PRODUCTION OF ANGULAR MOMENTUM IN DOUBLE BACKWARD SOMERSAULTS

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INTRODUCTION: Three variations of double backward somersaults are common in gymnastics floor exercise routines; double tucked, double piked and double straight. The momentum required to perform these skills is generated by a gymnast during the approach run, roundoff and flic-flac, and by the actions that the gymnast performs during the takeoff. Small differences in the approach parameters and in the body actions that a gymnast makes will influence the linear and angular momentum and hence govern the height and rotation for a particular double backward somersault. The takeoff action commences when the toes touch the floor at the end of the flic-flac and ends when the toes leave the floor as the gymnast rises into the air to execute the double somersault. During the ground contact phase of the takeoff, changes in a gymnast's body configuration can alter whatever linear and angular momenta have been generated during the approach and pre-flight. Previous studies of gymnastics somersaults have shown that angular momentum decreases during the ground contact phase of takeoff and that the total angular momentum required to complete a double backward somersault depends on the body configuration adopted by the gymnast in flight (Hwang, et al., 1990; Brüggemann, 1994). The purpose of this study was to examine the relationship between the gymnasts' actions and the linear and angular momentum in the takeoffs for double backward somersaults.

METHODS: Twelve female gymnasts, showing varying degrees of body extension in the flight phase of double backward somersaults, were recorded with two video cameras during the floor exercise routines at the Atlanta Olympic Games. The video cameras (Sony DCR-VX1000E and Sony CCD-VX1E) were operated at 50 fields per second with exposure times of 1/300s. The twelve analysed movements were divided into two equal groups of straight (S, layout) and non-straight (N, tucked and piked) somersaults to investigate the relationships between incoming and outgoing momentum values and body configuration changes during takeoff.

All video images were digitised using the Target system (Kerwin, 1995). The Direct Linear Transformation (Abdel-Aziz and Karara, 1971) was used to reconstruct the 3D co-ordinates of the digitised joint centers. Inertia data for each gymnast were derived from mean data sets and were customised to each competitor using estimates of segment lengths from the digitised data. Normalised angular momentum about a transverse axis through the mass center was calculated using the methods of Yeadon (1990). Changes in joint angles and average joint angular velocities at the ankles, knees, hips and shoulders were determined from touchdown to takeoff. Mass center locations in the pre-flight (flic-flac flight phase) were fitted for horizontal motion with a straight line and for vertical motion with a parabola. An interpolating quintic spline (Wood and Jennings, 1979) was fitted through the digitised data points and the touchdown and takeoff times were determined from the vertical displacement of the right toes to the nearest millisecond. The resulting mass center vertical and horizontal velocities at touch down and takeoff could be determined with similar time precision.

RESULTS: RMS differences between the measured locations of the calibration reference points and their predicted location were 0.0073 m horizontally and 0.0026 m vertically.

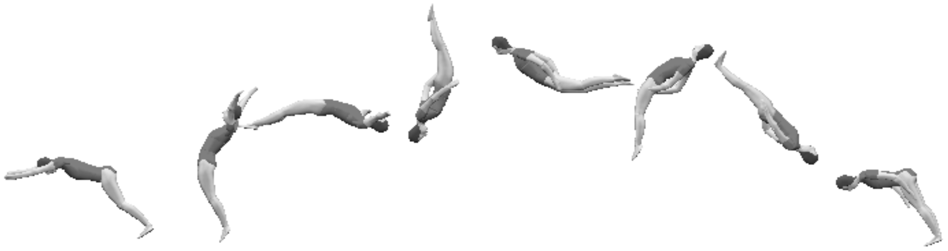
Incoming angular momenta were higher (S = 2.4, N = 2.1, $p<0.05$) and ground contact times were shorter for group S (S = 0.112s, N = 0.125s, $p<0.001$). There were no significant differences between other incoming variables although there was a much smaller range in the gymnasts' mass center horizontal velocities in group S (4.6, ±0.1) than in group N (4.3, ±0.6). Full details are provided in Table 1. Vertical mass center velocity at touch down, (S = -1.3, ±0.2; N = -1.5, ±0.1) although not significantly different between the two groups, were markedly lower than the value of +0.3 $m.s^{-1}$ previously reported by Hwang et al., (1990). Mass center horizontal velocity at takeoff was significantly higher for group S than for group N (S = 2.3, ±0.3; N = 1.7, ±0.3).

Table 1. Contact times, touchdown (Td) and takeoff (To) linear velocity and angular momentum (H) values for double backward somersaults in straight (S) and non-straight (N) body positions.

Gymnast #	Contact time (s)	I_Td SS/s	I_To SS/s	I_To SS/flt	Vh_Td m/s	Vh_To m/s	Vv_Td m/s	Vv_To m/s
S228	0.116	2.67	1.85	1.72	4.6	2.0	-1.7	4.2
S252	0.118	2.53	1.90	1.73	4.6	2.4	-1.5	4.0
S287	0.113	2.32	1.78	1.70	4.6	1.7	-1.2	4.5
S290	0.108	2.35	1.86	1.68	4.8	2.4	-1.1	4.1
S299	0.110	2.53	1.84	1.69	4.5	2.6	-1.0	4.2
S309	0.105	2.11	1.81	1.68	4.6	2.4	-1.3	4.1
Mean	**0.112**	**2.42**	**1.84**	**1.70**	**4.6**	**2.3**	**-1.3**	**4.2**
StDev	**0.005**	**0.20**	**0.04**	**0.02**	**0.1**	**0.3**	**0.2**	**0.2**
N269	0.125	2.24	1.25	1.15	4.4	2.2	-1.5	4.1
N267	0.127	2.04	1.27	1.16	4.6	1.5	-1.6	4.2
N284	0.130	2.08	1.14	1.09	3.4	1.9	-1.7	4.4
N319	0.120	1.90	1.03	0.97	4.2	1.7	-1.4	4.2
N333	0.121	2.22	1.19	1.17	3.9	1.4	-1.4	4.6
N336	0.126	1.94	1.00	1.00	5.2	1.6	-1.4	4.8
Mean	**0.125**	**2.07**	**1.15**	**1.09**	**4.3**	**1.7**	**-1.5**	**4.4**
StDev	**0.004**	**0.14**	**0.11**	**0.09**	**0.6**	**0.3**	**0.1**	**0.3**

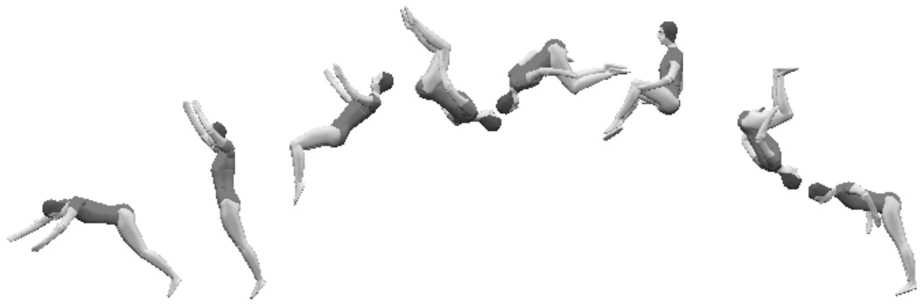
SS/s = Straight somersaults per second, SS/flt = Straight somersaults per flight time, Vh = mass center horizontal velocity, Vv = mass center vertical velocity

For double non-straight somersaults the gymnast changed from a piked to a straight shape throughout takeoff, whilst for the double straight somersaults the shape change was from piked to backward arched as shown in Figure 1.



Layout (S)

Piked (N)



Tucked (N)

Figure 1. Graphic images of layout (S), piked and tucked (N) double backward somersaults expanded horizontally to clarify body configurations during flight. Image 1 in each sequence = touchdown, image 2 = takeoff. Touchdown and takeoff angles were defined relative to the horizontal by a line joining the initial and final foot contact points with the corresponding mass center locations.

The touchdown angle for the straight somersaults were slightly nearer to the vertical than for the non-straight somersaults (S = 56.2, ±2.5°; N = 54.3, ±2.6°) but the difference was not significant. This finding matches the values reported by Hwang et al., (1990) who also found a non significant difference of approximately 3° between the touchdown angles for male gymnasts performing double straight and double tucked backward somersaults. There were no significant differences between the body configuration angles at touchdown and only the hip angles at takeoff were markedly different between the two groups, (touchdown: S = 130.0, ±3.0°; N = 127.2, ±3.1°, Takeoff: S = 221.9, ±5.7°; N = 190.5, ±16.1°). Rapid hip extension during ground contact produced very large changes in the hip angles between touchdown and takeoff with those for the straight somersault group being significantly larger than for the non-straight somersault group, (S = 92° and N = 63°, $P<0.001$).

DISCUSSION: Arriving with higher angular momentum at touchdown and arching during ground contact can be understood as techniques that gymnasts employ to increase ground reaction forces during takeoff. These forces increase angular momentum and add to vertical takeoff velocity.

Gymnasts lose angular momentum during the takeoff for all types of double backward somersaults but the rapid arching which occurs during takeoff for double straight backward somersaults makes a substantial contribution to the angular momentum in flight.

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