide further insight into potential inter-limb SI mechanisms.

CONCLUSION: The incidence of acute and chronic injuries is a serious problem in competitive gymnastics. Success in the sport of gymnastics requires gymnasts to experience high levels of mechanical energy and loading. Young, talent-selected gymnasts appear to show similar rates of asymmetry to elite gymnasts. Symmetry index magnitude appears stable with age. However, increasing ground reaction forces in 'older' gymnasts combined with pre-existing asymmetry may increase potential injury risk in older athletes. Early screening, asymmetry detection and intervention may assist in reducing potential injury risk as a result of inter-limb differences.

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