HOW SAFE ARE THE CODE OF POINTS LANDING TECHNICAL REQUIREMENTS IN ARTISTIC GYMNASTICS? PRELIMINARY RESULTS

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To examine the effect of the code of points landing technical requirements in artistic gymnastics, eight female artistic gymnasts performed backward somersault dismounts off a 90 cm vaulting box. Three dimensional motion as well as upper back accelerations were measured for three landing techniques: current competition landing with feet together (FT); competition landing with a step back (SB); landing with feet shoulder width apart (FA). Group average impact forces were lowest for the FA technique; individual analyses showed SB or FA techniques were safer for 75% of gymnasts. Upper back accelerations indicating how well they could control the impact shock did not differ between the three landing techniques. The landing rule in gymnastics does have an effect on the initial and overall impact loads for backward somersault dismounts.

KEY WORDS: force, acceleration, somersault, rules.

INTRODUCTION:

The ideal performance of two-foot (toe-heel) landings from high airborne skills in sports such as basketball and volleyball has been reported to include both feet roughly spaced shoulder-width apart with an even distribution of forces between them, and actively controlled hip, knee and ankle (plantar-) flexion with the knees aligned over the toes (Tillman et al., 2004). In artistic gymnastics however the rules of the sport restrict the athlete to landing with both feet together and penalises the gymnast for deep hip and knee flexion (Fédération Internationale De Gymnastique Women's Technical Committee, 2009). Landing with two feet together after high airborne skills in artistic gymnastics requires great stabilisation and eccentric strength to prevent the knee joints from collapsing due to the high external knee joint loads. The ground reaction forces of gymnastics landings are significant during both training (~5 Body Weights [BW]) and competition (~11 BW) especially if the landing is uneven (~18 BW) or if there is unusual foot placement (Panzer, et al., 1988). Coaches have anecdotally suggested that an additional step after a two foot landing on floor produces lower loads on the female gymnasts body (Black, 2009). Biomechanical exploration is required to ascertain the validity of these claims in order to guide potential changes to the rules to ultimately reduce the risk of injury to gymnasts.

The purpose of this study was to determine the effect of sport rules on the biomechanics of landings sustained after performing backward somersault dismounts in artistic gymnastics. This preliminary paper reports the ground reaction forces and upper back acceleration results from a wider study that also included kinematic and joint moment measures from three-dimensional motion analysis. It was hypothesised that the ground reaction forces and upper back accelerations would be highest to lowest when performing a two foot landing backward somersault with the feet together (current competition landing technique), landing with the feet shoulder width apart, then landing with two feet together followed by a step backwards.

METHODS: ***Participants*** Eight female artistic gymnasts aged 10-15 years (Height = 145.3 ±11.6 cm; Mass = 37.5 ±8.9 kg; Competition Level = 7 ±2) were recruited for this study from a regional gymnastic club in Melbourne, Australia. Participants were excluded if they had musculoskeletal injuries that had resulted in modified training during the six weeks prior to testing, were declared unfit by their coach or parent/guardian, or were unable to perform a backward somersault with the landing postures required (Slater et al., 2015). Approval for this study was obtained from the Australian Catholic University ethics committee. Participant and parent written informed assent/consent was obtained prior to participating in this study.

Procedure During the week prior to data collection, the gymnasts were asked to practice the three landing techniques during their daily training schedule under the supervision of their coach. The landing techniques included landing with the feet together (current competition landing technique) (FT), landing with the feet shoulder width apart (FA), and landing with two feet together followed by a step backwards (SB) with one foot only. The gymnasts were asked to complete one session of data collection of approximately 45 minutes in duration in the School of Exercise Science Motion Analysis laboratory. The gymnast's height and body mass was measured using a stadiometer (Stadi-O-Meter, Novel Products Inc, Rockton, Illinois, USA) and scales (HW-PW200, A&D Company Ltd, Japan). The gymnast was then asked to warm-up for five minutes on a cycle ergometer (828E Ergomedic bike, Monark, Vansbro, Sweden) followed by gymnastics specific static and dynamic stretching. An isoinertial measurement unit (IMU; 40 x 28 x 15 mm, 12 g, iMeasureU, Auckland, N.Z.) was then placed on the upper back over the second thoracic vertebra (T2). This accelerometer was fixed to the skin using double sided tape and Fixomull® stretch tape (Jiaxing How Sport Medical Instrument, Jiaxing, Zhejiang, China). The gymnast's bony landmarks on their trunk, legs and feet were then identified and marked using 18 small retroflective ball markers (12.7 mm diameter, Innovision Systems, Columbiaville, MI, USA). The landing techniques were executed from a backward somersault off a 90 cm high foam vaulting box (A13-129, Acromat, Australia) to replicate the velocity conditions of apparatus dismounts. The gymnasts landed onto two 3 cm carpeted landing mats (Total Depth = 6.4 cm, AB-100, Acromat, Australia). The gymnasts completed a second, shorter warm-up to familiarise themselves with the somersault while wearing the ball markers and IMU, and then completed three trials of each landing technique with one minute rest between each trial. The order of the techniques was randomised between the gymnasts.

Data Collection A nine-camera three-dimensional motion capture system (Vicon, Oxford, United Kingdom, 250 Hz) and two portable, multicomponent force platforms (OR6-6-2000, AMTI, Watertown, MA, U.S.A., 1000 Hz) embedded in the landing surface captured the gymnasts landing movement. The IMU data were captured separately using an iPad (iPad Air 2 WiFi 128 GB, Apple Inc., Cupertino, California, U.S.A.) via a Bluetooth connection and the manufacturer's application (app) software (Sensor Demo mode, IMU Suite, version 1.9).

Data Analyses The Vicon dynamic full body plug-in-gait model was used to calculate kinematic and kinetic data. All Vicon data was smoothed using a Woltring filter with a mean square error of 20. The peak resultant ground reaction force and impulse were identified and normalised with reference to the gymnast's body weight for each landing technique. The acceleration data were downloaded from the iPad onto a personal computer using Lightening software (iMeasureU, Auckland, N.Z.). The raw accelerations in the x, y and z directions were then combined into a resultant acceleration using the following equation: $a_r = \sqrt{a_x^2 + a_y^2 + a_z^2}$ where a_r is the resultant acceleration, a_x is the acceleration in the x-direction, a_y is the acceleration in the y-direction, and a_z is the acceleration in the z-direction. All accelerations were expressed in gravitational units (g) (one gravitational unit is equal to the gravitational acceleration of -9.81 m/s^2). The peak resultant acceleration (PRA) were then identified for each trial.

Normality of the data set was determined using a Shapiro-Wilk test in SPSS Statistics software (version 22, IBM, Armonk, NY, U.S.A.). The data was not normally distributed and therefore the data was log transformed. Cohen's effect size (ES) statistics were used to determine if there was a clinical difference between the landing techniques. Effect sizes above 0.19 were considered as showing a difference worthy of consideration (small = 0.2 to 0.59, moderate 0.6 to 1.19 and large $\geq$1.2; Hopkins, 2002).

RESULTS: Tables 1 and 2 provide the peak resultant ground reaction forces, the landing impulses, and peak resultant accelerations for each landing technique. Peak ground reaction force for landings from a backward somersault is a measure of the initial landing load. Peak ground impact forces of 6 to 18 BW were observed for the gymnasts' landings. On average the peak ground impact forces were lowest for the feet apart (FA) technique, followed by the feet together (FT) and step back (SB) techniques, however greater variability (standard deviation [SD]) in the gymnasts landing forces were observed for the non-competition (SB and FA) techniques. Effect size (ES) statistics revealed trivial to small differences between techniques for the impact forces between the FT and SB techniques (ES = 0.18 [Trivial], FT and FA techniques (ES = -0.24 [Small]), and the SB and FA techniques (ES = -0.31 [Small]). The landing impulse is a measure of the total force over time during the landings, and therefore a measure of overall impact load. Greater variation was again observed for the non-competition (SB and FA) techniques. Landing impulses ranged from 0.4 to 1.1 BW.s. On average the landing impulses were lowest for the feet apart (FA) technique, followed by the step back (SB) and feet together (FT) techniques. Effect size (ES) statistics revealed trivial to small differences between techniques for landing impulse between the FT and SB techniques (ES = 0.15 [Trivial], FT and FA techniques (ES = -0.47 [Small]), and the SB and FA techniques (ES = -0.22 [Small]). The peak upper back acceleration is a measure of how

Table 1: Peak resultant ground reaction force and landing impulse. upper back acceleration for each landing technique. Forces are normalised to body weight (BW) and impulse is normalised to body weights per second (BW.s). Abbreviations: M is the mean result and SD is the standard deviation.

Gymnast	Peak Resultant Force (BW)						Landing Impulse (BW.s)					
	Feet Together		Step Back		Feet Apart		Feet Together		Step Back		Feet Apart	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
A	11.97	3.74	12.19	3.47	14.31	1.31	0.77	0.13	0.95	0.18	0.90	0.04
B	10.04	5.07	6.45	0.73	7.87	0.83	0.69	0.34	0.35	0.10	0.54	0.12
C	14.82		14.50	1.57	6.18	0.38	0.79	0.00	0.82	0.20	0.36	0.06
D	15.24	2.32	16.39	1.67	17.17	2.12	0.83	0.06	0.76	0.09	0.74	0.08
E	14.16	2.09	15.47	1.02	11.81	3.72	1.04	0.10	1.11	0.12	1.04	0.16
F	13.02	3.08	15.38	1.91	14.04	1.86	0.94	0.32	1.15	0.13	1.12	0.25
G	15.92	1.90	17.62	1.22	17.96	0.61	0.98	0.01	0.84	0.44	1.11	0.07
H	11.79	5.90	16.82	3.75	15.55	1.08	0.92	0.24	0.92	0.09	1.02	0.21
M	13.37		14.35		13.11		0.87		0.86		0.85	
SD	2.01		3.60		4.23		0.12		0.25		0.28	

Table 2: Peak upper back acceleration for each landing technique. Accelerations are reported in gravitational (g) units.

Gymnast	Peak Resultant Upper Back Acceleration (g)					
	Feet Together		Step Back		Feet Apart	
	M	SD	M	SD	M	SD
A	12.25	2.77	11.26	3.74	10.63	1.51
B	17.07	2.41	14.69	1.47	17.16	1.92
C	13.72	4.50	16.26	1.61	15.55	1.58
D	14.64	0.29	14.42	1.35	13.81	1.94
E	9.85	1.35	10.77	1.91	9.09	3.18
F	14.94	0.80	12.87	2.19	14.35	0.26
G	13.59	1.05	14.30	0.61	14.92	1.51
H	14.83	1.00	15.13	1.20	15.23	1.77
M	13.86		13.71		13.84	
SD	2.13		1.92		2.68	

Table 3: Individual landing technique recommendations based on peak ground reaction force, landing impulse, and peak upper back acceleration results.

Gymnast	Peak Resultant Force (BW)	Impulse (BW.s)	Peak Upper Back Acceleration (g)	Mean Recomm-endation
A	Feet Together	Feet Together	Feet Apart	Feet Together
B	Step Back	Step Back	Step Back	Step Back
C	Feet Apart	Feet Apart	Feet Together	Feet Apart
D	Feet Together	Feet Apart	Feet Apart	Feet Apart
E	Feet Apart	Feet Apart	Feet Apart	Feet Apart
F	Step Back	Feet Together	Step Back	Step Back
G	Step Back	Step Back	Feet Together	Step Back
H	Feet Together	Feet Together	Feet Together	Feet Together
Feet Together (#)	3	3	3	2
Step Back (#)	3	2	2	3
Feet Apart (#)	2	3	3	3

well the gymnast controls (reduces) the landing loads through their body. The peak accelerations ranged from 9 to 17 g and were lowest for the SB technique, followed by the

FA and FT techniques. Only trivial differences were identified between techniques for the upper back accelerations (FT vs SB: ES = -0.06; FT vs FA; ES = -0.05; SB vs FA; ES < -0.01). In summary, on average the feet apart technique resulted in the lowest initial and overall impact loads. Only trivial differences were identified between the peak upper back accelerations, indicating the gymnast's ability to reduce the transfer of the impact loads through the body was the same, irrespective of the landing technique performed.

Table 3 summarises the individual gymnasts' data in terms of the safest technique, where the safest technique is identified in the order of the lowest (safest) to highest (higher risk) force and acceleration values. It shows that on average, the FT technique was safest for two of the gymnasts, whilst the SB and FA technique was each safest for three of the gymnasts in the group.

DISCUSSION: The landing forces measured in this study (~6-18 BW) were higher than previous observations of training (~5 BW) and competition (~11 BW) (Panzer et al., 1988). Whilst the overall results indicated that the feet apart technique resulted in less initial and overall impact load, this study shows the importance of individual analyses. The individual analysis revealed that the safest technique differed between gymnasts. For 38% of gymnasts the feet apart technique had the lowest impact, and the step back technique was best for a further 38% of gymnasts. Only 25% of gymnasts favoured the current competition landing technique with feet together. However it was revealed during testing that none of the gymnasts completed the preceding familiarisation training. Therefore the results should be treated with caution as the results may have been different had the gymnasts completed the preceding training as requested. Despite the gymnasts possible lack of familiarity with the two requested techniques (noting these landing techniques are often observed in training), these initial results indicate that for 75% of the gymnasts tested, performing a different landing technique to what is prescribed by the sports rules (Code of Points) resulted in a lower impact load.

The force/impulse results indicate the ground impact load and the accelerations indicate how well the gymnast controls the landing by trying to reduce the impact load (shock). The initial results of this study indicated that there was no effect of technique on the impact shock. Further analyses of the data (e.g. joint flexion angles, joint reaction forces) will be completed to determine whether there were any differences in the gymnasts landing technique. The gymnasts were not instructed to change their landing technique in any other way, except for the position and control of their legs/feet. No differences in technique may indicate the potential for further improvements in the landing rules (e.g. allow a deeper squat) that may reduce the impact shock. Further research is warranted on this topic using a greater number of gymnasts, inclusive of forward rotation landings, and familiarisation training that is supervised by the researcher.

CONCLUSION: The landing rule in gymnastics does have an effect on the initial and overall impact loads. On average, this study showed that changing to a feet apart or step back technique could immediately begin to reduce these impact loads in 75% of gymnasts.

REFERENCES:

Black, D. (2009). Judging judges. *International Gymnast USA, December*, 48.

Fédération Internationale De Gymnastique Women's Technical Committee. (2009). *2009 Code of Points — Women's Artistic Gymnastics*. Switzerland: Fédération Internationale De Gymnastique.

Hopkins WG. (2002). A scale of magnitudes for effect statistics. A New View of Statistics. Auckland: Hopkins, W.G.

Panzer, V. P., Wood, G. A., Bates, T. B., & Mason, B. R. (1988). Lower extremity loads in landings of elite gymnasts. In G. De Groot, A. P. Hollander, P. A. Huijing & G. J. Van Ingen

Slater, A., Campbell, A., Smith, A., Straker, L. (2015). Greater lower limb flexion in gymnastic landings is associated with reduced landing force: A repeated measures study. *Sports Biomechanics, 14*, 45-56.

Tillman, M. D., Hass, C. J., Brunt, D., & Bennett, G. R. (2004). Jumping and landing techniques in elite women's volleyball. *Journal of Sports Science and Medicine, 3*, 30-36.