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KINEMATIC ANALYSIS OF HIP JOINT MODIFICATIONS IN SWITCH LEAP: COMPENSATORY MECHANISMS DUE TO REDUCED MOBILITY IN THIS AREA

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ABSTRACT. Artistic gymnastics include a series of artistic elements where the joints' mobility represents an essential factor for the accuracy of the execution in both beam and floor routines. The reduced mobility is responsible for the occurrence of compensatory movements. This type of repetitive and long-term compensations can damage the joints involved in execution of an accurate switch leap element. The aim of the study was to analyze the compensatory mechanisms due to reduced mobility in the hip joint that can occur during the execution of a switch leap. 6 female gymnasts (8-10 years) from C.S.S.1 Timisoara have been analyzed when they executed switch leap on the floor. The kinematic analysis was carried using inertial sensors for movement tracking technology. The evaluated parameters were: leg separation angle (LSA), lateral pelvic tilt (LPT) and pelvic rotation (PR). The data revealed a LSA of 137.5± 2.239° which corresponds to the second level of penalty (0.30 points). The compensatory movements were revealed by the level of LPT and pelvic rotation. Depending on the front leg, the compensatory tilt, represented by the elevation of the hip joint, was found on the right or left part accordingly. Regarding the pelvic rotation, this is performed in the backward direction on the same part with the tilt. The kinematic analysis of the switch leap element provides supplementary data that can be taken into consideration by the gymnasts and coaches during the training period in order to reduce the risk of injuries and the risk of falling from the beam.

Keywords: *hip joint modifications, gymnastics, switch leap, compensatory mechanisms, flexibility*

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Introduction

The complexity of the elements of artistic gymnastics requires a technical preparation and artistic mastery at the highest possible level as determinants for a cleanest execution (Vernetta et al., 2022). Biomechanical attributes of the specific movements are the most important determinants of the difficulty of the elements in women artistic gymnastics (Berisha, 2021, Fink &Lopez, 2015; Fink& Hoffmann, 2015). Regarding the artistic elements, as it is the switch leap, besides elegance a great sense of balance, strength coordination and agility are required (Bobo-Arce & Méndez-Rial, 2013; Di Cagno, Battaglia, Fiorilli, Piazza, Giombini, Fagnani & Pigozzi, 2014; Douda, Toubekis, Avloniti & Tomakidis, 2008; Vernetta, Montosa, Beas Jiménez & López-Bedoya, 2017 Miletić, Katić & Males, 2004; Vernetta, Fernández, López-Bedoya, Gómez-Landero & Oña, 2011). Moreover, mobility of a specific joint, which represents the ability to describe active movements through a specific range of motions (Jeffreys, 2016), can be considered to be a form of functional flexibility that is combined with other skills such as strength in order to obtain the maximal performance, (Berisha, 2021) and could refer to it both for a specific joint or as a global characteristic of body segments. Flexibility is an important skill in artistic gymnastics, mainly at the balance beam (Faur, 2014). Artistic gymnastics include a series of artistic elements where the joints' mobility represents an essential factor for the accuracy of the execution in both beam and floor routines. The introduction of different artistic leaps in the routines, that could be presented with a clean execution, represents nowdays a desiderate in order to obtain a higher starting mark, considering that, by comparison, the acrobatic elements have already achieved a superior level of difficulty. However, the artistic elements have to be performed as accurately as possible in order to reduce the risk of injuries. The general hypermobility of the joint, defined as an increased range of motion that exceeds the normal limits for each joint according to age, gender and ethnicity (Seckin et al., 2005) has a cyclic evolution. This is a feature that mainly characterizes early childhood and decreases with age up to 9-12 years so that after this age a new stage of growth can be observed around the age of 15, especially in girls due to hormonal constellation. After this age and especially at the time of reaching maturity, in the case of both genders, a reduction in mobility is observed (Hakim, Grahame, 2003). In artistic gymnastics this aspect could be considered as an advantage (McCormack et al 2003). Regarding the hip joint, excessive mobility can lead to different injuries such as dislocations, soft tissue injuries or painful joints (Seckin et al., 2005; Smith et al., 2005). In gymnastics, the presence of hypermobility is a frequently encountered fact in sportswomen, and although the extreme values of the range of motion at the level of the joints have generated heated discussions between the various categories of specialists, there is still no clear consensus regarding the advantages of this hypermobility, respectively its association with risk of injury (Bukva et al., 2018; Grahame, Bird & Child, 2000; Larson et al, 1993; Decoster et al., 1997). However, the reduced mobility is responsible for the occurrence of compensatory movements, such as lateral tilt and rotation within the hip and lumbar spine joints, which are not normally involved in the execution of the elements.

In women artistic gymnastics the switch leap is an artistic element that can be performed. executed both on the floor and on balance beam, but most frequently on the beam, being an element of difficulty (0.2 points).

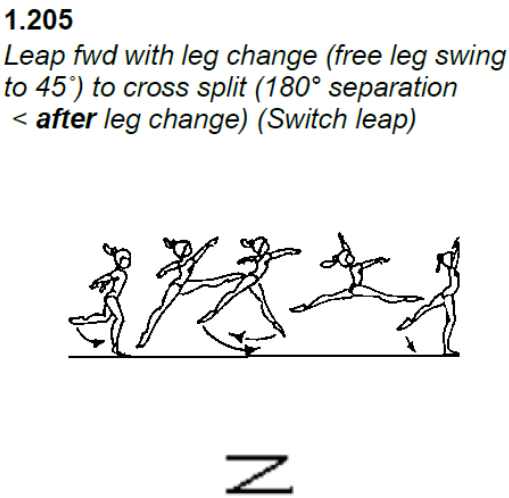


Fig. 1. *Switch leap according to Code of points*

This type of repetitive and long-term compensations can, thus, damage both the joints normally involved in execution of an accurate switch leap element and also in the associated joints that are involved in the compensatory mechanisms. On the floor, usually there are no major consequences determined of these compensatory movements but on the beam there is a cause-effect link between compensatory movements and the falls from the apparatus. Both on floor but mostly on the beam executions the code of points specifies that for missing degrees of leg separation in leaps there are different levels of penalties according to the magnitude of the leg separation angle reduction. The aim of the study was to analyze the compensatory mechanisms due to reduced mobility in the hip joint that can occur during the execution of a switch leap from a kinematic point of view.

Material and methods

The study was carried out on a group of female gymnasts (8-10 years) from C.S.S.1 Timisoara have been analyzed when executed switch leap on the floor.

On the data collection day, all participants presented a good physical condition with no reported injuries. All gymnasts performed the analyzed element (the switch leap) in a miniseries of 3 repetitions (Domokos et al., 2020).

The equipment and experimental procedure The gymnast performed the switch leap 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 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, forearms, and hands as previously described ("Xsens MVN User Manual," Xsens Technologies, 2018, Domokos et al., 2020) (Fig 2a).

Experimental procedure

As previously described (Domokos et al., 2020), 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 inertial multisensory suit, placed as described above/below, 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 (Domokos et al., 2020) (fig 2b).

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 CSS1Timisoara 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 (Domokos et al., 2020).

a) 

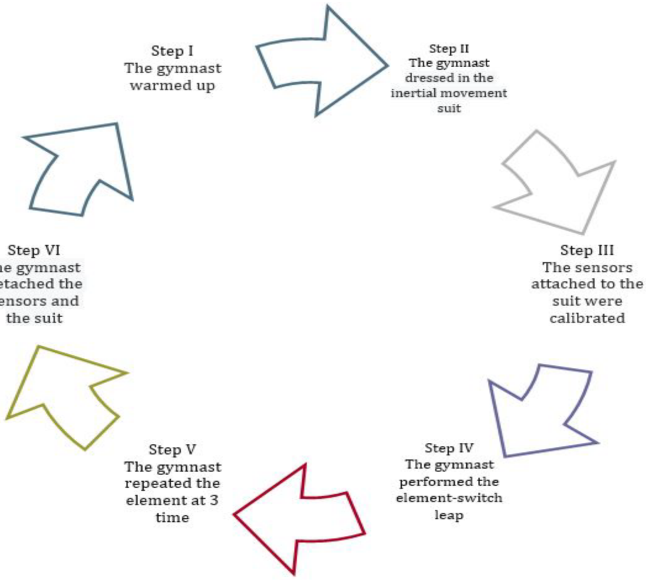
b) 

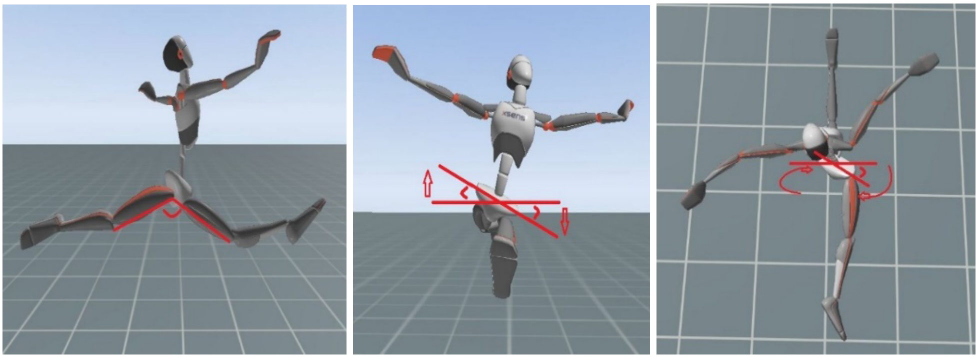
Fig 2. *a) Experimental set up and b) procedure protocol*

Data analysis

Data collection consisted of gathering data simultaneously from all 17 sensors for inertial movement tracking. To get accurate data regarding the range of motion in joint angles, the motion trackers were positioned on segments, in special locations. in order to determine the following parameters: leg separation angle (LSA); lateral pelvic tilt (LPT) and pelvic rotation (PR).

Thus, for the specific kinematic analysis of switch leap executions, the analyzed information were those recorded from the sensors were positioned on specific zones as follows:

- leg separation angle (LSA): angle between split of the legs (fig. 3a).
- lateral pelvic tilt (LPT): degree of lateral deviation (drop/hike) around an anteroposterior axis (fig. 3b).
- pelvic rotation (PR). Degree of pelvic rotation in the transverse plane around vertical axis (fig. 3c).



a) b) c)

Fig. 3. *Graphic representation of the parameters: a) LSA, b) LPT; c) PR*

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

Results

The data are expressed as mean values ± standard error of mean (SEM) or mean values ± standard deviation (SD) and revealed a LSA of 137.5± 2.239° which corresponds to the second level of penalty, according to the Code of Points of 0.2 points. Performing an intragroup analysis we found that for the LSA that only one gymnast (G2) presented a lesser value of the LSA which was significantly ($p < 0.05$) and very significantly ($p < 0.01$) reduced than the majority values within the group (fig.4).

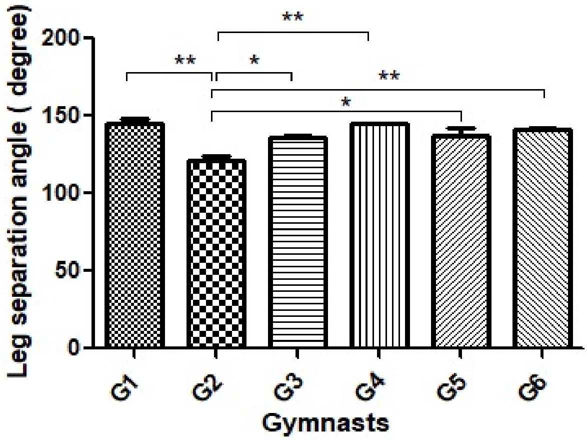


Fig. 4. *The Leg separation angle differences within the group*

When compared to the standard indicated by the Code of points, where the LSA for this element is about 180 °, our results revealed that in all gymnasts there is an extremely significant reduction of LSA ($p < 0.001$). In order to obtain the most accurate estimation, the results have been expressed as percentage from the Control value assumed to be 100%. Analyzing the pool data collected from the study group in comparison to Control expressed as mean value ± SD, the difference between the recorded data indicated a reduction of the LSA with approximately 25% (23.63 ± 5.227% vs 100% in Control) (fig. 5).

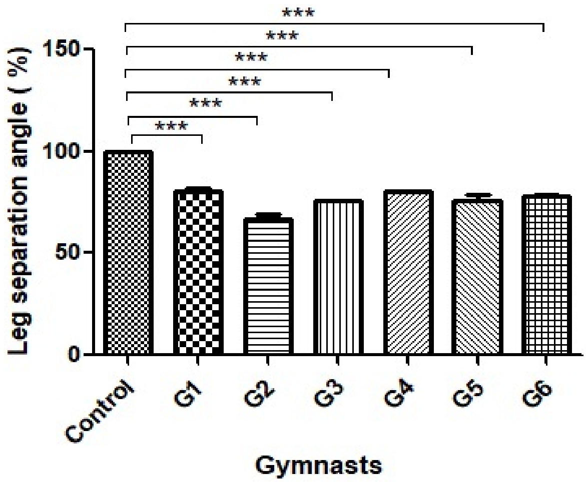


Fig. 5. *The Leg separation angle differences comparing to the standard from Code of points*

The compensatory movements were revealed by the level of LPT and pelvic rotation. Depending on the front leg, the compensatory tilt, represented by the elevation of the hip joint, was found on the right or left part, accordingly. Regarding the pelvic rotation, this is performed in the backward direction on the same part with the tilt. Analyzing the data, we found that 4 out of 6 gymnasts presented a left pelvic tilt associated with right rotation.

When analyzed the pool data regarding the degree of tilt on all executions, we found a mean deviation from the horizontal line of 12.414 ±10.97°. After analysis performed within the studied group (Two Way ANOVA followed by Bonferroni's Multiple Comparison Test) we found a few significant individual differences between the gymnasts as we depicted in fig. 6. In this case the highest tilt was found in gymnast number 4 (G4) which presented a highly significant value of the tilt in comparison with the rest of the group. Analyzing the LSA we found that the degree of this parameter in this subject is the highest one within the group (144.9 ± 0.488°) the next value being about 144.9±5.341°. Moreover, by analyzing the values obtained for all executions performed by G4 we found that this gymnast's performance was the most homogenous in comparison with the rest of the group, a feature that was observed also when analyzed the LPT (fig. 7).

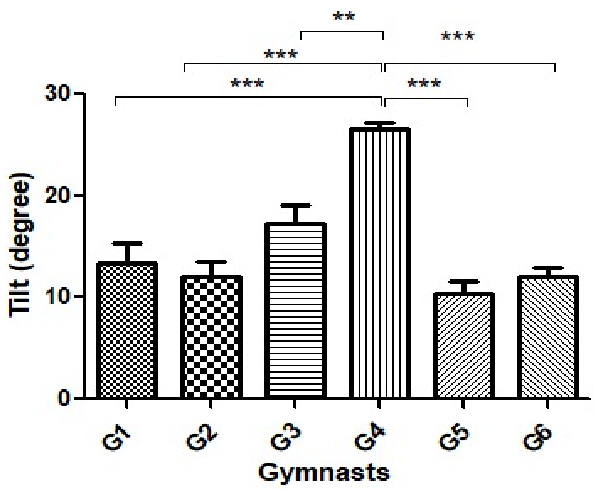


Fig. 6. *The lateral tilt degree differences within the group*

Regarding the pelvic rotation, we found also that G4 presented the highest hip rotation within the group, thus, maintaining the same trend as for the rest of the parameters. In contrast to the other parameters, we also found another gymnast (G5) that presented a significantly higher rotation (p< 0.05

and $p < 0.01$, respectively) than the rest of the group. Comparing the rest of the parameters we found that G5 presented a LSA comparable to the mean value of the group and for the LPT the results revealed even a better result by the fact that this gymnast presented the lowest value within the group suggesting that in her case the compensatory mechanism in order to obtain the larger LSA is represented only by the rotation. In comparison for G4 which presented the highest LSA the compensation was more complex, combining both rotation and the tilt. The rest of the gymnasts presented relatively high LSA without a great value for the other two parameters, suggesting that in their case they present a good flexibility according to the age group.

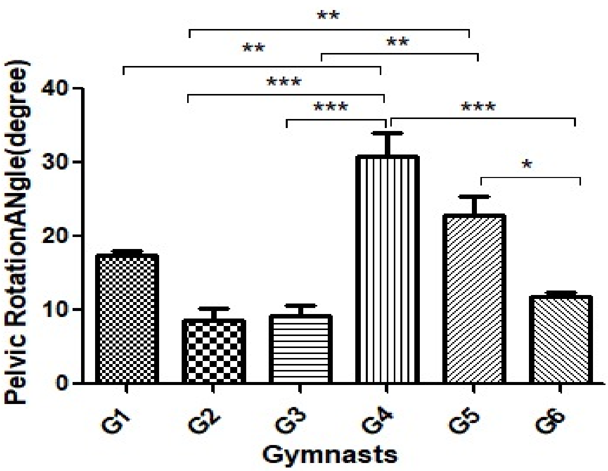


Fig. 7. *The pelvic rotation differences within the group*

By analyzing the correlation between the LSA and the other parameters we found a Spearman r correlation coefficient of 0.6244, indicating a medium positive correlation when correlated to rotation, suggesting that this parameter could be considered a highly significant determinant factor ($p < 0.01$) when analyzing the compensatory mechanism for obtaining a higher leg separation angle result that was not found also in the case of the tilt (Spearman r coefficient – 0.40, p-ns).

Discussions

In women artistic gymnastics, it is a costume for the athletes to try to depeche their physical limits in order to achieve the mastery in their executions (Brugemann, 2005).

During the last decades the evolution of artistic gymnastics increased dramatically in terms of difficulty of the single skills or the entire routines. An important condensation of elements with increased difficulty can be found both in the floor and beam exercises (Fetzer 1997). This was not a sufficient condition in order to obtain the highest scores from the judges. Consequently, the artistic part was developed in order to add value to the routines. For the artistic part of the routines one of the physical skills necessary is represented by flexibility. O'Connell, Posthumus & Collins (2013) characterized the flexibility through the range of motion (ROM) parameter which describes the relative position of two body segments linked by the joint. Thus, angular variables could be used in order to assess the flexibility (López-Bedoya, Vernetta, Robles & Ariza, 2013) in different joints according to the specificity of the element. In the present study several angular variables were used in order to characterize the flexibility of the hip joint in relation to the specific position of the element. In our case, using three different angular variables offered a cumulative set of information that can describe the movement in the hip joint during the switch leap execution which could add value to the visual description found in the Code of points (https://www.gymnastics.sport/site/). The visual description is a bidimensional one and can miss aspects that are important for the evaluation of the element. Thus, the lateral pelvic tilt or rotation could be assessed only on a 360° view in order to be accurate. Our work methodology with inertial sensors provides this kind of view ("Xsens MVN User Manual," Xsens Technologies, 2018) and by using it we were able to describe more detailedly all the changes that occurred during the switch leap executions.

Regarding the compensatory mechanisms, they intervene in order to correct potential deficiencies objectified by the lack of mobility. In the case of switch leap, according to our results we could find that the lateral pelvic tilt and pelvic rotation are responsible for the increasing leg separation angle. The presence of a small tilt or rotation is difficult to be seen by naked eye and this can lead to an over evaluation of the execution. However, the presence of these compensatory mechanisms help the gymnast not to be penalized according to code of points, where it is stipulated that a leg spread angle lesser than 180° is considered insufficient split by the judges (https://www.gymnastics.sport/site/).

Conclusion

The kinematic analysis of the switch leap element provides supplementary data that can be taken into consideration by the gymnasts and coaches during the training period in order to reduce the risk of injuries and the risk of falling from the beam.

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All authors contributed equally.

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