ORIGINAL ARTICLE

Body movements on the men's competition mushroom: a three dimensional analysis of circular swings

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Objectives: To develop a method for the three dimensional analysis of body movements and body positions during the performance of circular swings on the competition mushroom, an apparatus used by young gymnasts for pommel horse training.
Methods: Five experienced male gymnasts, all of national level, performed three series of 10 circular swings on the competition mushroom. An optoelectronic instrument was used for the detection of the three dimensional movement of 13 body landmarks. From landmark trajectories, several technical measurements were obtained: diameters of ideal circles of ankles, hips, shoulders; deviation of the ankle diameters from circularity and from the horizontal plane; angle between the shoulder, hip, and ankle. The values were used for a quantitative assessment of performance of the five gymnasts.
Results: During the exercise, each ankle should follow a nearly horizontal circular path (deviation from circularity ranged from 3.6% to 6%, deviation from horizontality was 9.4–19.7%), there should be an angle of about 180° at the hips (actual values 146–153°), and the shoulders should move as little as possible, and only in the lateral plane, without major anteroposterior movements (shoulder movement was 27–31% of ankle movement, hip movement was 16–20%).
Conclusions: The method could help coaches and gymnasts to determine which parts of the body are not repeating a selected movement with sufficient accuracy and to quantify improvements made after a specific training programme.

During the execution of artistic gymnastics exercises the judges must evaluate each performance ''objectively, accurately, consistently, ethically, fairly, and quickly''.[1] To this end, detailed codes of points are prepared by the international federation and constantly reviewed according to the characteristics of an evolving discipline.[2] The primary purpose of each code of points is ''to provide an objective means''[1] of evaluation. In the code, each exercise is given a particular value, mainly depending on its difficulty.

During competitions, the actual execution of a gymnast is evaluated considering the errors related to technique and body position.[1] The different body positions in space, as well as the reciprocal arrangement of the various parts of the body, determine the aesthetic aspects of the exercise. Indeed, all parts of the body must harmonise to allow a successful and appreciated execution.[2–4] The same criteria are obviously used by coaches during daily training.

Current technology allows the three dimensional detection and recording of fast and complex movements and the quantitative analysis of the spatial and temporal patterns of motion of body landmarks.[4–7] In investigations performed on gymnastics, data are mostly used as input values for simulation models.[6 7] These data could also be used to provide measurements similar to those qualitatively assessed by judges and coaches.

The aim of this study was to develop a method for the three dimensional analysis of body movements and body positions during the performance of circular swings on the competition mushroom, an apparatus used by young gymnasts for pommel horse training. Preliminary data on five gymnasts are reported.

METHODS

Participants

Five experienced male gymnasts, all in good health, volunteered for the study (table 1). They were all of national level, and had 7–14 years of specific training in gymnastics. After all the experimental procedures and possible discomforts and risks of the study had been fully described, written consent was obtained from each participant. The protocol used was approved by the local ethics committee.

Body weight was measured to the nearest 0.5 kg on a beam balance scale, and stature was measured to the nearest 1 cm with a stadiometer. Before data collection, body composition was estimated by bioelectric impedance analysis performed with a BIA 101/SC instrument (Akern srl, Firenze, Italy) using the standardised protocol described by the manufacturer. Percentage body fat-free mass estimates were obtained using software provided by the manufacturer.[8]

Movement studied

Spherical retro-reflective markers (diameter 1 cm), corresponding to 13 anatomical landmarks, were positioned on the body of each gymnast (fig 1). In the same session and after a warming up period, each participant performed three series of 10 circular swings on the competition mushroom, with a five minute rest between each series. All the participants were told to perform their best.

During the exercise, each ankle should follow a nearly horizontal circular path, there should be an angle of about 180° at the hips, and the shoulders should move as little as possible, and only in the lateral plane, without major anteroposterior movements.

Film acquisition

An optoelectronic computerised instrument (Elite System, BTS, Milan, Italy) was used for data acquisition. It allowed the automatic analysis of the movement from the three dimensional coordinates of different body landmarks which were detected by eight infrared sensitive, charge coupled device cameras working at 100 Hz.[9 10] The eight cameras were positioned at variable heights from the floor and at various

Table 1 Basic details of the five gymnasts analysed

Gymnast	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	%FFM (%)
M1	21	162	74	28.20	86.5
M2	21	177	63	20.11	81.6
M3	20	160	62	24.22	76.8
M4	18	165	62	22.77	84.0
M5	21	176	75	24.21	88.0
Mean	20.2	168	67.2	23.90	83.4
SD	1.3	8.0	6.7	2.93	4.4

BMI, Body mass index, ratio of body weight to squared standing height; %FFM, percentage fat-free mass, estimated from bioelectric impedance analysis.

angles of a working volume of 380 × 380 × 280 cm to film each participant from different corners and points of view.

Before each acquisition session, a metric calibration and correction of optical and electronic distortions was performed. During the execution of the movement, special software recognised the coordinates of the centre of gravity of each marker for any TV camera. Subsequently, all the coordinates were converted into real metric data, and a set of x, y, z coordinates for each landmark in each frame which constituted the movement was obtained.[9 10]

Data analysis

Data were analysed separately for each gymnast and each series of 10 circular swings.

For each swing, the three dimensional coordinates of the right and left lateral malleoli (ankles), anterior superior iliac spines (hips), and acromia (shoulders) were used to compute the ideal circles projected on the horizontal plane as follows. From all the time frames of the swing (mean 1393, range 1290–1490), the centre of gravity of the trajectory of the landmark was calculated, the trajectory was projected on the horizontal plane passing through its centre of gravity, and the radius between the position of the landmark in each time frame and the centre of gravity was computed.

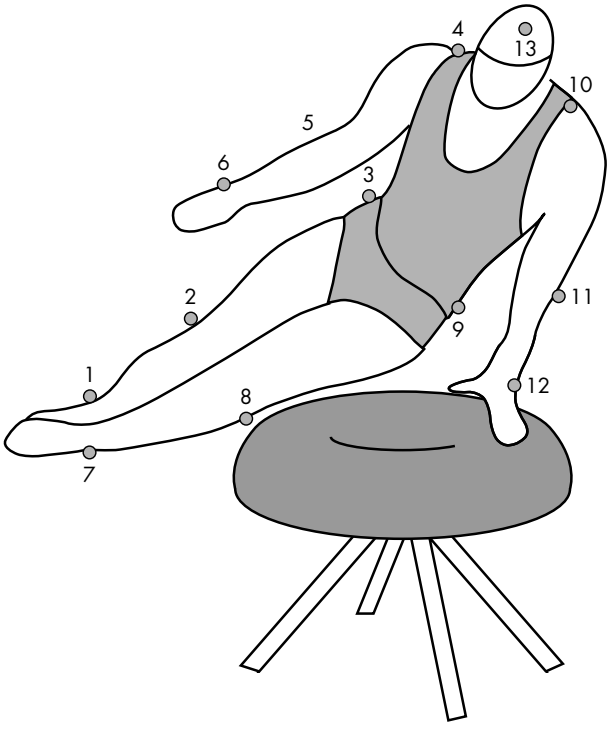

Figure 1 Anatomical landmarks analysed as the gymnast performs a circular swing on the competition mushroom: 1, right lateral malleolus (ankle); 2, right fibular head (knee); 3, anterior superior iliac spine (hip); 4, right acromion (shoulder); 5, right olecranon (elbow); 6, right styloid process of the ulna (wrist); 7, left ankle; 8, left knee; 9, left hip; 10, left shoulder; 11, left elbow; 12, left wrist; 13, vertex (head).

The diameters (mm) of the left and right ideal circles (ankles, hips, shoulders) were obtained. For each series, descriptive statistics of the 10 diameters were calculated. From the ankle diameters, the coefficient of variation (percentage ratio of standard deviation to mean) was used as an index of deviation from circularity. The deviation of the actual trajectory of the ankles from the horizontal plane was assessed as the percentage ratio of the maximal (the most different from zero) vertical coordinate to the relevant circle diameter.

To account for different body size and shape, the diameters were also normalised as suggested by Kerwin and Trewartha[4]: all values were divided by standing height and percentage fat-free mass, and multiplied by the mean values of the group.

In addition, the angle (degrees) between the shoulder, hip, and ankle was calculated for each side of the body in each frame of movement.

Statistical calculations

Mean (SD) was calculated for each variable within the gymnast and series using either univariate or bivariate (angles) statistical analysis. Data were compared between body side (right and left), series (three repetitions), and gymnasts (five men) by analysis of variance and Watson-Williams' test, followed by post hoc tests. Correlation coefficients were computed between anthropometric variables and diameters. Significance was set at 5% ($p<0.05$).

RESULTS

Within each gymnast and analysed landmark (ankle, hip, shoulder), the diameters computed in the three series were similar and symmetrical (two way factorial analysis of variance, factor 1: series, factor 2: body side, $p>0.05$ for factors and series × side interaction). Pooled (series and side) values were computed for each gymnast. From correlation analysis, standing height explained between 84% (ankle) and 20% (hip) of the interindividual variation in the diameters, and percentage of fat-free mass explained between 65% (hip) and 30% (ankle) of the variation.

To allow a comparison between the different gymnasts, mean diameters were normalised. All three normalised diameters were significantly different between gymnasts (table 2). In particular, gymnast M2 had the largest standardised ankle diameter and the smallest hip diameter (both values were significantly different from the other ones at post hoc analysis).

The smallest deviation from circularity of the ankle diameters was found in gymnast M2, the largest in gymnasts M1 and M4 (significant effect of gymnast, $p<0.001$, two way analysis of variance on log transformed values; no significant

Table 2 Diameters of circular swing completed on the competition mushroom by the five gymnasts in three series of 10

	Series 1				Series 2				Series 3					
	R		L		R		L		R		L		Normalised†	
Gymnast	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ankle														
M1	1481	75	1477	79	1512	92	1517	88	1529	89	1527	92	1511*	86
M2	1708	84	1723	67	1729	65	1714	78	1748	62	1725	84	1671*	70
M3	1383	74	1378	64	1414	82	1410	68	1421	76	1413	68	1598	81
M4	1632	91	1610	105	1642	87	1633	79	1641	89	1630	89	1647*	88
M5	1688	89	1688	95	1702	94	1701	92	1705	86	1708	89	1535*	79
p Value‡													0.001	
Hip														
M1	285	87	268	84	288	93	280	88	294	92	281	97	283	87
M2	256	88	284	94	286	97	260	84	293	95	256	83	264*	85
M3	247	84	260	94	259	90	269	101	266	90	266	91	298	100
M4	299	105	320	109	302	107	312	106	306	101	310	114	311	104
M5	344	101	327	93	332	92	348	106	347	102	333	102	306	85
p Value													0.042	
Shoulder														
M1	396	63	396	71	426	66	416	70	429	66	420	82	415*	68
M2	520	92	509	60	513	73	528	91	512	62	524	85	454	132
M3	362	63	358	74	380	79	379	93	382	60	379	61	425*	80
M4	510	81	488	72	258	85	502	67	532	80	512	79	517*	77
M5	495	71	520	71	533	69	502	65	498	60	532	68	459	62
p Value													0.001	

All values are mm.
†Normalised mean diameter, mean diameter divided by height and percentage of fat-free mass, and multiplied by the mean values of the group.
‡One way analysis of variance, 2,295 degrees of freedom; *significant difference at post hoc analysis.

Table 3 Circular swing on the competition mushroom: deviations from circularity and from the horizontal plane of the ankle trajectory

	Deviation from circularity						Deviation from horizontal plane					
	Series 1		Series 2		Series 3		Series 1		Series 2		Series 3	
Gymnast	R	L	R	L	R	L	R	L	R	L	R	L
M1	5.0	5.3	6.1	5.8	5.8	6.0	9.6	13.8	10.5	14.1	10.8	18.0
M2	4.9	3.9	3.7	4.6	3.6	4.9	14.5	9.7	10.3	14.2	9.4	17.2
M3	5.3	4.6	5.8	4.8	5.4	4.8	14.0	12.6	19.7	11.8	14.8	10.1
M4	5.6	6.5	5.3	4.9	5.4	5.4	11.6	9.4	11.8	12.5	14.0	14.7
M5	5.3	5.6	5.5	5.4	5.1	5.2	11.1	13.6	12.9	14.4	12.8	10.8

All values are percentages.

effect of series, no gymnast × series interaction) (table 3). The deviations of the same diameters from the horizontal plane were not significantly different between gymnasts or series, and no gymnast × series interaction was found.

Within gymnast and repetition, the left and right side mean angles between shoulder, hip, and ankle were symmetrical (Watson-Williams' test, $p>0.05$ on all occasions), and pooled values were computed (table 4). A two way factorial analysis of variance found a significant effect of gymnast ($p<0.001$): the largest value was found in M5 (about 155°), the smallest value in M2 (approximately 144.5°).

DISCUSSION

During the performance of the various techniques of gymnastics, a proper body form, including the reciprocal position of the various parts of the body in space, as well as the mode in which they move during the execution of the routine, is the key indicator of the correctness of the movements.[1 2 4] This "harmony" is not usually measured, but it probably depends on the temporal and spatial characteristics of the trajectories made by the limbs, trunk, and head.

Previous quantitative investigations performed on gymnastics mainly focused on floor exercises.[4–6] Data on ring

Table 4 Circular swing on the competition mushroom: angle between the shoulder, hip, and ankle

	Series 1				Series 2				Series 3			
	R		L		R		R		L		R	
Gymnast	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
M1	145	6.4	149	6.2	147	5.9	150	6.0	147	6.0	150	6.0
M2	147	10.7	143	10.0	143	10.8	146	11.0	143	10.2	145	11.0
M3	144	4.5	146	6.4	145	5.8	146	5.4	146	4.9	148	5.3
M4	147	7.6	143	7.2	148	6.9	146	7.8	151	6.7	149	7.2
M5	154	5.9	157	7.8	156	8.1	154	6.0	154	6.0	156	8.0

All values are degrees.

What is already known on this topic

Three dimensional analysis of body movements in gymnastics has been used to gather values for simulation models. Previous quantitative investigations have focused mainly on floor exercises, ring routines, and the horizontal bar.

What this study adds

A method for analysing body movements and positions during the performance of circular swings on the competition mushroom has been developed. This may be useful to gymnasts and their coaches for determining which parts of the body are not performing the movement with sufficient accuracy and for quantifying improvements after a specific training programme.

routines[7] and on the horizontal bar[2] have also been reported. In contrast, the pommel horse and the competition mushroom seem to have been neglected. In this study, we focused on the ankle, hip, and shoulder movements, as well as on the three dimensional arrangement of the trunk with respect to the lower limbs during the execution of circular swings on the competition mushroom. For a correct performance of the circular swings, each ankle should follow a nearly horizontal circular path. In addition, there should be an angle of about 180° at the hips, and there should be limited movement of the shoulders.

For the ankles, three measurements were performed: the diameter of the projected circle, the deviation of the trajectory from circularity, and its deviation from the horizontal plane. The dimensions of the circles depend on anthropometry (the taller the gymnast, the longer the lower limbs), muscular strength, and actual technical ability: the more the gymnast swings on the horizontal plane, the larger the projected circle. The present gymnasts had different body dimensions, and the circle diameters were normalised.[4] The values reported in the last column of table 2 should therefore depend only on technical ability.

The angle between the trunk and the lower limbs was measured, as well as the diameter of the projected shoulder movement.

Overall, gymnast M2 had the largest standardised ankle diameter and the most circular trajectory. Accordingly, he had the smallest standardised hip diameter. In contrast, he had the smallest hip angle. From this point of view, the current analysis did not allow us to rank the five gymnasts analysed consistently. It should be emphasised that not all of them were currently using the competition mushroom.

The competition mushroom is used by young gymnasts (8–14 or 9–12 years of age depending on the country) for pommel horse training. In Italy and Germany, the apparatus is also used for local and national competitions. Unfortunately, we cannot study gymnasts younger than 18 years of age. We chose the smaller apparatus because the pommel horse was too heavy (about 90 kg) to be carried into the laboratory. The use of the simpler apparatus (the competition mushroom) allowed us to extract the key values for a quantitative assessment of gymnasts performing circular swings. The same protocol could be used to appraise the actual performance on the pommel horse. At the same time, gymnasts still competing on the competition mushroom could be tested, and the method could supply useful information for the training of child and adolescent gymnasts.

The method could also help gymnasts to determine which parts of the body are not performing the movement with sufficient accuracy[4 6] and to quantify improvements made after a specific training programme.

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REFERENCES

1 **Fink H**. *Men's code of points*. Moutier, Switzerland: Fédération Internationale de Gymnastique, 2000.
2 **Takei Y**, Nohara H, Kamimura M. Technique used by elite gymnasts in the 1992 Olympic compulsory dismount from the horizontal bar. *Int J Sport Biomech* 1992;**8**:207–32.
3 **Claessens AL**, Lefevre J, Beunen G, *et al*. The contribution of anthropometric characteristics to performance scores in elite female gymnasts. *J Sports Med Phys Fitness* 1999;**39**:355–60.
4 **Kerwin DG**, Trewartha G. Strategies for maintaining a handstand in the anterior-posterior direction. *Med Sci Sports Exerc* 2001;**33**:1182–8.
5 **Davlin CD**, Sands WA, Shults BB. Peripheral vision and back tuck somersaults. *Percept Mot Skills* 2001;**93**:465–71.
6 **King MA**, Yeadon MR. Coping with perturbations to a layout somersault in tumbling. *J Biomech* 2003;**36**:921–7.
7 **Yeadon MR**, Brewin MA. Optimised performance of the backward longswing on rings. *J Biomech* 2003;**36**:545–52.
8 **Piccoli A**, Brunani A, Savia G, *et al*. Discriminating between body fat and fluid changes in the obese adult using bioimpedance vector analysis. *Int J Obes* 1998;**22**:97–104.
9 **Sforza C**, Turci M, Grassi G, *et al*. The repeatability of choku-tsuki and oi-tsuki in traditional Shotokan karate: a morphological three-dimensional analysis. *Percept Mot Skills* 2000;**90**:947–60.
10 **Sforza C**, Turci M, Grassi G, *et al*. Repeatability of mae-geri-keage in traditional karate: a three-dimensional analysis with black-belt karateka. *Percept Mot Skills* 2002;**95**:433–44.