IS THERE ANY EFFECT OF THE SEVERITY OF FLEXIBLE PES PLANUS ON THE BALANCE PERFORMANCE IN ELITE GYMNASTS?

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Abstract

Flexibility is an important component of athleticism in gymnasts' training, as its insufficient development can significantly complicate the process of formation of specific skills and movement coordination and limit the possibility of manifesting and increasing strength and speed abilities (Дейнеко & Біленька, 2021). The aim of this study was to analyse the impact of the severity of FPP on balance performance in different planes (frontal, sagittal and overall balance) in the Turkish national youth team. This study is a prospective and double-blinded cohort study conducted in the Department of Physiotherapy and Rehabilitation of Bolu Abant Izzet Baysal University. The evaluation protocol consists of two main phases: first, the measurement of joint positions or angles (subtalar joint position, subtalar joint angle, first metatarsophalangeal (MTP) extension angle and tibia-femoral angle measurement), second, the measurement of balance. 20 participants aged 13-18 years, male and female, from the Turkish national youth gymnastics team were included in this study. Linear regression analysis was performed to determine whether there is an effect of severity of FPP on balance performance. There is no clear effect of FPP severity on balance performance in youth gymnastics at the national level. However, some evaluations show significant associations in the frontal plane in relation to the mediolateral stability index. None of the assessments showed a significant association with the anteroposterior stability index.

Keywords: *elite gymnasts, pes planus, balance performance.*

INTRODUCTION

Gymnastics has been accepted as a framework for many different disciplines since ancient times. It is a professional, popular and attractive sport. The International Gymnastics Federation has classified gymnastics into 8 categories: rhythmic, artistic, acrobatic, aerobic, trampoline, group gymnastics, parkour and tumbling (FIG, 2023). Optimal performance in gymnastics is associated with many factors such as sensory-motor, physiological and balance (Ahmadabadi, Avandi, & Aminian-Far, 2015). Balance is one of the crucial factors because it is related to the level of flexibility, reaction time, motion control, injury rate and the number of falls (Cottyn, De Clercq, Pannier, Crombez, & Lenoir, 2006; Wrisley & Whitney, 2004). According to the definition, balance is 'the ability to retain equilibrium by positioning the gravity center over the support base (Browne & O'Hare, 2001). Single leg stance tests are frequently used both for testing and training balance in sports medicine (Riemann & Davies, 2013).

Since the lack of balance control is related to an increased risk of injury or falling (Wrisley & Whitney, 2004), the prophylactic programs or rehabilitation protocols should be maintained to enhance postural balance (Cobb, Tis, Johnson, & Higbie, 2004). It is clear that changes in foot posture such as pes planus, cavus, or rectus, may affect human balance in all axes, such as the sagittal plane (anteroposterior), frontal plane (mediolateral) or overall balance (Hertel, Gay, & Denegar, 2002; Park, Lee, & Park, 2021). Most published studies have demonstrated that pes planus or cavus is associated with less postural balance when compared to pes rectus (Cote, Brunet, Gansneder, & Shultz, 2005; Kabak, Kocahan, Akinoglu, Genc, & Hasanoglu, 2019; L.-C. Tsai, Yu, Mercer, & Gross, 2006). According to Cobb et al. (2004), pes planus showed reduced postural balance in anteroposterior direction compared to pes rectus.

Pes planus is a common condition for both children and adults. An epidemiological study on 825.964 adolescents showed a high prevalence of pes planus with 12.4% mild pes planus and 3.8% severe pes planus (Tenenbaum et al., 2013; Yucesan et al., 1993). Another study on 19.750 children, between 6-15, demonstrated the prevalence of flexible pes planus (FPP) as 0.23% (Yucesan et al., 1993). Pes planus is a general term that consists of various definitions and may be classified into two forms: rigid and flexible (Dars, Uden, Banwell, & Kumar, 2018). First, pes planus is related to forefoot supination with hell eversion or pronation (Ferciot, 1972). Second, Staheli (Staheli, Chew, & Corbett, 1987) describe pes planus as a wide base foot contact. Third, pes planus is associated with the lack of longitudinal arch or the abnormally collapsed longitudinal arch in the foot (Forriol & Pascual, 1990). If the longitudinal arch on the foot changes during weight-bearing compared to non-weight bearing, it can be considered as flexible pes planus (Roth, Roth, Jotanovic, & Madarevic, 2013). The difference in foot posture between weight-bearing and non-weight-bearing in FPP is rearfoot eversion (Kothari, Dixon, Stebbins, Zavatsky, & Theologis, 2015). If the rearfoot shows the same rearfoot eversion during both weight-bearing and non-weight-bearing, it can be called rigid pes planus (RPP) (Evans, 2008). The RPP accounts for only 1% of total pes planus cases (Evans, 2008). There is no gold standard diagnostic technique for FPP (Stavlas, Grivas, Michas, Vasiliadis, & Polyzois, 2005). For the diagnose of FPP, the heel position (varus/valgus), rearfoot angle, arch formation and navicular height may be evaluated during weight-bearing and non-weight-bearing (Dars et al., 2018). The combination of some assessments and the analysis of foot postures may be performed to reach high accuracy in RPP diagnosis (Evans, 2008). Many treatment options have been proposed for FPP in both childhood and adulthood. Some clinicians prefer not to administer any treatment because they claim asymptomatic pes planus does not reduce sports performance and motor ability (Pfeiffer, Kotz, Ledl, Hauser, & Sluga, 2006; Tudor, Ruzic, Sestan, Sirola, & Prpić, 2009). However, others suggest that FPP may cause abnormal gait, pain, poor balance and motor dysfunction (Harris et al., 2004; Rome, Ashford, & Evans, 2010). Many studirs have shown reduced FPP after implementing interventions such as stretching and strengthening exercise,s foot orthosis, joint manipulations and activity modification (Halabchi, Mazaheri, Mirshahi, & Abbasian, 2013; Harris et al., 2004). It is clear that many studies have focused on the relationship between pes planus and balance performance (Cote et al., 2005; Hertel et al., 2002; Kabak et al., 2019; Park et al., 2021; L. C. Tsai, Yu, Mercer, & Gross, 2006). However, there is limited knowledge regarding the effect of FPP degree on balance performance. This study aims to analyze the impact of FPP severity on balance performance in different planes (frontal, sagittal, and overall balance) in Turkish National Team Juinors Gymnastics. It is hypothesized that gymnasts with higher FPP severity may exhibit lower balance performance.

METHODS

This prospective cohort study was carried out at the Bolu Abant Izzet Baysal University Physiotherapy and Rehabilitation Department. Participants, both females and males, aged between 13-18, from the Turkish National Team Junior Gymnastics. were recruited for this study. All volunteer participants' parents/guardians or coaches were informed about the study and signed consent forms. This study was conducted with a double-blinded design, ensuring that both the examiner physiotherapist and the participants were not aware of its aim. This study was approved by the Bolu Abant Izzet Baysal University Research Ethics Committee. Participants were included if they met the following criteria (1) aged between 13-18, (2) uninterrupted training for at least 4 years, (3) having 1- or 2-degree pes planus (4), not having rigid pes planus (5), not having any pathological disease related to the foot, ankle, knee or hip, and (6) competing at the National Team Gymnastics level.

The measurements were executed in the following order: Feiss line test, body measurements (Tanita TBF-310), joints position or angle measurements, and balance measurements (The Biodex Balance System).

To assess whether the participants had 1- or 2- degree pes planus, the Feiss line test was conducted. A physiotherapist was trained to perform this test. The physiotherapist drew a line between the first metatarsal head and the medial malleolus, and this line was compared with the position of the navicular head on the medial side. The gap between the line and the navicular head divided into 3 equal gaps, determining first, second or third grades pes planus or pes cavus. This test was repeated in sitting and standing positions to ensure the absence of RPP (navicular drop test).

The evaluation protocol was explained to the participants at the beginning. The evaluation protocol consisted of two main stages: first the joints positions or angle measurements (subtalar joint position, subtalar joint angle, first metatarsophalangeal (MTP) extension angle and tibia-femoral angle measurement), second, balance measurement. Each evaluation test was performed by the same examiners.

1. *Joints positions or angles*

measurements

a. Subtalar joint position measurement

This measurement was conducted both during prone and standing on a podoscope for both legs. For this measurement, the subtalar joint center was determined as the pivot, and then the position between the calcaneus center and Achilles tendon was recorded in terms of varus or valgus with a goniometer. The difference between standing and prone positions was determined as the FPP degree. This measurement was modified from the navicular drop test.

b. Subtalar joint angle measurement

When the gymnast was in the prone position, the first examiner was asked to do ankle active inversion and eversion, and the active range of motion (ROM) was measured with a goniometer. Then, the second examiner performed passive inversion and eversion, and these ROMs were also recorded. For inversion or eversion, the subtalar joint posterior aspect at the malleoli level was determined as the pivot, and then the angle between a line passing from the lower foot and a line bisecting calcaneus was measured. All ROMs for both feet were recorded in terms of degrees.

c. First metatarsophalangeal extension angle measurement

When the participant was standing, the first examiner was asked to perform MTP active extension, and then the examiner measured and recorded it with a goniometer. Then, the second examiner made passive MTP extension, and it was measured and recorded for both feet. For the first MTP extension, the MTP joint center was determined as the pivot, and then the angle between the metatarsal midline and phalanx midline was measured.

d. Tibia-femoral angle extension

This measurement was conducted both during the supine and standing position for both legs. For this measurement, the patella center was determined as the pivot, and then the angle between the femur midline and tibia midline was recorded with a goniometer.

***2.** Dynamic balance measurement*

Balance measurement was performed using The Biodex Balance System (Biodex Medical Systems Inc, Shirley, New York). The Biodex Balance System has been developed for assessment, treatment and training during both dynamic and static motions. Initially, the examiner demonstrated the Biodex Balance System to the participants, and the participants were given enough time to warm-up and train on the System. Single-leg stance tests on both legs and double-leg stance tests were performed while the participants had both eyes first open, and then closed. The system's degree of mobility was set at 1 (the highest mobility level) during closed and opened eyes in the sagittal plane (anteroposterior), frontal plane (mediolateral), or overall balance. All tests were repeated 3 times, and the best score was recorded.

Linear regression analysis was performed to determine whether there is an effect of FPP severity. The regression analyses were between the mediolateral stability index and the following variables: subtalar joint position, subtalar joint angle, and tibia-femoral angle. Additionally, regression analysis was performed between the anteroposterior stability index and the first metatarsophalangeal extension angle. Moreover, analyses between the overall stability index and all joints' positions or angles measurements were conducted. Statistical analyses were performed using SPSS (Version 26, IBM Corporation, Armonk, NY, USA). The level of significance (p-value) was set at <0.05.

RESULTS

Demographic information including sex, education level and the gymnastic specialization is shown in Table 1. Physical information, including age, height, mass, year in gymnastic, continuous year sin gymnastic, number of trainings, and Tanita information, is presented in Table 2. Table 3 displays the minimum (min), maximum (max), mean, and standard deviation (SD) of evaluated results, including subtalar joint position, subtalar joint inversion angle, subtalar joint eversion angle, MTP extension angle and tibia-femoral angle. Table 4 presents the measurements of overall, anteroposterior and mediolateral stability index in dynamic measurements

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Table 1: Demographic information including sex, education level and special area

		n	%
Sex	Female	10	50
	Male	10	50
Education level	University	1	5
	High school	15	75
	Secondary school	4	20
Gymnastics category	Artistic gymnastics	16	80
	Trampoline gymnastics	4	20

n: Number of Participants, **%:** Percentage of Participants

Table 2: Physical information including age, height, mass, year in gymnastic, continuous years of training gymnastics, number of trainings, and Tanita information.

	Mean	SD
Age (year)	15.75	1.77
Height (cm)	159.60	14.11
Mass (kg)	76.20	11.23
Training history in gymnastics	9.10	2.12
Years in gymnastic (continuous)	9.05	2.16
Number of training sessions per week	7.80	2.04
BMI	19.60	2.34
Fat (%)	13.34	5.35
Minerals (%)	4.47	0.27
Protein (%)	18.78	1.22
Muscle Mass (kg)	40.58	9.54

SD: Standard Deviation **BMI:** Body Mass Index

	n	Min.	Max.	Mean	SD

Right Subtalar Joint Position	20	12.00	26.00	19.35	4.48
Left Subtalar Joint Position	20	5.00	26.00	16.00	5.60
Right Subtalar Joint Inversion Angle	20	0.00	25.00	8.25	7.44
Left Subtalar Joint Inversion Angle	20	-5.00	19.00	6.90	6.78
Right Subtalar Joint Eversion Angle	20	0.00	20.00	4.90	5.97
Sol Subtalar Joint Eversion Angle	20	0.00	19.00	7.45	6.57
Right MTP Extension Angle	20	10.00	35.00	21.35	7.04
Left MTP Extension Angle	20	11.00	31.00	19.65	5.41
Right Tibiofemoral Angle	20	-7.50	7.60	0.94	3.95
Left Tibiofemoral Angle	20	-5.70	8.00	1.00	3.69

Table 3: The results of evaluated joint measurements.

n: The Number of Participants, **Min**: Minimum, **Max**: Maximum, **SD**: Standard Deviation

Table 4: The measurements of overall, anteroposterior, and mediolateral stability index.

	n	**Min.**	**Max.**	**Mean**	**SD**
Right Overall Stability Index	20	1.10	17.10	5.20	4.75
Left Overall Stability Index	20	0.60	12.30	5.23	3.46
Right Anteroposterior Stability Index	20	0.60	7.50	2.74	2.06
Left Anteroposterior Stability Index	20	0.50	6.40	2.72	1.84
Right Mediolateral Stability Index	20	0.70	14.70	3.87	4.15
Left Mediolateral Stability Index	20	0.30	9.80	3.93	2.86

n: The Number of Participants, **Min**: Minimum, **Max**: Maximum, **SD**: Standard Deviation

Table 5: The statistical analysis of linear regression between joint angle positions and stability indexes.

	Right Overall S. I.	Left Overall S. I.	Right AP S. I.	Left AP S. I.	Right ML S. I.	Left ML S. I.
Right Sub. J. P.	p=0,73				p=0.65	
Left Sub. J. P.		p=0.21				p=0.28
Right Sub. J. Inv. A.	p=0.16				p=0.11	
Left Sub. J. Inv. A.		**p=0.01***				**p=0.01***
Right Sub. J. Ev. A.	p=0.57				p=0.20	
Left Sub. J. Ev. A.		p=0.10				**p=0.05***
Right MTP Ex. A.	p=0.60		p=0.56			
Left MTP Ex. A.		p=0.64		p=0.59		
Right TF. A.	p=0.09				p=0.09	
Left TF. A.		P=0.05				**p=0.03***

J.P: Joint Position, **Inv:** Inversion, **Ex:** Extension, **A:** Angle, **MTP:** Metatarsophalangeal, **TF:** Tibiofemoral, **S.I:** Stability Index, **AP:** Anteroposterior, **ML:** Mediolateral, * = $p < 0.05$.

A regression analysis between the balance measurements and the measured joint positions and angles is presented in Table 5. Both right and left subtalar joint positions did not exhibit any significant associations with their related stability indexes. Similarly, both right and left MTP angles did not show any significant relations with anteroposterior stability. However, significant relationships were observed between left mediolateral stability and certain assessments, such as left subtalar joint inversion (p=0.015), left subtalar joint eversion (p=0.05), and left tibiofemoral angle (p=0.039). Notably, the left subtalar joint eversion angle had a significant impact on overall left stability (p=0.019)

DISCUSSION

The study found that there is no significant relationship between the severity of FPP and balance in Turkish National Team junior gymnasts. As a result, the initial hypothesis suggesting a negative impact of FPP severity on balance stability was rejected. The findings highlight that FPP severity may not be the sole determinant affecting balance. Previous research has indicated that individuals with abnormal foot posture, such as pes planus, tend to exhibit compromised balance ability (Hertel et al., 2002; Park et al., 2021). However, these studies have not specifically delved into the impact of the severity of abnormal foot postures. It is noteworthy that flexibility in pes planus may manifest as a lack of apparent rearfoot eversion during non-weightbearing, with clear rearfoot eversion evident when transitioning to weightbearing conditions (Kothari et al., 2015). This study provides a comprehensive evaluation, considering motion changes from prone or supine to standing, and distinguishing between active and passive ranges of motion (ROMs). By recruiting exclusively gymnasts with FPP, the research focused on understanding the flexibility grade of pes planus. Despite the absence of clear associations between the subtalar joint and balance, the study revealed notable relations between left foot mediolateral stability and subtalar eversion, inversion, and tibiofemoral angle. Previous studies have indicated a connection between abnormal subtalar joint, particularly eversion, and FPP attributed to a lowered medial longitudinal arch (Ledoux & Hillstrom, 2002; Sinclair, Svantesson, Sjöström, & Alricsson, 2017; Zaret & Myerson, 2003). The findings of this study suggest that the relationship between the subtalar joint and balance may be more dependent on the subtalar joint's passive angle rather than its position.

Balance in gymnastics is associated with several determinants such as muscle strength, flexibility, reaction time, core stability, endurance, agility, and velocity (Ahmadabadi et al., 2015; Kabak et al., 2019; Pollock, Durward, Rowe, & Paul, 2000; Russo et al., 2021). Apparently, the severity of FPP or subtalar joint position represents just one element within the broader framework of factors contributing to balance. When analyzing balance performance in gymnastics, it can be more meaningful to take into consideration some of the previously mentioned determinants.

The mention of high joint range of motions and low body fat percentage among National Team Gymnasts raises intriguing considerations. The correlation between these factors and the observed high level of FPP, especially the substantial difference in subtalar joint positions between prone and standing positions, adds depth to the analysis. Furthermore, the gymnasts' ability to perform well when falling from significant heights onto one leg suggests a potential relationship between this performance and the high level of FPP. The notion of compensation by high muscle contraction and strength adds an interesting layer to understanding the complex interplay of factors influencing gymnastic balance.

Single-leg stand on a dynamic surface is not a difficult evaluation method for gymnasts. It can be safely assumed that gymnasts from the National Team would exhibit significantly better balance performance when compared to healthy sedentary peers. Maybe, a more complex analysis method should be used for further studies. However, the Biodex Balance System is a reliable and objective assessment method for athletes, capable to assess in different planes (sagittal, frontal and overall) (Dabbs, Sauls, Zayer, & Chander, 2017). Integrating data on muscle strength could potentially unveil additional insights into the intricate dynamics of balance in gymnasts.

For this study, 20 junior gymnasts on the national level were recruited. The sample size may be too small. However, it was a deliberate choice to recruit only national-level gymnasts. Further studies focusing on multiple centers may counterbalance the small size and provide more meaningful results.

CONCLUSION

There is no clear impact of the FPP severity on balance performance among national-level junior gymnasts. However, some analyses show significant relations on the frontal plane (mediolateral stability index). There is no significant association with the anteroposterior stability index. These findings provide a better understanding of the relationship between the severity of FPP and balance. Future studies should employ more complex assessment tools for both FPP and balance assessments and recruit a larger national-level sample size.

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