EXERCISE AND SPORTS SCIENCES

ORIGINAL ARTICLE

KINEMATICS OF KEY TECHNIQUE VARIABLES IN THE BACKWARD HANDSPRINGS OF ELITE GYMNASTS

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ABSTRACT

Introduction: Gymnastic is the most ancient and spectacular closed skills sport. Nonetheless, often technical parameters of execution are taught only by trainer experience. Thus, a lack of objective data about gymnastic performance (kinematics references) is present. Objective: In the current study, we wanted to quantify linear and hyperextension back movements during the performance of backward handsprings. Methods: A non invasive detection of backward handsprings was made using a 3D optoelectronic instrument. Thirteen spherical retro-reflective markers (diameter 1 cm) were positioned on the body of 9 experienced gymnasts: right and left lateral malleolus, fibular head, greater trochanter, acromion, olecranon, styloid process of the ulna; vertex. In the same session and after a warming-up period, each participant performed 15 repetitions of backward handsprings. Ten repetitions were analyzed, and the 3D tracks of the 13 landmarks measured. Results: On average, men performed longer backward handsprings than women (men, 122% of height; women, 98%); women attained a larger vertical height (women, 62% of height; men, 58%). The lower limb arrangement was homogenous among the gymnasts: posterior knee angles ranged between 80° and 118°. No lower limb abduction was observed: knee width was 7 cm smaller than intertrochanter width; ankle width was 8 cm smaller than knee width. At take-off, the trunk-thigh angle showed an excellent body alignment, with values very close to 180°. Women performed the handstand phase with closer wrists than men (men, 134% of shoulder width; women, 121%). Conclusion: The results may offer data to improve learning, defining golden standard execution taken from high level gymnasts with few injuries.

Keywords: sport analisys, flic flac, closed skills, artistic gym.

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INTRODUCTION

Gymnastics is one of the sports that best combine esthetics and technical skills, requiring the execution of highly acrobatic sequences of body movements[1,2]. The gymnasts are therefore required several hours of technical, strength, and flexibility training to obtain the best results[3].

Previous studies mostly analyzed the risk and the incidence of injuries during the execution of this closed-skill sport[4-7], and investigated the biomechanical characteristics of several technical elements[8-13].

Also, the anthropometric and physical features of elite gymnasts have been studied[1,14].

In contrast, the requested technical skills, and the typical exercise sequences, were scantly investigated from a scientific point of view[15-19]. In particular, Grassi, et al.[17] investigated the performance of the backward handspring (also called backward flic-flac), a technique of floor gymnastics. The backward handspring (often connected with round-off elements) is an important acrobatic element of floor exercise tumbling used by both male and female gymnasts. Grassi, et al.[17] focused on the spatiotemporal consistency of repeated landmark trajectories through the measure of the standard deviation between standardized trajectories[16]. In particular, in all participants (men and women) the trajectories drawn by thighs and shoulders showed the best repeatability while the wrist trajectories were the most variable among trails and gymnasts[17].

In the current study, the same gymnastic technique film acquisition analyzed by Grassi, et al.[17] was further investigated. Some technical measurements were quantified about backward handspring (spine hyperextension not excluded). In particular, in this preliminary study, objective spatial measures (nine key technique variables) referred to the technical arrangement were identified among those observed by trainers during learning sessions, and scored by judges during rating. Differences between sexes were taken into account. These results may offer a baseline to help the learning and correct execution of the exercise because provide metric objective data about the body arrangement in elite gymnasts.

METHODS

Participants

The same gymnasts and sequences analyzed in the study by Grassi, et al.[17] were used in the current study. In brief, nine experienced gymnasts (six men, three women), all in good health, were recruited for the study (table 1). They all were high-level athletes (national team), and had 7 to 14 years of specific training in gymnastics.

The gymnasts were fully informed about the nature and possible risks of the study. Written informed consent was obtained from each participant or from parents of participants younger than 18 years. The protocol used in the current study 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. The inter-trochanter and inter-acromion widths were also measured. The Body Mass Index (BMI) was calculated for all subjects (table 1).

Table 1. Subjects.

Gymnast	Age	Standing height	Body weight	BMI	Acromion width	Inter-trochanter width
	(years)	(cm)	(Kg)	(Kg/m^2)	(cm)	(cm)
M1	21	162	74	28.20	30.4	35.9
M2	23	168	70.5	24.98	32.7	38.6
M3	21	178	63	19.88	33.1	37.7
M4	16	165	62	22.77	28.6	37.0
M5	21	176	75	24.21	37.2	38.0
M6	20	160	62	24.22	29.2	34.8
Mean	20.3	168.2	67.8	24.04	31.9	37.0
SD	2.3	7.4	6.1	2.73	3.2	1.4
F1	19	177	75.5	24.13	26.2	38.2
F2	20	158	55	22.03	27.6	37.2
F3	17	153	48	20.51	25	35.2
Mean	18.7	162.7	59.5	22.21	26.3	36.9
SD	1.5	12.7	14.3	1.80	1.07	1.5

Age and anthropometric characteristic of the analyzed gymnasts.

Procedures

The backward handspring is a complete back rotation of the body around a horizontal axis, with an intermediate inverted hand support (IHS). It is composed of two flights, the first rearward from feet to the hands, the second from hands to the feet (figure 1).

Thirteen spherical retro-reflective markers (diameter 1 cm) were positioned on the body of each athlete: right and left lateral malleolus, fibular head, greater trochanter, acromion, olecranon, styloid process of the ulna. The head marker was fixed on an elastic cotton cap.

A video-based optoelectronic stereophotogrammetric system (Elite system; BTS Milano, Italy) recorded the position of the thirteen markers in a working volume of 380 x 280 x 280 cm with a static accuracy of 0.02% on a 90 cm long wand. In particular, nine cameras working at a 100 Hz sampling rate surrounded the execution area filming the gymnasts from different points of view (figure 2).

After their typical self selected warm up activities, each gymnast performed 15-20 repetitions of backward handspring. All the participants were told to perform at their best. To avoid fatiguing effects, the backward handspring were subdivided into three series of five repetitions (1 min of stop between each execution, 5 min between each series). Each gymnastic element was executed starting from the standing position on two 2 x1 m rubber mats (Mat gold, Agosport, Milano, Italy). The mats (4 cm thick and weighed 16 kg) were positioned aside their smaller border to make a 4x1m floor. A national team trainer observed all trials to control the general correctness from a technical point of view.

Data analysis

Data analyses were performed separately for each gymnast. The first ten backward handsprings correctly performed by the gymnast and recorded by the system were used for the quantitative analysis.

Using the 3D co-ordinates (x, y, z) time histories of each body landmark, and mathematical operations from Euclidean geometry, measurements of body arrangement were calculated to obtain metric parameters of technique. In particular, each exercise was scroll down by a national gymnastic team trainer who selected the film acquisition frames for the following 13 technique variables:

a. Body back-projection and its symmetry at the beginning of movement (figure 1A): horizontal projection of the linear distance between the ankle and the hip (greater trochanter), unit: cm. The calculation was performed separately for the right (R) and the left (L) side, and the relevant percentage symmetry computed [(R-L)/(R+L) x 100].
b. Lower limb arrangement at the beginning of movement (figure 1A): posterior knee angle (between the greater trochanter-fibular head line and the fibular head-ankle line, average right-left value, unit: degrees); right-left ankle width, and right-left knee width (unit: cm).
c. Body arrangement at take-off (between knee flexion and extension, just before the beginning of the first flight, (figure 1B): angle of escape (between the ground and the acromion-fibular head line), trunk-thigh angle (acromion-greater trochanter-fibular head); both angles were the average right-left value, unit: degrees.
d. First flight: length (distance between take off, figure 1B, and landing on the hands, figure 1D), and maximum height (figure 1C, y coordinate of the greater trochanter); both distances were the average right-left value, unit: cm.
e. Parallelism of feet (at take off, figure 1B) and hand supports (at the end, figure 1D) during the first flight: angle between the ankle and the wrist lines (figure 3; unit: degrees).
f. Upper limb arrangement during IHS (figure 1D): linear upper limb flexion (difference between the acromion–wrist distance in standing position and during IHS, average right-left value); right-left wrist width (unit: cm).
g. Linear metric upper limb pushing at the beginning of the second flight (figure 4): difference between the acromion y coordinate (height from the ground) during the IHS (figure 1D), and when the ascendant phase is finished (figure 1E); the distance was the average right-left value, unit: cm.
h. Second flight length: distance between IHS (figure 1D) and end position (figure 1F); unit: cm.
i. Total length of the backward handspring (sum of the lengths of the two flights); unit: cm.

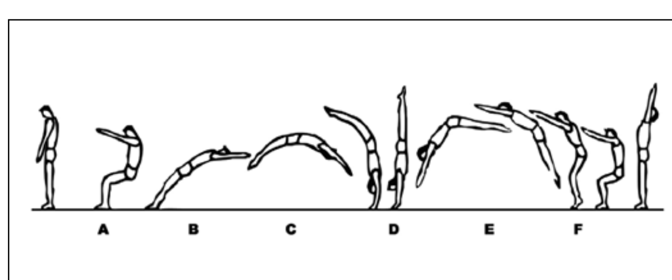

Figure 1. Backward handspring and its technical phases. A. Back-projection; B. Take off; C. First flight; D. Inverted Hand Support; E. Second flight; F. End position.

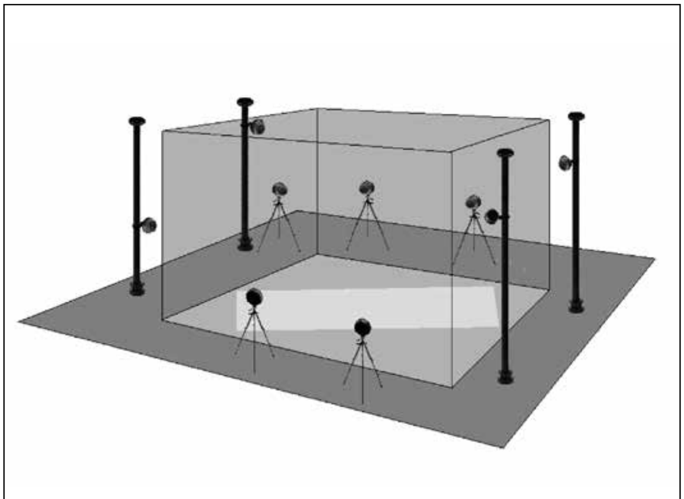

Figure 2. Working volume and position of the nine TV cameras.

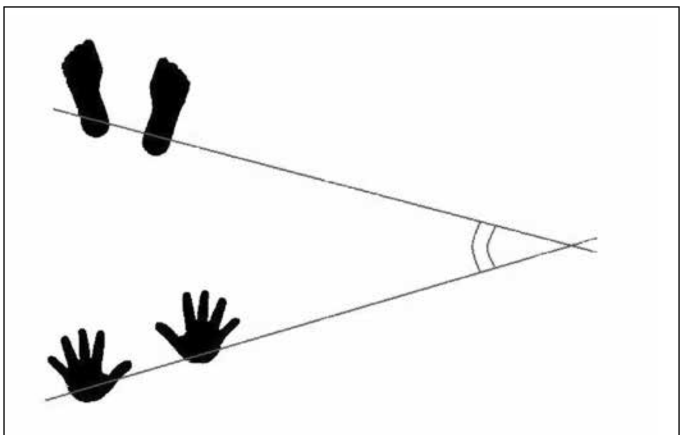

Figure 3. Feet and hand parallelism in successive supports.

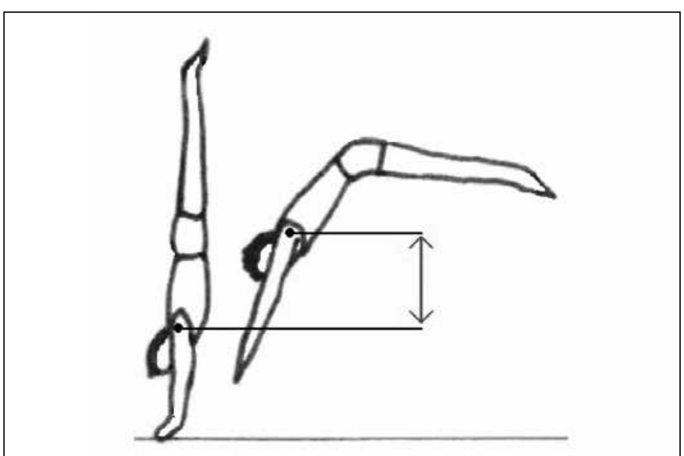

Figure 4. Upper limb linear pushing parameter.

Statistical analysis

All the parameters were calculated separately for each gymnast and repetition; descriptive statistics over the ten repetitions were obtained using either univariate (distances) or bivariate (angles) statistic.

RESULTS

Men performed longer backward handsprings than women (table 2); in both sexes, the first flight was somewhat smaller than the second one (on average, 48% of total flight in men, 46% in women). The first to second flight ratio was somewhat larger in men (95%) than in women (88%). Both flights remained longer in men than in women even after correcting for standing height (first flight, 58% of height in men, 45% in women; second flight, 63% in men, 53% in women). In contrast, the maximum height of the first flight was larger in women than in men; additionally, they attained a larger height both as a percentage of their standing height (women, 62%; men, 58%), and as a percentage of the length of their first flight (women, 139%; men, 102%). Overall, the backward handspring in women was performed with a shorter first flight (using more spine hyperextension).

At the beginning of movement, all gymnasts had symmetric back projections of their bodies (table 3, maximum asymmetry 4.7%), with similar values in men and women, with the posterior knee angles ranging between 80° and 118°. Their knee (between the two fibular heads) and ankle widths (between the two lateral malleoli) showed a good alignment, without limb limb abduction. On average, in men knee width was 17% of standing height, and 9 cm smaller than intertrochanter width; in women it was 14% of standing height, 6 cm smaller than intertrochanter width. Ankle width was 11% of subject height, and it was 9 (men) and 4 (women) cm smaller than knee width.

At take-off, the departure angles (between the ground and the acromion-fibular head line) were, on average, 40° in men and 48° in women (table 3). The trunk-thigh angle showed an excellent body alignment in all subjects (all values were very close to 180°).

During IHS, seven gymnasts of nine had a close parallelism between their hand and foot supports (table 4): only M2 and F1 had angles larger than 20°. On average, the upper limb flexion was similar in men and women; in contrast, women performed the IHS with closer wrists than men, both as absolute values and as a percentage of shoulder (interacromia) width (134% in men; 121% in women).

The linear upper limb pushing at the beginning of the second flight was very variable among the analyzed gymnasts, ranging between 10 and 32 cm; on average, this movement corresponded to 12% of standing height in men, and 9% in women.

Table 2. Kinematic measurements of the backward handprings: flight length and height.

Subject	1st Flight length (cm)	2nd Flight length (cm)	Total Length (cm)	1st Flight Height (cm)
M1	96	104	200	94
M2	114	128	242	88
M3	85	102	187	110
M4	93	68	161	97
M5	90	113	203	106
M6	108	123	231	91
F1	75	73	148	100
F2	64	101	165	105
F3	80	82	162	97

Length and height of the two flights of the backward handspring.

Table 3. Kinematic measurements of the backward handprings: gymnasts during take off.

	Beginning of the backward handspring					Take-off	
Subject	Back-projection (cm)	Symmetry (%)	Posterior knee angle (deg)	Ankle width (cm)	Knee width (cm)	Angle of escape (deg)	Trunk-thigh angle (deg)
M1	33.0	-1.65	108	19.6	31.7	39	182
M2	33.6	0.25	88	17.8	25.5	33	182
M3	32.3	-1.95	109	23.8	31.0	48	181
M4	23.6	-3.25	99	18.2	23.2	40	181
M5	24.7	1.6	103	18.8	27.8	42	181
M6	23.6	-4.72	79	15.7	28.7	37	182
F1	30.5	-0.25	116	16.6	19.4	48	182
F2	30.3	-1.18	118	17.6	20.7	51	181
F3	26.3	-4.56	100	17.5	28.0	45	182

Body arrangement at the beginning of the backward handspring, and at take off. Back-projection, posterior knee angle, angle of escape, trunk-thigh angle: average right-left value; positive symmetry: right side larger than left side.

Table 4. Kinematic measurements of the backward handprings: gymnasts during hand support.

	Inverted Hand Support			Beginning of the 2nd flight
Gymnast	Hand-feet parallelism (deg)	Linear flexion of upper limbs (cm)	Wrist widths (cm)	Upper limb pushing (cm)
M1	3	10	45	26.4
M2	20	16	38	31.6
M3	7	3	48	15.1
M4	1	4	44	21.2
M5	5	5	40	14.4
M6	10	13	39	16.0
F1	29	4	29	13.9
F2	9	10	40	10.1
F3	4	10	27	18.7

Body arrangement during inverted hand support, and at the beginning of the second flight. Hand-feet parallelism: positive values; upper limb flexion and pushing: average right-left value.

DISCUSSION

The backward handspring is an acrobatic element that is often used for tumbling into floor exercise during competitions. Previous biomechanical investigations on floor gymnastics mostly focused on force reactions[8,2], suggesting important elements to improve performance and make it safer. Nevertheless, detailed data focusing on the actual performance of technical elements are also crucial for teaching and learning[16,17,19].

The current pilot study took some technical parameters into account to define the characteristics of execution of backward handspring. Quantitatively, three-dimensional evaluations are necessary to assist the technical teaching giving to experienced trainers an objective support that can both help the gymnasts and put the bases for a widespread, shared reference[12,16,19]. As suggested by Baudry, et al.[16], the method could also be used to measure the improvements in movements after training sessions.

The backward handspring was divided into simple steps and body positions that represent important consecutive factors for a successful performance (i.e., vertical height, flight length and back projection) to be taken into account.

For example, in several occasions the performance was different in men and women. Male gymnasts performed a first flight with similar height and length, while female gymnasts had a relatively higher first flight (vertical displacement larger than horizontal one). Women had a more vertical angle of departure at take-off (on average, 48° vs. 40° in men), and a larger posterior knee angle (table 3). The larger spinal mobility and flexibility in women may be a key factor in this different performance. Spinal movements during the performance of backward handspring range from flexion and hyperextension in few seconds, posing the lower back at great injury risk[4,5,8,20].

Body alignment was almost perfect in all gymnasts (trunk-thigh angle very close to 180°). Indeed, the body alignment is one of the most important technical parameters in gymnastics[3], as underlined in several previous investigations[16-19].

The level of hand-feet parallelism during the back projection suggest an advanced performance. Indeed, a linear back projection is important for the generation of momentum and horizontal velocity[9]. Additionally, considering that in gymnastics the upper extremities are regularly used to sustain body weight, a correct execution of all phases (above all the IHS) is necessary not only for a successful performance, but also to avoid (or reduce) macro- and micro-injuries during the execution of floor exercises[4,6,8,19,21].

Indeed, the upper limbs must amortize the body weight and instantly create a push off: thus the arm alignment become crucial to avoid additional stresses used to correct the error. As shown by Kerwin & Trewartha[19], wrist movements and torque are particularly important in gymnasts while reaching the handstand. In particular, even if upper extremity injuries account only for 15-25% of gymnastic injuries[4,5], wrist pain from overuse injuries (stress fracture and distracting injury in particular),[6] appears to be very common, and to have a negative effect on gymnastic training, reducing its intensity and duration[8,21].

Lower extremity injuries account for most of gymnastic injuries (up to 70%)[4,5]: ankles, the most frequently involved joints, sustain repetitive loading during the execution of floor exercises. Indeed, landing collects the largest frequency of injuries (31%) during both competition and training[5].

The method described in the current study may be used to collect data on a wide group of elite gymnasts of both sexes to define some "gold standard execution", with parameters related to individual anthropometric measures. Furthermore, the same technical parameters could be used in the biomechanical approaches to gymnastic performance, improving the modeling and optimizing the algorithms of execution[8-11,22].

CONCLUSION

A correct execution (performed by national team gymnasts like in this study) may also be used as a baseline for didactic-preliminary execution that help trainer to put marks on the floor and references during learning session.

The golden standard execution performed by national gymnasts (with few injuries) could be used as a reference to reduce accidents also in less expert athletes[5,7,8].

All authors have declared there is not any potential conflict of interests concerning this article.

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