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Kinematic analysis of the spine and hip for the "Danilova" artistic gymnastics element

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Abstract

Introduction: Women's artistic gymnastics is a sport that has experienced a continuous evolution over the years, both from a technical point of view and from the point of view of the correctness of the executions. Flexibility, strength, dexterity, and many other motor qualities are present in this sport. Danilova or "free (aerial) walkover forward" is an acrobatic flight element in artistic gymnastics. This element can be executed both on the floor and on the balance beam, but most frequently on the beam, being an element of difficulty D (0.4 points). *Material and methods***:** 13 artistic gymnasts, components of junior and senior Romanian Olympic teams (age: 14 ± 1.93 years, height: 149.35 ± 7.94 cm, weight: 40.01 ± 7.41 kg) were recruited for the study. The gymnasts performed the free (aerial) walkover forward (Danilova) element on the floor. To record the element for obtaining the three-dimensional kinematic data analysis, gymnasts have been equipped with a multiple sensor suit. Data collection consisted of gathering data simultaneously from all 17 sensors. In order to get accurate data regarding the range of motion in joint angles, motion trackers were positioned on segments, in special locations. *Result**s***: Our data show that during the final phase of the execution of the free (aerial) walkover forward element, all gymnasts presented the extension of the spinal column, at two different moments: i) when the foot comes in contact with the ground, in the landing phase and ii) when lifting the torso in the final stage of the landing phase, respectively. Our results revealed that the second extension is significantly greater than the first one in all gymnasts (maximal spinal extension (M.S.E.): -46.76 ± 2.521) vs. spinal extension at foot contact (S.E.F.C.)-39.32 ± 2.309, $p<0.05$). The data analysis showed that there is no correlation between the S.E.F.C and the length of the Danilova element. The hip joint angle was in moderate positive correlation with the M.S.E. (Pearson r= 0.5808, R^2= 0.3374), but not with the S.E.F.C. (Pearson r= -0.304, R^2= 0.09243). The completion of the element is the result of either mobility of the spine or compensation due to hip extension. The length of the Danilova element was not found to be correlated with neither of the parameters (hip extension S.E.F.C, M.S.E.). A lower degree of mobility of the lumbar area is not an impediment in performing an accurate Danilova element, some gymnasts being able to perform a significantly shorter element (the found length range of the Danilova element within the study group is 0.94- 1.43 m). *Conclusion:* A good performance of free (aerial) walkover forward is possible either in the case of increased mobility at the level of the lumbar spine or, with the help of compensation in the mobility of the hip joint. The secondary spinal extension is presented as a cofactor with an assistance role during the stage of returning to the initial position.

Key words*: kinematics, gymnastics, Danilova spine, hip*

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Rezumat

Introducere: Gimnastica artistică feminină este un sport care a cunoscut o evoluție continuă de-a lungul anilor, atât din punct de vedere tehnic, cât şi din punct de vedere al corectitudinii execuţiilor. Flexibilitatea, rezistența, dexteritatea şi multe alte calități motrice sunt prezente în acest sport. Danilova este un element acrobatic dinamic în gimnastica artistică care poate fi executat atât pe sol, cât şi pe bârnă, fiind un element de dificultate D (0,4 puncte). *Material şi metodă*: Studiul s-a realizat pe un lot de: 13 gimnaste componente ale echipelor olimpice româneşti de junioare şi senioare (vârstă: 14 ± 1,93 ani, înălțime: 149,35 ± 7,94 cm, greutate: 40,01 ± 7,41 kg), care au efectuat elementul Danilova înainte pe sol. Pentru a înregistra elementul în vederea analizei cinematice tridimensionale a datelor, gimnastele au fost echipate cu un costum cu mai mulți senzori. Colectarea datelor a constat în înregistrarea simultană a semnalelor de la toți cei 17 senzori. Pentru a obține date exacte cu privire la intervalul de mişcare, unghiurile articulare, senzorii de mişcare au fost poziționați pe segmente, în poziții bine definite. *Rezultate*: Datele noastre arată că, în faza finală a execuției elementului Danilovă înainte, toate gimnastele au prezentat extensia coloanei vertebrale, în două momente diferite: i) când piciorul vine în contact cu solul, în faza de aterizare şi ii) la ridicarea trunchiului în etapa finală a fazei de aterizare. Rezultatele noastre au arătat că, la toate gimnastele a doua extensie este semnificativ mai mare decât prima (extensia maximă a coloanei vertebrale (MSE): -46,76 ± 2,521 vs. extensia coloanei vertebrale la contactul cu piciorul (SEFC) -39,32 ± 2,309, p <0,05). Analiza datelor a arătat că nu există nicio corelație între S.E.F.C. şi lungimea elementului Danilova. Unghiul articulației şoldului a prezentat o corelație moderată, pozitivă cu M.S.E. (Pearson r = 0,5808, R2 = 0,3374) dar nu şi cu S.E.F.C. (Pearson r = -0,304, R2 = 0,09243). Finalizarea elementului este rezultatul fie al mobilității coloanei vertebrale, fie al compensării datorate extensiei şoldului. Datele noastre au arătat existența unei corelații între lungimea elementului Danilova cu niciunul dintre următorii parametri: extensia şoldului S.E.F.C, M.S.E. Un grad mai mic de mobilitate a zonei lombare nu este un impediment în execuția elementului Danilovă înainte, gimnastele, cu o mobilitate mult mai redusă, putând executa Danilova înainte pe o distanță semnificativ mai mică (intervalul de lungime pentru elementul Danilovă înainte în cadrul grupului de studiu fiind: 0,94 - 1,43 m). *Concluzii:* Realizarea unei Danilove înainte corecte din punct de vedere tehnic este posibilă fie în cazul existenței unei mobilități crescute la nivelul coloanei lombare, fie datorită compensării determinate de modificarea poziției articulației şoldului cu accentuarea extensiei. Extensia secundară a coloanei vertebrale este prezentă ca un cofactor cu rol de asistență în etapa de revenire la poziția inițială.

***Cuvinte cheie**: cinematică, gimnastică, Danilova înainte, coloană, şold*

Introduction

Women's artistic gymnastics is a sport that has experienced an incredible evolution over the years, both from a technical point of view and from the point of view of the correctness of the executions. Gymnastics is a complex sport in which all physical qualities are required. Flexibility, strength, dexterity, and many other motor qualities are present in this sport. Gymnastics is one of the sports in which injuries are frequent and very severe, but not only injuries can take a gymnast out of competitions, but also overwork or wear and tear that occurs after multiple reps. After long repetitions, the state of fatigue appears and, implicitly, overload that can lead to injury.

Gymnastics is a sport which requires a great range of motion in most joints. Flexibility plays a considerable role in the success of a routine. In many cases, the score is directly influenced by the possibilities of a gymnast's 'body motion'. The lack of flexibility in one or more joints may slow down the learning process or make it quite difficult. In fact, it has been demonstrated that gymnasts are the most flexible athletes [1].

Flexibility is an important skill in artistic gymnastics, mainly at the balance beam. Flexibility is the ability of the human body to perform motor acts with a high degree of amplitude [2].

Flexibility is usually defined as the range of motion in a joint or related series of joints such as the spine [1].

Danilova or "free (aerial) walkover forward" is an acrobatic flight element in artistic gymnastics. This element can be executed both on the floor and on balance beam, but most frequently on the beam, being an element of difficulty D (0.4 points).

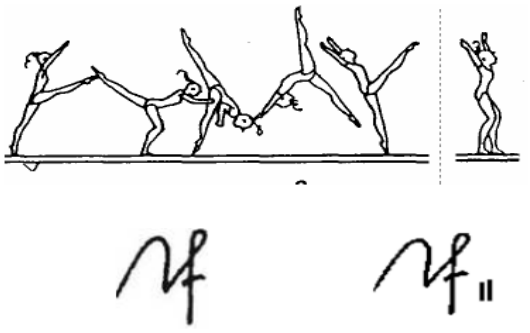

Fig.1 Free (aerial) walkover forward, landing on one or both feet (Code of Points, FIG) [3]

Jump forward on one leg (Danilova). From jumping on one leg (right) with the arms forward, impulse on the left leg. The arms perform an energetic backward balance, simultaneously with the strong release of the right leg stretched back. The position of the body in the air is like a forward turn, the difference being that hands, instead of being placed on the ground, act with great speed backwards. The back in extension is kept tense; also, during the flight, legs are kept apart, perfectly stretched [4].

In this research direction, Silvia Stroescu analyzed the biomechanics of the movement of this element, where the angles required in the following steps were analyzed [11].

In what we intend to analyze, no detailed studies have been done.

Injuries and problems common at the elite level of gymnasts are spondylosis (osteoarthritis of the joints between the center of the spinal vertebrae), vertebral apophyseal compression fractures, and mechanical back pain. Lower back injuries often inhibit performance in the gymnasts training schedule. The lumbar back region in the vertebral column is the most injured mainly because of the loads transmitted by the lumbar spine. In activities such as gymnastics, figure skating and ballet, abnormal stress occurs on the apophyseal joints. Low-back pain can occur at several places in the lumbar spine. Muscles are often the problem while abrupt onset pains occur, irritated by a rapid movement for example. The low-grade chronic type of pain in the lower back is often seen as a consequence of overuse [5].

The purpose of this study was to perform a kinematic analysis of the spine and changes in the hips during free (aerial) walkover forward. Firstly, to reduce the occurrence of pain in the most requested area, namely the lumbar region, and secondly to reduce the risk of falling from the balance beam, because this apparatus measures 10 cm wide, caused by hip rotation.

Material and methods

Participants

13 artistic gymnasts, components of junior and senior Romanian Olympic teams (age: 14± 1,93 years, height: 149.35 ± 7.94 cm, weight: 40.01± 7.41 kg), were recruited for the study. Their training program, at the National Sports College - "Cetate

Deva" has been planned on an average duration of 30 ± 2 hours/week.

On the data collection day, all participants presented a good physical condition with no reported injuries.

All gymnasts performed the analyzed element (Free aerial walkover forward-Danilova) in a miniseries of 3 repetitions and the best execution was chosen according to the code of points in effect [10].

Equipment

The gymnast performed the free (aerial) walkover forward element on the floor. To record the element for obtaining the three-dimensional kinematic data analysis, gymnasts have been equipped with a multiple sensor suit (Xsens MVN BIOMECH (Xsens Technologies BV, Enschede, Netherlands).

In order to accurately track the motion of human body, the multiple sensor suit used a kinematic measurement system consisting of 17 motion trackers, attached to different body segments such as: feet, lower legs, upper legs, pelvis, shoulders, sternum, head, upper arms, fore arms, and hands (Fig 2). The MTw sensors were positioned, using a full body strap set according to the Xsens recommendations [6, 7]. The present study was performed using the Awinda system, i.e. second generation wireless inertial-magnetic motion trackers (MTw) developed by Xsens. The system operates with a 60 Hz output frame rate [8], [10].

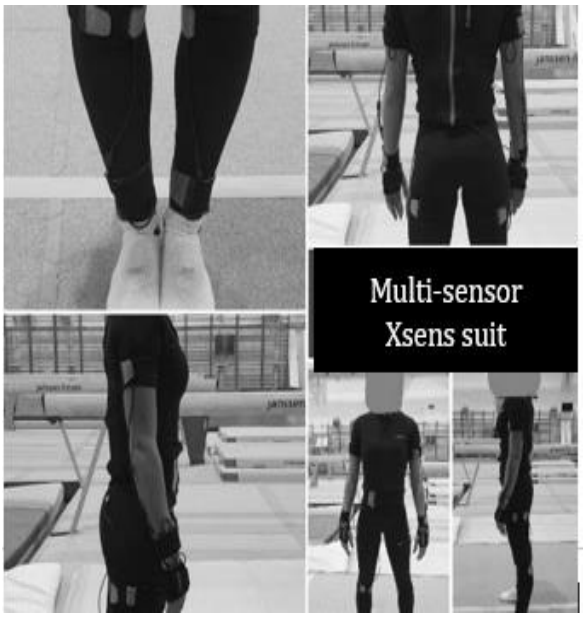

Fig. 2 The subject dressing with the multi-sensorial suit

The International Gymnastics Federation approved the floor surface used within the present study.

The study was performed with the approval of the National Gymnastics Federation, the Board of the technical team of the National Sports College- "Cetate Deva" and Ethical Committee of the Physical Education and Sport Faculty - West University of Timisoara. All the collected personal and experimental data complied with the GDPR legislation [9], [10].

Experimental procedure

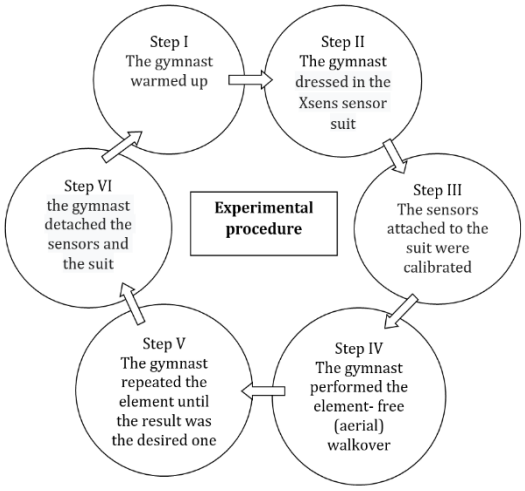

Fig 3 The stages of the experimental procedure

Before the element analysis, the gymnasts participated in a 30-minute general warm-up. When the warm-up period was finished, the gymnasts were randomly chosen for executing the element after they were equipped with the Xsense sensors placed as described above/bellow, and tested. The time interval of 2-3 minutes required to complete the placement of the multisensory system did not affect the gymnasts' warm up.

When the stage was set, the testing regarding sensor-equipment communication was carried out. The calibration of the sensors lasted about 3 minutes and the individual recording of the analyzed element was performed in a 10-minute interval.

To obtain the maximum performance, while one gymnast was tested another gymnast prepared for the test by performing light exercises in order to maintain the warm-up.

Data analysis

Data collection consisted of gathering data simultaneously from all 17 sensors of MVN-Xsens. To get accurate data regarding the range of motion in joint angles, the motion trackers were positioned on segments, in special locations. Therefore, for spinal kinematics, sensors were positioned on the pelvis (flat on sacrum) and on the sternum (flat on the middle of the chest, also identified as the T8 location). For the spine and hip analysis, the following kinematics parameters were extracted:

- spinal joint angle or the angle between T8 (red line in figure 4) and the pelvis (yellow line in figure 4) joint angle during extension of the trunk;
- hip joint angle represented by the joint between the pelvis (red line from fig. 5) and upper leg (green line from pic.5);
- the length of the Danilova element represented by the distance between take-off and landing contacts.

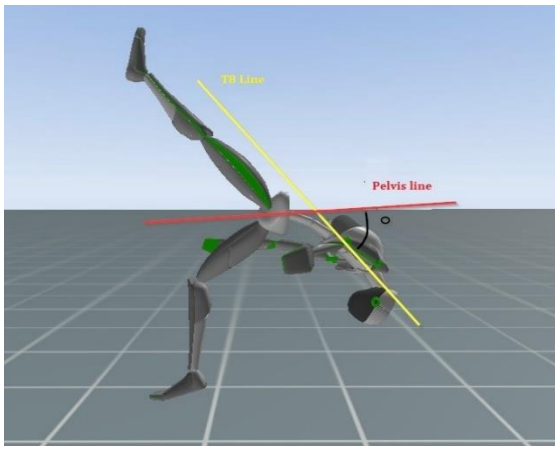

Fig. 4 Angle of the spinal extension

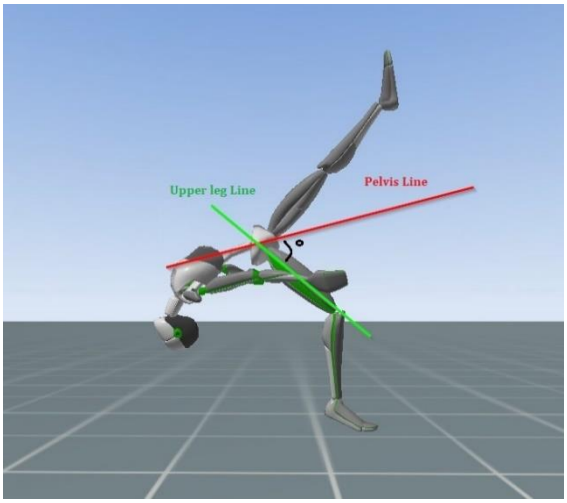

Fig. 5 Hip joint angle

The statistical analysis was performed using statistical tests: Student-*t* test, correlation with determination of the Pearson r coefficient, (GraphPad v. 5.0).

Results

Our data show that during the final phase of the execution of the free (aerial) walkover forward element, all the gymnasts presented an extension of the spinal column, at two different moments (Fig. 6), as follows:

1. An extension when the foot comes in contact with the ground, in the landing phase.
2. An extension when lifting the torso in the final stage of the landing phase (return to the standing position).

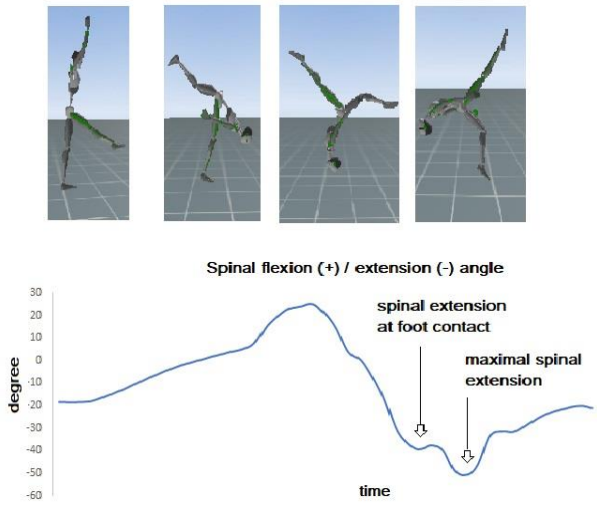

Fig. 6. Spinal joint angle evolution during free (aerial) walkover forward execution

Our results revealed that the second extension is significantly greater than the first one in all gymnasts (maximal spinal extension M.S.E.: -46.76 ± 2.521 vs. spinal extension at foot contact S.E.F.C.-39.32 ± 2.309, $p<0.05$) as depicted in figure 7.

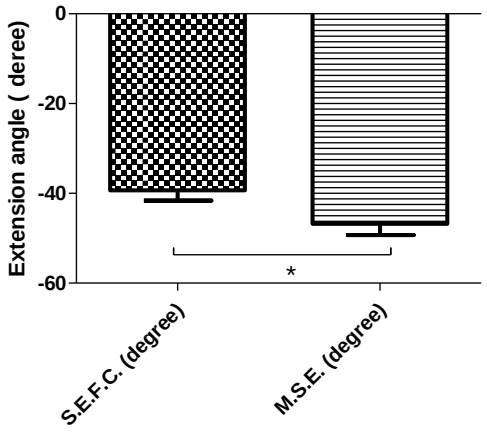

Fig. 7 Spinal extension at foot contact (S.E.F.C.) vs maximal spinal extension (M.S.E.)

The data analysis showed that there is no correlation between the spinal extension at foot contact to the ground and the length of the free (aerial) walkover forward element. Though, a different degree of hip joint angle was found in all gymnasts.

The hip joint angle was in moderate positive correlation (figure 6) with the M.S.E. (Pearson r= 0.5808, R^2= 0.3374), but not with S.F.E.C. (Pearson r= -0.304, R^2= 0.09243).

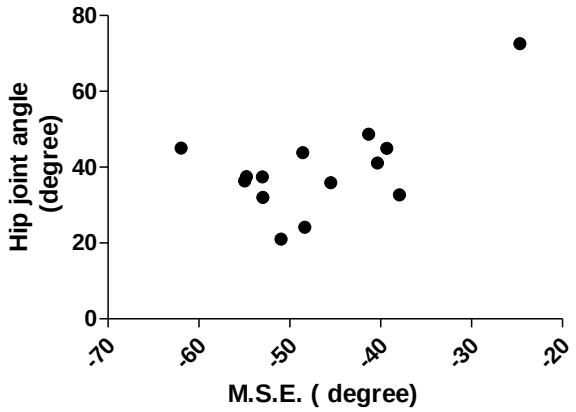

Fig. 8 Correlation maximal spinal extension-hip joint angle

Regarding the execution of the free (aerial) walkover forward element, there is no indication for the analysis of the hip extension in terms of penalty. Our results showed that all the performed (Danilova) elements could be validated. The interesting fact is that the completion of the element is the result of either the mobility of the spine or compensation due to hip extension. The length of the Danilova element was not found to be correlated with neither of the above-mentioned parameters (hip rotation S.F.E.C, M.S.E.).

An interesting example is represented by the subject D. A. who presented the most immobile spine, objectified by a degree of S.E.F.C. of $22,88^0$ which determined a larger hip extension at the moment of foot-ground contact from the beginning of the landing phase, corresponding to a value almost twice as big as the mean value of the analyzed group 72.56^0 vs. $36.98^0 \pm 2.25$. Due to this large hip rotation, the gymnast was able to execute one of the shortest Danilova elements.

From a technical approach point of view, it was observed that a lower degree of mobility of the lumbar area is not an impediment in performing an accurate free (aerial) walkover forward (Danilova) element. Analyzing the length of the element, we found a lower homogeneity of the group (coefficient of variation= 59.84%). Some gymnasts performed a longer Danilova element, in terms of distance between take-off and landing contact, even if the mobility of the spine is good. While other gymnasts, with a much lower mobility, performed a significantly shorter element (the found length range of the Danilova element is 0.94- 1.43 m). For the rest of the parameters the variation coefficient indicated very homogeneous results within the group.

Discussions

The deepening of the analysis showed that in gymnasts with reduced spine mobility, there is an involvement of the hip in the execution, performing an internal rotation with different degrees of rotation.

The free (aerial) walkover forward is a dynamic acrobatic element frequently included in balance beam routines, both as an individual element and in combinations of elements. Regarding the fixed dimension on the beam it is important for the gymnasts to perform the Danilova element as accurately as possible to maintain their balance and, last but not least, the aesthetics of the exercise. Thus, the Danilova element must be short in order to preserve the balance within the performance and also to allow the linkage with the other acrobatic elements.

Analyzing the gymnasts' performances from the Romanian Olympic Team we discovered that an

accurate Danilova can be performed with no influence of some elements that occur in a very well established succession such as flexion from the upsurge phase or spinal extension from the foot ground contact moment, as a measure of mobility.

However, there is a compensatory factor represented by hip extension that occurs in some performances. This rotation helps the less mobile gymnasts to accomplish a good element evaluated in terms of length. The maximum height of the mass center is a parameter that presented an independent behavior in relation to the spinal extension during the free (aerial) walkover forward, this parameter being especially dependant on the height of the gymnasts.

Another interesting fact is that the movement is not cursive, all gymnasts presenting a second extension of the spine that occurs within the final phase of the landing, when the body must be repositioned to an orthostatic position. The role of this secondary spinal extension could be associated with the impulse necessary at the beginning of the return phase of the trunk.

Conclusion

A good performance of the free (aerial) walkover forward is possible either in the case of increased mobility at the level of the lumbar spine or, with the help of compensation in mobility of the hip joint. The secondary spinal extension is presented as a cofactor with an assistance role during the stage of returning to the initial position.

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