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Original Investigation

Asymmetries in Postural Stability and Balance Parameters during Specific Elements in Sub-Elite Rhythmic Gymnasts

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Purpose: This study aims to investigate the level of lower-limb functional asymmetries in sub-elite rhythmic gymnasts while performing sport-specific elements, including passe and side passe balance stance.
Methods: The analysis focuses on postural stability and balance parameters, measured using Gyko, a 3-axis accelerometer, gyroscope, and magnetometer device. The task was to execute a passe balance and maintain the position for 30 seconds, which was the duration of the test, and then perform the same task with the other leg. The test was repeated for both legs in a side passe balance stance. Sixteen active female sub-elite rhythmic gymnasts participated in the study.
Results: The results reveal significant differences in the mean travel velocity in all anatomical planes during the passe elements, indicating asymmetry in postural stability in favor of the non-dominant leg ($P \leq .01$). Similarly, in the side passe balance test, significant differences were observed in the mediolateral (in favor of the dominant leg) and anteroposterior (in favor of the non-dominant leg) total distances, indicating asymmetry in postural stability ($P = .03$). However, no significant differences were found in other postural stability parameters, the ellipse (EA) and the total length of the trajectory (Len(D)).
Conclusions: Evident asymmetries in movement speed during the passe element and imbalances in weight distribution during the side passe balance test do not appear to compromise overall postural stability considering that asymmetry was not proven in several variables, such as the ellipse or the total length of the trajectory. These findings shed light on the potential impact of asymmetries on performance and injury risk in rhythmic gymnastics, emphasizing the importance of considering sport-specific balance tests.

Keywords: gymnastics, Gyko, asymmetry, passe elements, injury risk.

Introduction

Rhythmic gymnastics (RG) is characterized by aesthetic movements, flexibility, and artistic and competitive components[1]. It is a sport that involves a specific training process, young athletes, early specialization, a high volume of training, repetition, and significant physical and psychological stress during competitions[2]. In accordance with the rules of RG, technical elements such as rotations and balances are performed on tiptoes, which can lead to an overload of the foot joints. Gymnastics is a sport that places an exceptional load on the foot and ankle, more so than any other sport[3]. Rhythmic gymnasts, in particular, must maintain pointed feet throughout their routines and often perform in the "rélevé" position, where they rise on the tips of their toes for a minute and a half.

Quality of foot performance is crucial in gymnastics[4]. The strain placed on the feet, especially the stable foot, is considerable in young gymnasts who are still developing. Research indicates a strong correlation between standing balance on one leg and the severity of footprint grading in children[5], highlighting the impact on foot morphology during balance performances. Anatomically, the ankle joint is meant to be mobile, and RG training enhances dynamic balance ability and the ankle's range of motion. A wide ankle range of motion positively influences dynamic balance[6]. This combination of factors demonstrates how gymnastics demands and improves specific physical attributes, particularly in the feet and ankles. Performing balance exercises on tiptoes in RG can cause foot joint overload and increase the risk of ankle sprains and chronic sports-related injuries in children and adolescents[7,8]. These injuries are commonly reported among elite and sub elite female gymnasts[9].

Besides the importance of technical performance asymmetries in RG[10], which are related to ambidexterity; functional asymmetries are equally important and have been investigated in RG[11]. Furthermore, asymmetries in aesthetic sports like gymnastics may have a negative impact on the performance and increase the risk of injuries, as the preferential use of one of the lower limbs leads to adaptations at morphological, structural and functional levels[12,13]. Juvenile and adult rhythmic gymnasts with extensive training time were shown to have lower limb girth asymmetries due to exercises performed on the preferred side[14]. However, authors[15] investigated anteroposterior and mediolateral center of pressure parameters and found significant differences only between the dominant and non-dominant legs in median frequency parameters. Nevertheless, their research did not utilize sport-specific balance tests and they used a force platform which provides kinetic data.

The passe element in rhythmic gymnastics is a rotation element that showcases the gymnast's technique, flexibility, and control. It involves the athlete lifting one leg, bending at the knee, and placing the foot against the inside of the supporting leg's knee. The gymnast maintains balance and executes various movements while in this position, demonstrating grace and precision. The passe element requires a combination of strength, coordination, and body awareness as the gymnast rotates and transitions smoothly between different positions. It is a fundamental element in rhythmic gymnastics routines, often incorporated with other technical elements to create visually captivating and challenging performances.

The side passe balance element in rhythmic gymnastics is a fundamental skill that highlights the gymnast's balance and control. In this element, the athlete stands on one leg while extending the other leg out to the side, forming a 90-degree angle with the body. Arms are in lateral abduction. In this position, the gymnast extends both arms outwards to the sides, forming a straight line perpendicular to the body. The gymnast maintains a straight and upright posture while engaging their core muscles to stabilize the body. The side passe balance requires precise weight distribution, as well as strength and flexibility in the supporting leg and hip. It showcases the gymnast's ability to maintain equilibrium and poise while executing various movements, such as arm gestures or body rotations. The side passe balance element adds elegance and sophistication to rhythmic gymnastics routines, demonstrating the athlete's technical skill and artistry.

The purpose of studying functional asymmetries as a training indicator in sub-elite rhythmic gymnasts is to understand how these asymmetries impact performance and injury risk. Asymmetries can highlight imbalances that might predispose athletes to injuries and affect their technical execution. By examining these asymmetries through sport-specific balance tests, we can identify potential weaknesses or imbalances that need to be addressed in training. Understanding these asymmetries is essential for developing training programs that mitigate injury risks and enhance performance. Therefore, the aim of this study was to investigate the level of lower-limb functional asymmetries in sub-elite rhythmic gymnasts while performing sport-specific elements, including passe and side passe balance stance. By examining these asymmetries, we can gain insights into their potential impact on performance and injury risk in RG. It is important to conduct this research using sport-specific balance tests to provide a comprehensive understanding of the asymmetries in these particular elements.

Methods

Participants

The study included a sample of 16 active female sub elite rhythmic gymnasts (m_{age}±SD 11.81±1.83 years, m_{weight}±SD 36.94±9.88 kg, m_{height}±SD 149.69±11.66 cm) all from the same rhythmic gymnastics club in Croatia. All participants were competing on a national level and had a training attendance rate of more than 80% over the course of one year and actively participated in numerous competitions. All subjects had a dominant right side of the body/arm/leg. The inclusion criteria for the study were the absence of musculoskeletal injuries and a healthy overall health status, which was determined by the confirmation from the doctor about the completed medical examination. Given that the participants were minors, both the parents and the participants themselves were informed about the research goals and potential risks associated with participation, and their consent was obtained. The research protocol received approval from the local Ethics committee and the study was conducted in accordance with the principles outlined in the Declaration of Helsinki.

Study design and methodology

All measurements were conducted barefoot. The participants were measured before the training, ensuring they were rested and free of any health issues. Since the task was not physically demanding and was easy to perform, it was not necessary to conduct a warm-up before the testing. After the task was explained and demonstrated to them, the Gyko device (Microgate™, Bolzano. Italy) was attached to a special belt and positioned on the T1 vertebra, identified by manual palpation according to the manufacturer's instructions[16]. After device placement, the obtained values of height were entered into the GykoRePower program. The duration of the test itself was 30 seconds per leg. The GykoRePower program selected a movement test with a stabilization time of 1 second, which was not included in the calculation of results. Also, participants had a one trial attempt prior to the performance to get familiarized with the procedure.

Each participant first performed the passe balance with both the left and right leg. The task was to execute a passe balance on a high relevé and maintain this position for 30 seconds, which was the duration of the test, and then perform the same task with the other leg. This was followed by a short break of two minutes. After the break, they performed task 2, which was the side passe balance test, in the same manner. The participant first performed the balance on a high relevé with the right leg and maintained the position for 30 seconds, and then repeated the task with the other leg.

Gyko is a new measuring 3-axis accelerometer, gyroscope, and magnetometer that enables the measurement of accelerations and angular. Its reliability and validity have been demonstrated in several studies[17,18]. The Gyko device has been utilized in various studies to assess balance parameters, including recent research[19,20]. The focus of the analysis was on the following variables that characterize postural stability[21]: the 95% ellipse of confidence is the ellipse that contains approximately 95% of the points of the trajectory (EA) (mm^2), the total length of the trajectory obtained as the sum of the distances from one point to the next (Len(D)) (mm), the mean travel velocity of the trajectory (Vel(D)) (mm/s), the total distance in the medio-lateral direction given as the sum of the absolute distances between two consecutive points in the ML direction (Len(ML)) (mm), the mean travel velocity of the trajectory in medio-lateral direction (Vel(ML)) (mm/s), the total distance in the anteroposterior direction given as the sum of the absolute distances between two consecutive points in the AP direction (Len(AP)) (mm), the mean travel velocity of the trajectory in antero-posterior direction (Vel(AP)) (mm).

Statistical analysis

To this research, Tibco Statistica Enterprise (version 14.0.1.25.) was used. The normality of distribution for all variables was determined using the Shapiro-Wilk test. The data are presented as mean (SD) for variables that were normally distributed, while variables that were not normally distributed are presented as median (25-75th interquartile range). To compare the differences between the left and right passe elements and the side passe balance test, the paired sample t-test was conducted for normally distributed variables, and the Wilcoxon signed-rank test for variables that were not normally distributed. Significance was set up at $P< .05$.

Results

Table 1 presents the basic descriptive statistics for all Gyko variables. As this is the first research attempting to test postural stability during these specific elements, the data provided can serve as a valuable starting point for future studies. Additionally, the data can be considered as reference values for sub-elite

Table 1. Descriptive statistics for all observed variables; results of Shapiro-Wilk test for normality (*P*-value).

Variable	Valid N	M±SD	(MIN-MAX)	*P*
EA_L	16	1155.48*	(832.36-1696.03)*	**.02**
Len_(D)_L	16	142.38±38.73	(98.10-230.79)	.17
Vel (D)_L	16	63.78±14.78	(47.24-99.31)	.07
Len_(ML)_L	16	81.13*	(62.93-88.33)*	**.00**
Vel_(ML)_L	16	32.05*	(28.30-42.58)*	**.01**
Len_(AP)_L	16	95.87±21.85	(58.62-126.42)	.37
Vel_(AP)_L	16	42.88±7.68	(32.00-56.88)	.25
EA_R	16	1406.31*	(952.88-2017.97)*	**.00**
Len_(D)_R	16	147.35*	(119.57-179.91)*	**.02**
Vel (D)_R	16	81.28±26.13	(44.60-153.26)	.05
Len_(ML)_R	16	85.84*	(72.28-95.28)*	**.01**
Vel_(ML)_R	16	46.73±16.89	(27.22-90.73)	.06
Len_(AP)_R	16	110.58±40.54	(56.93-215.96)	.13
Vel_(AP)_R	16	56.420625±18.93	(30.63-105.97)	.17
EA_L_B	16	2576.26±1815.55	(268.80-5521.52)	.13
Len_(D)_L_B	16	1073.70±514.78	(216.98-1815.32)	.22
Len_(ML)_L_B	16	634.41±360.77	(148.18-1244.88)	.18
Len_(AP)_L_B	16	744.37±339.00	(129.83-1320.02)	.43
EA__R_B	16	2300.65±1879.00	(203.38-7422.86)	.06
Len_(D)_R_B	16	1074.52±530.66	(172.15-1873.10)	.48
Len_(ML)_R_B	16	484.32±256.70	(98.20-930.43)	.56
Len_(AP)_R_B	16	860.72±426.77	(113.91-1437.41)	.17

Notes: * denotes using median (25-75th percentile range), L represent left turn or leg, R represent right turn or leg and B represent balance.

rhythmic gymnasts, providing a reference for further research in this area, potentially exploring between-nation differences.

In the analysis of the left and right passe elements, significant differences were found in the mean travel velocity in all anatomical planes (Vel_(D) *P*= .005, Vel_(ML) *P*= .005, and Vel_(AP) *P*= .01), indicating asymmetry in the favor of the right leg. However, no statistically significant differences were observed in postural stability parameters, as shown in Table 2.

In the side passe balance test, significant differences were found in the mediolateral total distance (*P*= .005) (in the favor of the left leg) and the anteroposterior total distance (*P*= .03) (in the favor of the right leg), indicating asymmetry. The results are presented in Table 3. However, no statistically significant differences were observed in other postural stability parameters, the ellipse (EA) and the total length of the trajectory (Len(D)).

Table 2. Differences between left and right passe.

Pair of Variables	Valid	*P*-value
EA_L & EA_R	16	.30$^{\#}$
Len_(D)_L & Len_(D)_R	16	.12$^{\#}$
Vel_(D)_L & Vel_(D)_R	16	.00*$^{\#}$
Len_(ML)_L & Len_(ML)_R	16	.16$^{\#}$
Vel_(ML)_L & Vel_(ML)_R	16	.00*$^{\#}$
Len_(AP)_L & Len_(AP)_R	16	.16
Vel_(AP)_L & Vel_(AP)_R	16	.01*

Legend: * - significant differences, $^{\#}$ - Wilcoxon signed rank test

Discussion

The findings of this study highlight the importance of considering asymmetries in postural stability and weight distribution during specific elements in rhythmic gymnastics. The performance of balance exercises on tiptoes in rhythmic gymnastics can lead to foot joint overload and increase the risk of ankle sprains and chronic sports-related injuries in children and adolescents[7,8]. These injuries are commonly reported among elite and sub elite female gymnasts[9]. The repetitive nature of these movements, such as those performed in the passe and side passe balance elements, can contribute to these imbalances and potential injury

Table 3. Differences in Side passe balance test between left and right side.

Pair of Variables	Valid	*P*-value
EA_L_B & EA_R_B	16	.24
Len_(D)_L_B & Len_(D)_R_B	16	.98
Len_(ML)_L_B & Len_(ML)_R_B	16	.00*
Len_(AP)_L_B & Len (AP)_D_B	16	.03*

Legend: * - significant differences

risks.

The asymmetries observed in the study align with previous research that has reported functional and limb girth asymmetries in rhythmic gymnasts. Authors[11] found functional asymmetries between the feet of rhythmic gymnasts, while other[14] observed lower limb girth asymmetries in juvenile and adult rhythmic gymnasts with extensive training time. These asymmetries can have a negative impact on performance and increase the risk of injuries as the preferential use of one of the lower limbs leads to adaptations at morphological, structural and functional levels[12,13].

The analysis of the left and right passe elements in our study revealed significant differences in mean travel velocity across all anatomical planes, highlighting an asymmetry in movement speed. This suggests that gymnasts may inherently favor one side, leading to potential disparities in performance. Higher velocity, and therefore, less stability (as the subject is moving more rapidly to maintain balance) was observed for the passe done on the right leg. Although it may seem strange at first, because the assumption is that the subjects will have greater stability on the dominant leg, it makes sense because gymnasts do not use their dominant leg as the standing leg, but rather as the swinging leg. Therefore, as right-handed individuals, their better leg for passe balance is the left leg. Further, these asymmetries in movement speed could be due to a variety of factors including neuromuscular imbalances or preferential training patterns, which align with findings from other research indicating that even elite athletes often exhibit asymmetrical movement patterns due to sport-specific demands and individual training histories[22].

Interestingly, despite the observed asymmetries in movement speed, there were no statistically significant differences in postural stability parameters between the left and right sides. This indicates that the gymnasts were able to maintain overall postural stability on both legs even with differing movement velocities. This aligns with the literature suggesting that athletes can compensate for movement asymmetries to maintain stability, often through enhanced neuromuscular control and adaptive strategies[23].

In the side passe balance test, significant differences were found in the mediolateral and anteroposterior total distance, indicating asymmetry in movement control. However, more control in the mediolateral total distance was observed for the right leg (the swinging leg), and more control in the anteroposterior total distance was observed for the left leg (the standing leg). Like in the passe balance test, it seems that the left leg provided more anteroposterior stability in the side passe balance test as well. These imbalances can affect stability, particularly in a sport like gymnastics that demands high precision and control. Similar findings have been reported in studies of postural stability, where asymmetrical weight distribution was associated with increased postural sway and reduced stability[24]. In addition to reduced stability, potentially even more important is that this asymmetry can lead to pain and injuries. Authors[25] suggest that the nondominant leg showed greater cortical bone mineral density than the dominant leg which is used for mobility or manipulation whereas the non-dominant leg lends support during the actions of the dominant leg, which is consistent to our results as well. Further, the Achilles tendon of the dominant leg featured a significant higher length but a tendency toward lower maximum strain compared with the non-dominant leg[26]. So, leg dominance does lead to functional changes in certain body regions (such as bone density or Achilles tendon length) and it could be an important factor of injury incidence, however, this needs to be confirmed in future research.

The implications of these findings are significant for coaches and trainers, who should be aware of these imbalances and incorporate targeted interventions to improve balance and reduce the risk of injury. This might include specialized balance training and neuromuscular exercises designed to enhance symmetry in movement and weight distribution, while using bilateral instead of unilateral exercises daily. Research suggests that improving core and postural stability through specific exercises can mitigate the effects of asymmetry and enhance overall performance[27,28]. Further research is needed to explore the long-term effects of these asymmetries on performance outcomes and injury risk in gymnasts. Longitudinal studies could provide deeper insights into how these imbalances develop over time and the most effective methods for correction. Additionally, investigating the underlying causes of these asymmetries, such as muscle imbalances or biomechanical differences, could inform more targeted training and rehabilitation protocols. One of those causes could also be a postural problem, since postural assessment is very important in the development of balance[27].

It is important to note that this study had some limitations. The sample size was relatively small, consisting of 16 active female sub-elite rhythmic gymnasts. Therefore, the generalizability of the findings may be limited. Future research with larger and more diverse samples would provide a more comprehensive understanding of asymmetries in postural stability in rhythmic gymnastics.

Practical applications and Conclusions

Current study highlights the importance of recognizing and addressing functional asymmetries in rhythmic gymnasts to enhance performance and reduce injury risks. The significant differences observed in movement speed and weight distribution during the passe, and side passe balance elements underscore the need for targeted interventions.

Key conclusions from this study include:

- Significant differences in mean travel velocity between the left and right passe elements suggest an inherent side preference in gymnasts. This asymmetry, if unaddressed, may lead to imbalances that affect overall performance and increase the risk of injuries.
- The side passe balance test revealed significant asymmetries in the mediolateral and anteroposterior total distance. These imbalances can impact stability and control, crucial for the precision required in rhythmic gymnastics.
- Despite the observed asymmetries, gymnasts were able to maintain overall postural stability, indicating that they can compensate for these imbalances. However, reliance on compensatory mechanisms may not be sustainable long-term and could lead to overuse injuries.
- Addressing these asymmetries through specialized training programs is essential for optimizing performance and preventing injuries. Focused interventions can help gymnasts develop more balanced movement patterns and enhance their overall stability and control.

Further research with larger and more diverse samples is necessary to confirm these findings and explore the underlying causes of asymmetries. Longitudinal studies could provide deeper insights into how these imbalances develop over time, in what way they influence injury incidence, and maybe assess postural balance on a stabilometric platform to get valuable kinetic results with higher accuracy.

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The authors have no conflicts of interest to declare.

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Author-s contribution

Conceptualization, I.M. and M.M.; methodology, M.M.; software, I.M.; validation, A.K.; formal analysis, M.M.; investigation, I.M.; resources, I.M.; data curation, A.K.; writing—original draft preparation, I.M. and M.M.; writing—review and editing, A.K.; visualization, I.M.; supervision, A.K.; project administration, I.M. and M.M. All authors have read and agreed to the published version of the manuscript.

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