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Biomechanical Analysis of "Free (Aerial) Forward Walkover, Landing on One Foot" (Forward Danilova) on Balance Beam

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Abstract

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Acrobatics is the oldest gymnastic activity and the balance beam apparatus, with its structure, is part of it. For a very high level of preparation in women's balance beam, it is compulsory for them to have morphofunctional integrity of the musculoskeletal system, good joint mobility and muscle elasticity, and very good neuromuscular coordination. The element "Free (aerial) forward walkover, landing on one foot" (Forward Danilova) on balance beam is a dynamic acrobatic element classified in salto group, which is found in most integral exercises to the balance beam and/or floor exercise and can be presented in many forms. The biomechanical reason is that the gymnast can perform the elements in easier conditions. Thorough analysis of the biomechanical data allows outlining more detailed conclusions, such as those related to the kinematic and dynamic errors which lead to and cause other errors. Through these examples, we want to highlight the usefulness of kinematic biomechanical analysis, which covers both analytical interpretation for finding the errors and analytical mode to direct the gymnast, what to do to do it right.

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Keywords: Artistic gymnastics; biomechanical analysis; balance beam.

1. Introduction

In artistic gymnastics, balance beam is an event so difficult and spectacular at the same time. This apparatus is characterized by excellence in physical and mental balance. About the content, Regulations require that exercises are composed of elements from different structural groups: acrobatic elements with or without flight phase, performed forward, backward or sideways; elements of gymnastics as: pirouettes, leaps, jumps, combinations of steps, elements of balance.

Thorough analysis of the biomechanical data allows outlining more detailed conclusions, such as those related to the kinematic and dynamic errors which lead to and cause other errors.

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2. Materials and methods

2.1. Research purpose

Why a biomechanical analysis? According to Gagea (1994: 6), "apart from efficiency, there are other reasons that may justify the interest in the study of biomechanics. One of these is the need to expand the biomechanics-related knowledge, and the other one is to increase exercise capacity and performance in competitions".

In artistic gymnastics in general, and especially for balance beam apparatus, the learning of any technical element is carried out based on a biomechanical model that includes the integration of multi- and cross-disciplinary information from several areas of knowledge and involves completing the following steps:

- decomposition of movement into component phases;
- identification of key-joints and joint movements;
- determination of agonist and antagonist muscle groups involved in the specific action in each phase;
- identification of specific technical elements addressed (balance, muscle strength or power, mobility).

The importance of biomechanical analysis is given by the high performance level that requires the use of modern training technology in order to capture multiple angles of movement, with all its kinematics and dynamics, which will double the coach's "eye" and provide feedback to learning. So, the current technical level has reached its upper limit, imposing biomechanical analysis in learning.

2.2. Research hypothesis

Biomechanical analysis of qualitative research, in parallel with the use of video recording, will promote the removal of technical mistakes and will lead the gymnast to achieve the model execution.

2.3. Subjects

"Take into the consideration that training is performed in an individualized manner" (Teodorescu, 2009: 21). This study is based on a comparative biomechanical analysis between one gymnast who represents the model execution and six gymnasts who have just learned the studied element on balance beam (Forward Danilova). Of the six gymnasts, we chose to present the biomechanical analysis for Z.S., the most representative gymnast, with the best performance.

2.4. Description of "Free (aerial) walkover forward, landing on one foot" (Forward Danilova)

"Forward Danilova" is a dynamic acrobatic element classified into salto group, which is found in most integral exercises to the balance beam and/or floor exercise and can be presented in many forms. According to gymnast's skills, the coach can choose the basic variant (the one shown by us) with landing on one foot, or landing on both feet. In the *Code of Points* (2008), the element has the D value, which means a bonus of 0.40 tenths, or can be combined with other elements and earn a bigger bonus.

Biomechanically, mastery and regulation during the exercise can be made respecting the principle of the permanent projection of the centre of gravity on the narrow support area of the balance beam.

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Rational training for this apparatus requires learning the correct technique since the beginning and educating the sense of balance using visual analyser and kinaesthetic sensations (Şlemin, 1976: 86).

2.5. Biomechanical analysis of model execution and the best gymnast's execution in the two tests

- *Analysis of the preparatory phase*

"Step forward must be blocked in order to have a fixed foothold, and lunge will be to achieve the maximum load and necessary momentum for the next phase. Length of contact with the beam varies from 0.05 to 0.8 sec., while the centre of gravity moves forward relative to the fulcrum, according to the model gymnast" (Stroescu, 2014) (Fig. 1).

At the initial testing in the preparatory phase, the best gymnast, Z.S., presents a coxofemoral joint angle smaller than in the model gymnast, the scapular-humeral joint angle is large, the preparation step is short, which leads to weaker momentum (Fig. 2). In the final testing, the trunk remains bent in the preparatory phase, but other indicators approach to the model values (Fig. 3).

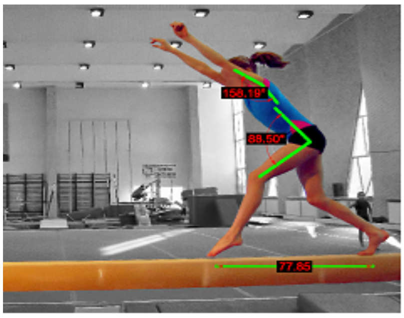

Fig. 1. Preparatory phase (model gymnast)

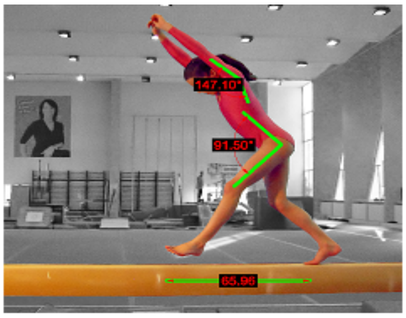

Fig. 2. Preparatory phase (initial testing)

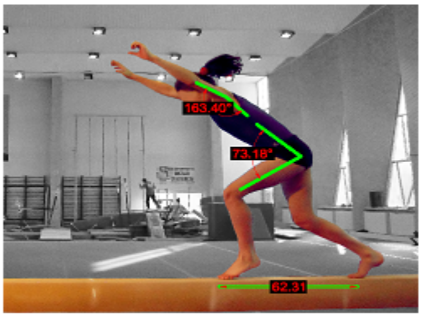

Fig. 3. Preparatory phase (final testing)

- *Analysis of routing - Loading phase*

"This phase is that in which there is continuous lowering and arm lowering, torso forward and down, while balancing in speed the oscillating rear leg. Since angular momentum is the product of the moment of inertia and angular velocity (Donskoi, 1959: 56), the gymnast can increase angular velocity when the oscillating body and leg reach the peak and achieve this tense "arc", which will trigger vertical momentum and detachment (Stroescu, 2014) (Fig. 4).

In this initial testing phase, the gymnast presents low mobility in the sacroiliac joint and incorrect head positioning (chin to chest) (Fig. 5). In the final testing, all values of joint angles are improved (Fig. 6).

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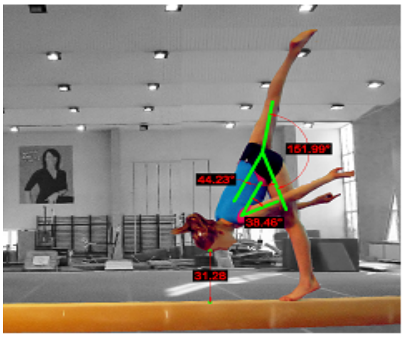

Fig. 4. Routing - Loading phase (model gymnast)

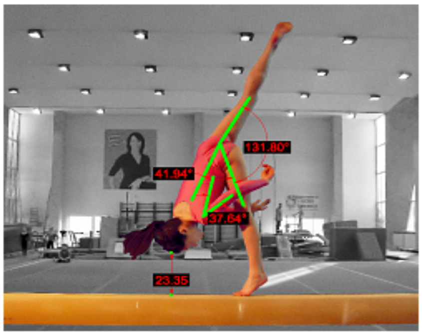

Fig. 5. Routing - Loading phase (initial test)

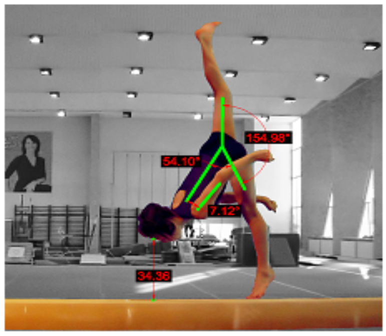

Fig. 6. Routing - Loading phase (final test)

- *Analysis of detachment - Elevation*

"This impetus triggered by the past actions of forces engaged is the culmination of achieving vertical phase separation. Detachment effort is made by the triple chain leg extension. Contraction of the muscle groups for overcoming mechanical work must coincide in time, contrary to the thigh and lower leg lever formats which constitute a deterrent (Fig. 7). Due to the small step of preparation, elevation is not sufficient, and that compensatory movement appears as a bent-leg landing" (Stroescu, 2014) (Fig. 8). The final testing of biomechanical indicators is close to the model values, except that further head positioning is poor (Fig. 9).

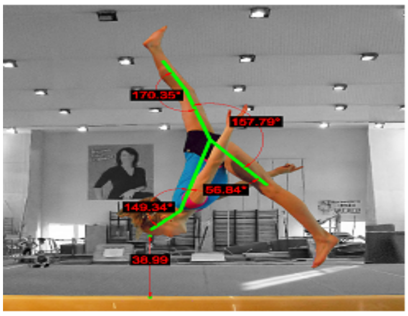

Fig. 7. Detachment - Elevation phase (model gymnast)

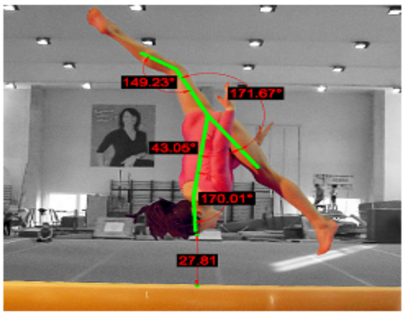

Fig. 8. Detachment - Elevation phase (initial test)

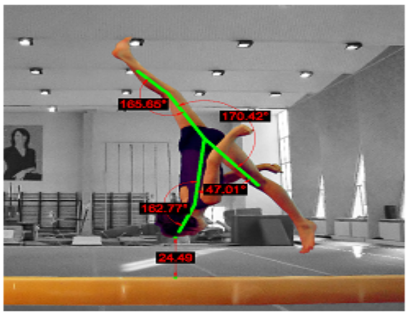

Fig. 9. Detachment - Elevation phase (final test)

- *Analysis of flight - Rotation*

"Movement biomechanics is always coordinated, which implies restrictions in trajectory, speed time and sometimes accelerations. While rotation occurs, swing foot landing prepares thus to form another tense "arc", which will help to further raise the trunk that, this time, remains in extension. Iliac and abdominal muscles play an important role in this movement phase, as they provide the physical support required to maintain the final position (Fig. 10).

During the flight phase, in the initial testing, the coxofemoral joint angle is too small, the gymnast bringing the trunk towards the foot in place of the spine extension, and the leg which has triggered the separation is not controlled (Fig. 11). In the final testing, biomechanical indicator values are close to the model" (Stroescu, 2014) (Fig. 12).

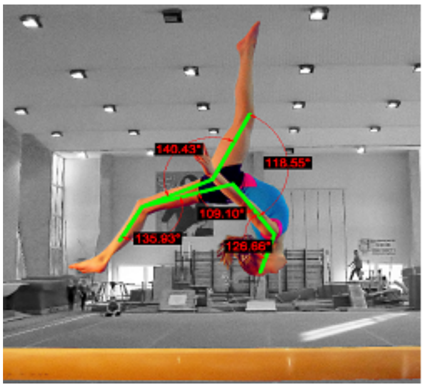

Fig. 10. Flight - Rotation phase (model gymnast)

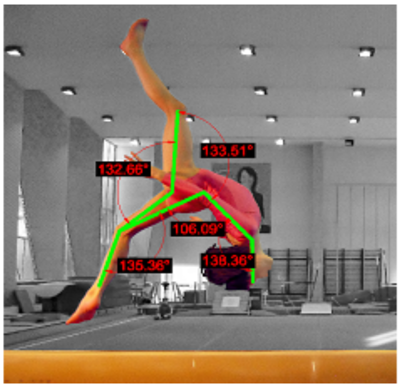

Fig. 11. Flight - Rotation phase (initial test)

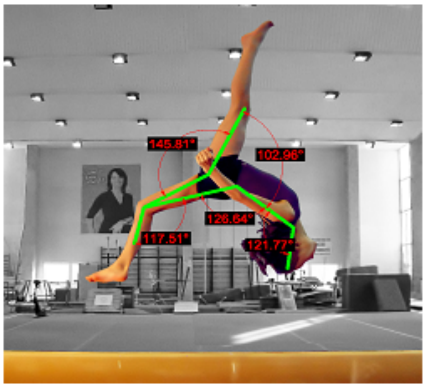

Fig. 12. Flight - Rotation phase (final test)

- *Analysis of landing phase*

According to the previous phase, the foot is ready for landing, and this is achieved by successive contacts of foot with cushions, while raising the trunk until it reaches the standing away position in the sagittal plane. Beam contact is gradually made with metatarsals, leaving the entire sole weight (Fig. 13). "These movements engage in effort the entire body, especially bone-ligament and muscle systems" (Grigore, 1998: 43).

"As regards landing in the initial testing (Fig. 14), wrong arm positioning (too close to the trunk) and lack of extension in the spine lead to a landing with major mistakes (additional movements of arms, incorrect positioning of feet and additional step for balancing). In the final testing, landing is done properly, without penalty" (Stroescu, 2014) (Fig. 15).

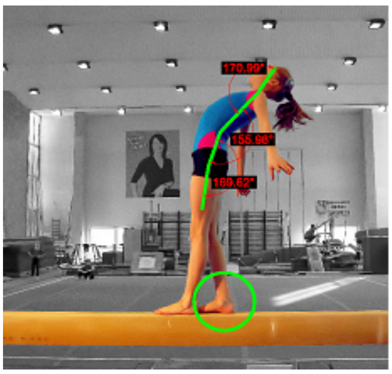

Fig. 13. Landing (model gymnast)

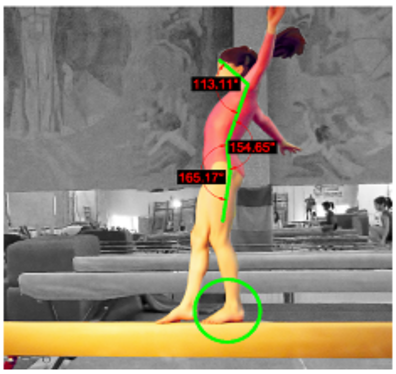

Fig. 14. Landing (initial test)

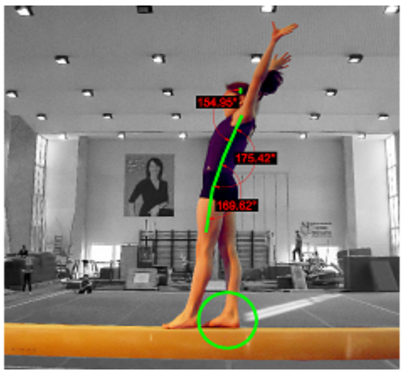

Fig. 15. Landing (final test)

3. Results

In Table 1, we presented the angle values obtained from the biomechanical analysis of the model gymnast and the gymnast Z.S., in the initial and final testing.

Table 1. Biomechanical analysis results

Danilova phases	Angles analysed	Model gymnast	Z.S. - initial testing	Z.S. - final testing
Preparatory phase	scapular-humeral joint angle	158.19°	147.10°	163.40º
	coxofemoral joint angle	88.50°	91.50°	73.18º
	step length	77.85 cm	65.96 cm	62.31 cm
Routing - Loading phase	sacroiliac joint angle	151.99°	131.80º	154.98º
	coxofemoral joint	44.23°	41.94º	54.10º
	scapular-humeral joint angle	38.46°	37.64º	7.12º
	beam - head distance	31.28 cm	23.35 cm	34.36 cm
Detachment-Elevation phase	sacroiliac joint angle	157.79°	171.67º	170.42º
	knee joint angle	170.35°	149.23º	165.65º
	coxofemoral joint	56.84°	43.05º	47.01º
	head position angle	149.34°	170.01º	162.77º
	beam - head distance	38.99 cm	27.81 cm	24.49 cm
Flight - Rotation phase	sacroiliac joint angle	140.43°	132.66º	145.81º
	knee joint angle	135.93°	135.36º	117.51º
	coxofemoral joint	118.55°	133.51º	102.96º
	spine angle	109.10°	106.09º	126.64º
	head position angle	126.66°	138.36º	121.77º
Landing	head position angle	170.99°	113.11º	154.95º
	spine angle	155.98°	154.65º	175.42º
	coxofemoral joint	169.62°	165.17º	169.62º
Execution time	routing - loading phase	280 ms	327 ms	301 ms
	flight phase	275 ms	606 ms	399 ms
	element execution	1.084 s	1.211 s	1.112 s

To highlight the effectiveness of biomechanical analysis, we used the Wilcoxon Test for assessing the statistically significant differences recorded between the two tests. For each part of the element, there are differences between the two tests, but they are not statistically significant, since the p-values of threshold significance provided by the Wilcoxon Test for each element are higher than 0.05.

In the following lines, we will present only the element phases for which statistically significant differences have been found (Table 2).

Table 2. Analysis of gymnasts during Routing - Loading phase

Danilova phases/ Biomechanical indicators	Testing	STATISTICAL INDICATORS					WILCOXON Test		Significant differences (Final-Initial)
Routing - Loading phase		Average	Std. deviation	Median	Range of motion	Coef. of variation	Z	P	
sacroiliac joint angle	I	133.52	10.81	128.99	24.08	8.10%	-1.992	0.046	Yes
	F	149.42	7.07	149.62	15.40	4.73%			
coxofemoral joint	I	42.66	7.02	40.71	19.79	16.46%	-0.314	0.753	No
	F	44.23	7.94	45.63	19.84	17.95%			
scapular-humeral joint angle	I	45.51	10.18	40.07	22.18	22.36%	-1.363	0.173	No
	F	36.08	20.84	41.88	49.19	57.76%			
beam - head distance	I	24.12	2.21	24.00	6.45	9.15%	-1.153	0.249	No
	F	26.84	5.49	28.18	15.79	20.47%			

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For each element of the routing - loading phase, there are differences between the results of the two tested gymnasts, but they are not statistically significant. An exception is the sacroiliac joint angle, for which the value of materiality is $p< 0.05$. P-values provided by the Wilcoxon Test for other elements of this phase are greater than 0.05. For the first two joints analysed (sacroiliac joint angle and coxofemoral joint angle), averages increased in the final testing, while for the other two joints (scapular-humeral joint angle and beam - head distance), averages decreased. The data dispersion is relatively homogeneous.

As to the execution time phase, average values fell in the final testing. Differences between the gymnasts' results in the two tests, for each element of this phase, are statistically significant, materiality values provided by the Wilcoxon Test showing that p is less than 0.05 (Table 3).

Table 3. Analysis of gymnasts - Execution time for Danilova

Danilova phases	Testing	STATISTICAL INDICATORS					WILCOXON		Significant differences
Execution time		Average	Std. deviation	Median	Range of motion	Coef. of variation	Z	P	(Final-Initial)
Routing - Loading phase	I	333.83	4.92	333.50	14.00	1.47%	-2.201	.028	Yes
	F	316.00	11.63	314.50	34.00	3.68%			
Flight phase	I	597.17	6.34	598.00	17.00	1.06%	-2.207	.027	Yes
	F	386.33	7.23	385.00	21.00	1.87%			
Element execution	I	1.221	0.007	1.22	0.02	0.53%	-2.201	.028	Yes
	F	1.147	0.023	1.15	0.07	2.01%			

Significant reduction of the three periods increased the execution speed on beam. At this point, the data dispersion for each component has a homogeneous structure. The results of gymnasts in performing the "Forward Danilova" element are presented in Table 4.

Table 4. Initial and final test results

No.	Name	Initial testing	Final testing
1.	M. A.	0.60	0.40
2.	C. I.	0.50	0.25
3.	Z. S.	0.40	0.05
4.	S. A.	0.65	0.20
5.	R. M.	0.35	0.15
6.	P. A.	0.55	0.30

4. Conclusions

Thorough analysis of the biomechanical data shows that the gymnasts' results have improved in the stage of learning and acquiring the Danilova element. Exemplifying, we can see that the worst penalty executions took 0.40 tenths, while the best executions received only 0.05 tenths. Specifically in our case, gymnasts who were successful in two tests have managed to improve their performance, being very close to the model gymnast's performance.

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