ORIGINAL ARTICLE

The impact of pilates mat training on flexibility and core strength in young female volleyball players

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ABSTRACT

The Pilates method consists of a series of exercises designed to stretch and strengthen muscles, thereby improving muscle elasticity and joint mobility. This study aims to evaluate the influence of Pilates on the spine, lower limbs, and abdominal strength using specific tests. Forty young female volleyball players from University Sports Center of Campobasso were equally randomized into two groups: the Pilates group and the control group. The Pilates group underwent a 32-week biweekly training program (from October 2022 to May 2023) in addition to their regular athletic training. All athletes participated in the following tests: Modified Schober Test (MST) for flexion and trunk rotation, Modified Fingertip-To-Floor Test (MFTFT), Straight Leg Raise (SLR), Popliteal Angle (PA), and Half Sit-Up (HSU). In the Pilates group, the results from the MST for flexion and trunk rotation, SLR, PA, and HSU showed statistically significant improvements 32 weeks after the start of the training protocol ($p < .05$). However, no significant changes were observed in the control group. Additionally, both groups demonstrated significant improvements in MFTFT. These findings suggest that Pilates training can be an effective method to enhance flexibility and performance in young female volleyball players. Coaches should consider incorporating Pilates into their programs.

Keywords: Performance analysis, Flexibility, Pilates method, Trunk rotation, Trunk flexion, Volleyball players.

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INTRODUCTION

Improving sports performance requires a multifaceted approach, combining physical training with psychological interventions to optimize results. The Pilates method, created by Joseph Pilates, exemplifies a body-mind exercise system designed to enhance physical function, pain management, and overall well-being (Di Lorenzo, 2011). Originally termed "*Contrology*," this method emphasizes the connection between mind and body to achieve optimal physical wellness. Key principles of Pilates (breathing, concentration, gravity, precision, control, and fluidity) differentiate it from other fitness modalities (Mętel, 2007), ensuring deliberate, purposeful movements that establish a strong foundation while minimizing the risk of injury (Palermi, 2021).

Central to Pilates is the "*Powerhouse*," or "*Girdle of Centre*," a core region extending from the sternum to the pelvis, encompassing the rectus abdominis, obliques, transversus, latissimus dorsi, lumbar muscles, and gluteals (Muscolino, 2003). Through self-resistance or mechanical resistance from tools like springs, Pilates develops long, strong muscles via dynamic (isotonic, isokinetic, plyometric) and static (isometric) contractions (Fayh, 2018). The effectiveness of the Pilates method is due to the specific repetitive movements that act on neuromuscular plasticity to reprogram the Postural Control System (Takakusaki, 2017 and Ivanenko, 2018), exploiting long-term effects to recreate body symmetry, unlike what happens in asymmetric sports (De Blasiis, 2022). Postural stability, variable not only in dysfunctional subjects but also in healthy ones in relation to different sensory conditions (Fullin, 2022 and De Blasiis, 2023), can be improved by the practice of Pilates. Practicing Pilates yields numerous benefits, including improved muscle strength and tone without excessive bulk, enhanced posture, breathing techniques, reduced waist circumference, fluidity of movement, relief and prevention of back pain, increased self-confidence, and reduced stress (Aladro-Gonzalvo, 2012). Its adaptability to individual goals makes Pilates a versatile exercise method, with routines performed on mats or specialized machines (De Souza Andrade, 2021). For all these reasons, Pilates is particularly suitable for volleyball players who undergo repetitive, intense flexion-extension movements of the lower limbs and spine region during matches. In fact, during the game, they perform transitions from flexed postures during ball reception to extended stances for attacks, jumps, and defensive actions like blocking or spinning demands substantial flexibility, especially for the hamstrings and spine. Some previous studies have analysed the effects of Pilates on volleyball players (Manshouri, 2015 and Ding, 2023) but none focused on the flexibility of the spine and lower limbs using specific tests.

This study investigates the impact of a 32-week biweekly Pilates regimen on volleyball players, focusing on three key areas: (1) spinal range of motion (ROM), critical for posture and spinal health; (2) lower limb flexibility, essential for mobility and injury prevention; and (3) abdominal strength, a cornerstone of balance, stability, and athletic performance. Emphasis is placed on active lumbar flexion, spinal extension, and spinal rotation to evaluate Pilates' holistic benefits. This study hypothesizes that participants will exhibit significant improvements in the targeted variables after the training program.

MATERIAL AND METHODS

Participants

This study was conducted with the collaboration of forty young female volleyball players sourced from the University Sports Center of Campobasso. The participants, aged between 12 and 16 years (mean age: 14 ± 1.48 SD) with a BMI averaging 20.45 ± 2.4 SD, were randomly allocated into two distinct groups: the Pilates group and a control group. To ensure the study's integrity, individuals with a BMI below the 10th per-centile or above the 90th percentile were excluded.

Exclusion criteria

The study's criteria for participation were stringent to maintain a homogenous sample. Exclusions were made for: subjects did not have any pathology/condition that could affect postural setting like fractures, previous traumas, significant scars; no one needed corrective lenses or orthodontic appliances, (Moffa, 2020) and subjects exhibiting heterometry of the lower limbs. Individuals with foot deformities were also excluded from the study. Pathologies, such as flatfoot, can impact plantar support, ambulation, and the standard execution of movements during sports activities. Such conditions can be managed through either conservative treatments or surgical approaches, even in adulthood with open surgery or with a percutaneous surgical approach through a minimal skin incision (Catani, 2021).

Informed consent and ethical considerations

Each participant's parents provided their informed consent to partake in both the study's activities and assessments. The research was granted approval by the local Ethics Committee (approval number: 29/2023). Additionally, all subjects underwent a comprehensive medical-sports examination, confirming their suitability for athletic endeavours.

Study duration and structure

The study spanned a period of 8 months. All participants were actively involved in volleyball, attending three weekly training sessions of two hours each and participating in one volleyball match weekly. Their volleyball experience exceeded a minimum of one year.

Group assignments

Participants were equitably divided, with twenty participants placed in the Pilates mat training group and the remaining twenty in the control group. The Pilates cohort engaged in a specialized 32-week Pilates mat training program, entailing two 60-minute sessions each week. In contrast, the control group persisted with their regular volleyball regimen.

Procedures

For this study, we selected specific tests, given their ease of execution, high reliability, and repeatability, ensuring consistency and accuracy:

1. Modified Schober Test (MST) – Evaluating flexion and trunk rotation.
2. Modified Fingertip-To-Floor Test (MFTFT).
3. Straight Leg Raise (SLR).
4. Popliteal Angle (PA)
5. Half Sit-Up (HSU).

Modified Schober Test (MST) – Evaluating flexion and trunk rotation

The MST test is used to measure the amount of flexion occurring in the lumbar spine. A point is marked midway between the two PSIS, which is the level of S2 then points 5 cm (2") below and 10 cm (4") above that level are marked. The distance between three points is measured, the patient is asked to flex forward, and the distance is measured again. The difference between two measurements is an indication of the amount of flexion occurring in the lumbar spine. Similarly, the subject is asked to bend backward, and the extension range is measured. To measure the rotation ranges two points are marked, one on xiphisternum and other on T12. The distance between these two points is measured. Then the subject is asked to rotate, and the distance is measured again. The difference between two measurements is the amount of rotation occurring in the lumbar spine (Varangaonkar, 2015). MST is a quick and non-invasive way to assess spinal mobility in patients with Ankylosing Spondylitis and other spinal conditions. However, it should be used in

conjunction with other clinical assessments and diagnostic tests to accurately diagnose and manage these conditions (Ward, 1991 and Tousignant, 2005). The MST eliminates the error in identifying the lumbosacral junction and ensures that the lumbar spine is considered.

Modified Fingertip-To-Floor Test (MFTFT)

MFTFT is a simple clinical assessment tool used to evaluate hamstring flexibility and lower limb function in patients with musculoskeletal conditions. This test is an adaptation of the traditional Fingertip to Floor Test, which is used to assess lower back and hamstring flexibility. The MFTFT is more comprehensive in assessing the flexibility of the lower back, hips, and hamstrings. The FTF test is used to evaluate not only the mobility of the entire spine, but also of the pelvis in the forward flexion movement. In this test the subject is standing on a 30 cm high box. The subject is invited to flex forward with the hands extended downwards and subsequently, having reached maximum flexion, the distance from the fingertips to the top of the box is measured. The results were given in centimetres. The MFTFT is a quick and non-invasive tool that can be used to assess hamstring flexibility and lower limb function in a variety of patient populations (Gauvin, 1990).

Straight Leg Raise (SLR)

The Straight Leg Raise (SLR) test is a commonly used clinical assessment tool for evaluating the presence of lumbar disc herniation and sciatic nerve impingement and lower limbs flexibility. This test involves passively raising the patient's straightened leg while the patient is lying down, to assess the degree of hamstring flexibility and the presence of pain or discomfort in the lower back and/or leg. To perform the SLR test, the patient lies down on their back with their legs straightened. The examiner lifts the patient's leg straight up, keeping the knee extended and the ankle in dorsiflexion, until the patient feels pain or discomfort in the lower back or leg. The angle at which the pain or discomfort occurs is recorded, and the test is repeated on the opposite leg. In patients with normal flexibility and no nerve impingement, the SLR test should result in no pain or discomfort up to an angle of approximately 70 degrees. However, in patients with lumbar disc herniation or sciatic nerve impingement, pain or discomfort may occur at a much lower angle, indicating the presence of nerve compression (Ekedahl, 2012 and Magee, 2013).

Popliteal Angle Test (PA)

The Popliteal Angle Test (PA) is a clinical assessment tool used to evaluate the flexibility of the hamstrings and hip flexors (Duncan, 2004). The test measures the angle between the leg and thigh when the patient's leg is passively extended at the knee joint while lying down. To perform the PAT, the patient lies flat on their back with one leg straight and the other leg bent at the knee. The examiner slowly raises the straight leg until the patient feels discomfort or the heel lifts off the table. The angle between the straightened leg and the table is measured, and the test is repeated on the opposite leg (Gajdosik, 1987). In patients with normal flexibility, the angle between the straightened leg and the table should be greater than 45 degrees. However, in patients with decreased flexibility due to musculoskeletal conditions, the angle may be less than 45 degrees, indicating tightness in the hamstrings and hip flexors. The PAT assesses hamstring and hip flexor flexibility in a variety of patient populations. The knee was extended until the next end point of resistance was felt. To eliminate possible initial muscle stiffness, the extension of the ipsilateral knee was performed 3 times before taking measurements (Ten Berge, 2007).

Half sit-up test (HSU)

The Half Sit-Up Test (HSU) is a clinical assessment tool used to evaluate abdominal muscle strength that can be even used in patients with musculoskeletal conditions such as low back pain or postoperative rehabilitation (Anderson, 2007). The test involves the patient performing a partial sit-up, lifting their head and shoulders off the ground, while the examiner measures the patient's ability to complete the movement and

the degree of abdominal muscle activation. To perform the HSU, the patient lies flat on their back with their knees bent and feet flat on the ground. The examiner holds the patient's feet and instructs the patient to perform a partial sit-up, lifting their head and shoulders off the ground while keeping their arms crossed over their chest (Arab, 2006). The examiner measures the patient's ability to complete the movement, the degree of abdominal muscle activation, and the presence of pain or discomfort. the subject performed as many half sit-ups as possible in 1 min.

Training protocols

Normal training protocol

The control group subjects adhered to their established routine, participating in three athletic training sessions per week.

Experimental (Pilates) training protocol

Participants in the Pilates group attended 1-hour Pilates sessions twice a week, in addition to their regular athletic training.

Pilates protocol description

Mat Pilates is composed of fundamental Pilates movements that primarily incorporate joint motions in sync with specific breathing patterns and an upright posture. The following exercises were included in the regimen: Crisscross, Push up series, Up town, Front back, one leg circle, Swimming prep, Roll-Up, Froggie, Butterfly, Spine Twist, Side Leg Lift, Staggered Legs, Triceps Extension, Heel Squeeze Prone, Prone Hip Extension, Prone Back Extension, Cat Stretch, Side Bend Prep, Spine Stretch, Rolling Like a Ball. The Hundred Movement, that is a classic Pilates mat exercise culminated each session. During the "*Hundred*" movement, participants maintained their feet off the ground in a standard position, bending the knees at a 90° angle. Arms remained elongated, hovering just above the abdominal base, with the head and shoulders elevated off the mat. At the same time, during all Pilates training, subjects were careful to actively use their abs to support their heads during four and six breath repetitions and move their heads up and down energetically (Uzun, 2020). Throughout the study duration, no injuries were reported, and all participants remained committed, with no dropouts.

Analysis

The statistical analysis was performed using IBM's SPSS software (International Business Machines Corporation ("*IBM*"), United States), utilizing paired t-tests to evaluate changes within groups.

Paired t-test was used to compare the pre- and post-training (T0 vs T1) results within the same group. This test assesses if the mean difference between paired observations (before and after the period of the study) is statistically significant, suggesting that the Pilates method significantly impacts the participants.

RESULTS

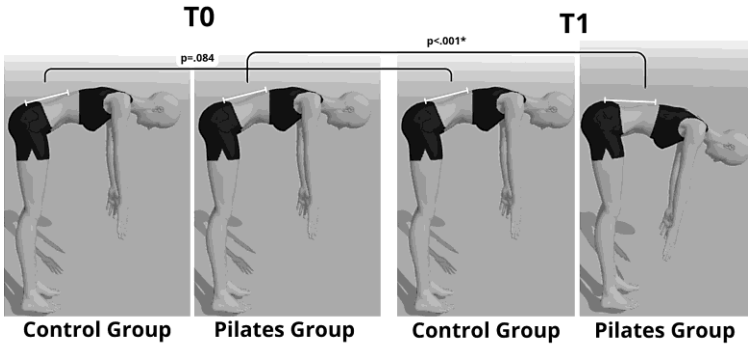
Modified Schober Test (MST) – Flexion

Modified Schober Test Results showed for the Pilates Group a significant change observed 32-weeks post-training initiation ($p < .001$), while for the Control Group No statistically significant change after 32 weeks ($p = .84$) (Table 1). The Pilates group displayed an average increase of 0.82 cm in flexion, whereas the control group showcased a lesser average improvement of 0.08 cm (Figure 1).

Table 1. This table shows the Modified Schober Test (MST) flexion results (cm).

MST- Flexion	T0 (Mean ± SD)	T1 (Mean ± SD)	T0 vs T1 (*p*-value)
Pilates Group	5.97 ± 0.27	6.79 ± 0.27	<.001*
Control Group	5.96 ± 0.28	6.04 ± 0.36	.084

Note. Significant differences are indicated via asterisk "" ($p < .05$).*



Note. Significant differences are indicated via asterisk "" ($p < .05$).*

Figure 1. Visual representation of the improvements observed for Modified Schober Test - Flexion before and after 32 weeks for both control group and Pilates group.

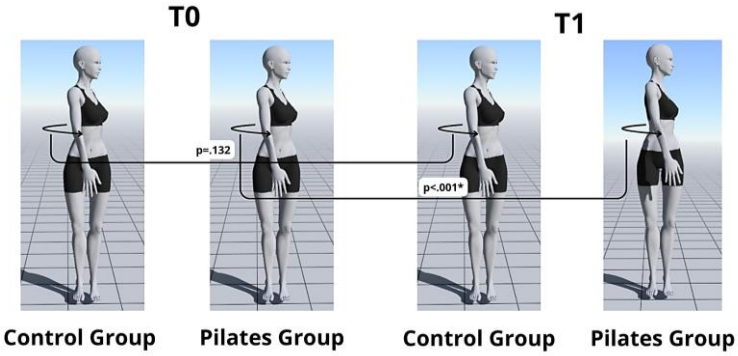
Modified Schober Test (MST) – Rotation

Pilates Group in trunk rotation test had Statistically significant improvement ($p < .001$). Control Group had No significant change ($p = .132$) (Table 2). The Pilates group exhibited an average enhancement of 0.23, while the control group's average increment stood at 0.13 (Figure 2).

Table 2. This table shows the Modified Schober Test (MST) trunk rotation results (cm).

MST-Rotation	T0 (Mean ± SD)	T1 (Mean ± SD)	T0 vs T1 (*p*-value)
Pilates Group	2.68 ± 0.22	2.91 ± 0.41	<.001*
Control Group	2.5 ± 0.20	2.63 ± 0.18	.132

Note. Significant differences are indicated via asterisk "" ($p < .05$).*



Note. Significant differences are indicated via asterisk "" ($p < .05$).*

Figure 2. Visual representation of the improvements observed for Modified Schober Test - Rotation before and after 32 weeks for both control group and Pilates group.

Modified Fingertip-To-Floor Test (MFTFT)

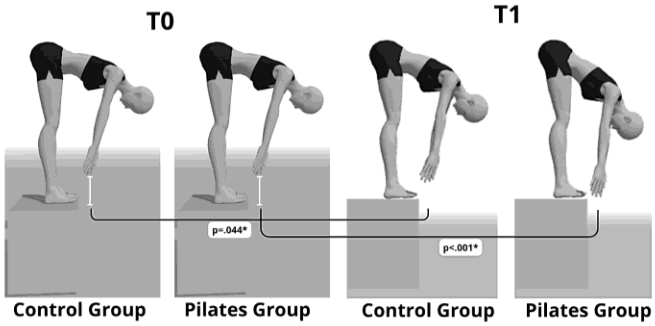
Both the Pilates and Control groups displayed statistically improved results 32 weeks post-training initiation (both $p < .05$) (Table 3). These results suggest that training both with and without Pilates sessions displayed similar

outcomes concerning the mobility of the spine and pelvis. However, Pilates improves the ROM of the lumbar spine more than conventional training. Conversely, Pilates practitioners observed a prominent average improvement of 3.85 cm, contrasting the control group's average hike of 0.75 cm (Figure 3).

Table 3. This table shows the Modified Fingertip to Floor test (MFTFT) results (cm).

MFTFT	T0 (Mean ± SD)	T1 (Mean ± SD)	T0 vs T1 (*p*-value)
Pilates Group	3.30 ± 1.59	-0.55 ± 1.63	<.001*
Control Group	5.15 ± 1.13	4.40 ± 1.09	.044*

Note. Significant differences are indicated via asterisk "" (p < .05).*



Note. Significant differences are indicated via asterisk "" (p < .05).*

Figure 3. Visual representation of the improvements observed for Modified Fingertip-To-Floor Test before and after 32 weeks for both control group and Pilates group.

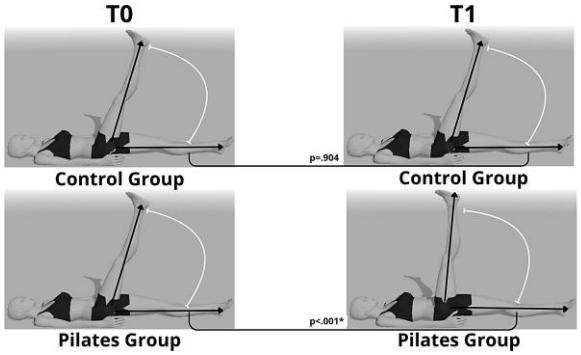
Straight Leg Raise (SLR)

From the results of the Straight Leg Raise (SLR) Test, the Pilates Group exhibited a notable enhancement, as evidenced by a *p*-value of less than .05. On the other hand, the Control Group displayed no significant alteration, with a *p*-value of .904 (Table 4). When examining the average progression, the Pilates participants saw an improvement of 9.7°, which was considerably greater than the modest 0.2° increment observed in the control group (Figure 4).

Table 4. This table shows the Straight Leg Raise (SLR) results (°).

Straight Leg Raise	T0 (Mean ± SD)	T1 (Mean ± SD)	T0 vs T1 (*p*-value)
Pilates Group	65.8 ± 5.8	75.5 ± 4.38	<.001*
Control Group	65.8 ± 5.46	66.0 ± 6.37	.904

Note. Significant differences are indicated via asterisk "" (p < .05).*



Note. Significant differences are indicated via asterisk "" (p < .05).*

Figure 4. Visual representation of the improvements observed for Straight Leg Raise test before and after 32 weeks for both control group and Pilates group.

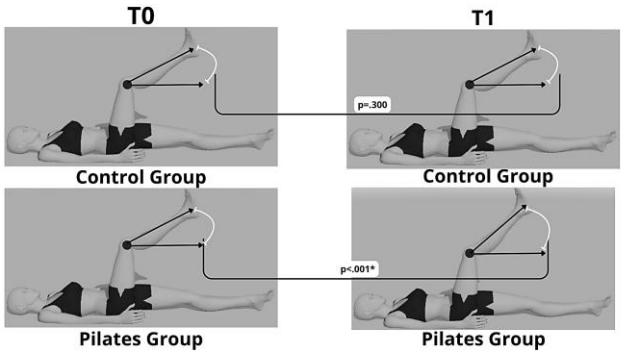
Popliteal Angle Test (PA)

In the results of the Popliteal Angle Test (PA), the Pilates Group showed a significant improvement ($p < .05$). In contrast, the Control Group did not exhibit any noteworthy change, with a p-value of .300. The Pilates group's average improvement was significant at 17.15°, with the control group only registering an average increment of 2.05° (Table 5).

Table 5. This table shows the Popliteal Angle Test (PA) results (°).

Popliteal Angle test	T0 (Mean ± SD)	T1 (Mean ± SD)	T0 vs T1 (*p*-value)
Pilates Group	46.5 ± 5.91	63.65 ± 3.36	<.001*
Control Group	47.05 ± 5.48	49.10 ± 4.95	.3

Note. Significant differences are indicated via asterisk "" ($p < .05$).*



Note. Significant differences are indicated via asterisk "" ($p < .05$).*

Figure 5. Visual representation of the improvements observed for Popliteal Angle Test before and after 32 weeks for both control group and Pilates group.

Half Sit-Up (HSU)

In the half sit-up test results, the Pilates group demonstrated a marked enhancement, with a p-value of less than .05. In contrast, the control group exhibited no such significant improvement ($p = .191$). Specifically, the Pilates group increased their average score by approximately 25.36%. In comparison, the control group saw a more modest improvement, with their scores increasing by 5.10%% (Table 6).

Table 6. This table shows the half sit-up results (as many half sit-ups as possible in 1 min).

Half Sit-Up Test	T0 (Mean ± SD)	T1 (Mean ± SD)	T0 vs T1 (*p*-value)
Pilates Group	31.95 ± 7.1	40.05 ± 5.16	<.001*
Control Group	32.35 ± 7.80	34.00 ± 7.82	.191

Note. Significant differences are indicated via asterisk "" ($p < .05$).*

DISCUSSION

The Pilates method comprises a series of exercises designed to stretch and strengthen muscles, primarily aiming to enhance muscle elasticity and joint mobility. This method is particularly beneficial for volleyball players, who regularly perform repetitive, high-intensity flexion-extension movements of the lower limbs. Players transition from flexed postures during ball reception to extended stances for attacks, jumps, and defensive actions such as blocking or spinning. These movements require a good level of flexibility, especially for the spine and lower limbs. Improved flexibility optimizes performance and reduces injury risk, making Pilates training a valuable addition to volleyball training programs.

This study aimed to evaluate the impact of Pilates on spinal flexibility, lower limb mobility, and abdominal strength using specific assessments. Results from the Modified Schober Test (MST) for spinal flexion and rotation demonstrated significant improvement in the Pilates group after 32 weeks, suggesting enhanced spinal flexibility. The trunk rotation assessment further highlighted the positive effect of Pilates on rotational mobility of the thoracolumbar spine, an essential factor in injury prevention, particularly in sports like volleyball, swimming, and tennis. Notably, while some participants showed Schober test measurements below 5 cm, which typically indicates reduced spinal mobility, this was more likely due to age-related factors rather than any pathological conditions. Thus, the MST results support the effectiveness of Pilates in improving athletic performance and reducing sports-related injuries.

The Modified Fingertip-to-Floor Test (MFTFT) measured the flexibility of the lumbopelvic junction, revealing a statistically significant increase in both groups, with the Pilates group showing slightly greater improvement. This suggests that Pilates training positively influences spinal flexibility.

The Popliteal Angle (PA) and Straight Leg Raise (SLR) Tests assess range of motion (ROM) in the hip and knee joints, focusing on the hamstrings and hip extension, respectively. Both tests showed substantial improvement after 32 weeks of Pilates training, indicating enhanced lower limb mobility. These findings further reinforce Pilates as an effective method for improving flexibility in the lower limbs.

The Half Sit-Up Test (HSU) demonstrated marked improvement in abdominal strength in the Pilates group compared to the control group. Strong abdominal muscles are crucial for trunk stability, posture, and facilitating smooth transitions between postures, all of which are vital for volleyball players' performance.

Overall, this study indicates that Pilates mat training can effectively improve spinal and lower limb flexibility in young female volleyball players. These results are in accordance with (Manshouri, 2015 and Ding, 2023) who state that Pilates significantly enhances flexibility, which is crucial for volleyball players to perform efficiently and reduce injury risks.

Moreover, as Vaquero-Cristóbal (2015) notes, Pilates not only helps reduce the risks of conditions like obesity, diabetes, and cardiovascular disease but also enhances athletic performance. The specific Pilates exercises selected for this study were aimed at improving core strength, stability, and flexibility, key attributes for volleyball athletes. The results highlight the potential benefits of incorporating Pilates into the training regimen of young volleyball players, offering performance enhancements and injury prevention. Furthermore, engaging in Pilates during adolescence may foster long-term physical activity habits, which is critical given that physical inactivity is a leading risk factor for mortality worldwide (Lavie, 2019).

CONCLUSIONS

Our study highlights the significant potential of Pilates mat training in improving flexibility among young female volleyball players. Volleyball, as a dynamic sport, demands a high degree of physical versatility, where flexibility plays a critical role in optimizing performance, enhancing agility, and minimizing injury risks. Beyond its impact on flexibility, Pilates offers a holistic approach by integrating core strength, posture improvement, and breath control. These attributes are particularly valuable for volleyball players, enabling smoother transitions, more effective jumps, and rapid movements essential for both offense and defence. The comprehensive benefits of Pilates suggest its utility as a valuable component in the training regimens of volleyball players. Coaches, trainers, and sports therapists may consider incorporating Pilates to provide athletes with a well-rounded program that combines flexibility, strength, and endurance. Such integration

could enhance performance while supporting injury prevention and long-term physical health. While our findings are encouraging, they underscore the need for further research to fully understand the broader impact of Pilates in sports training. Future studies could explore the longitudinal effects of Pilates on parameters such as athletic performance, stamina, and injury resilience. Investigating these aspects in greater detail would not only reinforce the initial insights from our research but also offer a more comprehensive understanding of the role Pilates can play in optimizing training strategies for athletes.

AUTHOR CONTRIBUTIONS

Alessandro Cattolico, Carmine Sellitto and Ciro Ivan De Girolamo conceptualized the project and coordinated the research team; these three authors contributed equally to this work and share first authorship. Carmine Sellitto was responsible for data collection and analysis, including statistical analysis. Stefano Moffa ensured the linguistic accuracy of the manuscript and evaluated the reliability of the tests. Katia Corona contributed to data collection and conducted measurements. Ciro Ivan De Girolamo, Luigi Bagella, participated in data collection and analysis. Germano Guerra co-conceptualized the project, led the research group, and managed athlete coordination. Domenico Tafuri and Antonio De Luca reviewed the manuscript for critical content. Angela Lucariello conceptualized the project and served as a project coordinator. All authors read and approved the final version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Aladro-Gonzalvo, A. R., Machado-Díaz, M., Moncada-Jiménez, J., Hernández-Elizondo, J., & Araya-Vargas, G. (2012). The effect of Pilates exercises on body composition: A systematic review. Journal of Bodywork and Movement Therapies, 16(1), 109-114. https://doi.org/10.1016/j.jbmt.2011.06.001

Anderson, D. E., Mann, B. J., Hsu-Wei, A. A., & Chesworth, B. M. (2007). Comparison of the abdominal muscles in individuals with and without chronic low back pain using ultrasound imaging. Journal of Orthopaedic & Sports Physical Therapy, 37(10), 635-641.

Arab, A. M., Behbahani, R. B., Lorestani, L., & Azizkhani, H. (2006). Measurement of abdominal muscle strength using the half sit-up test. Journal of Back and Musculoskeletal Rehabilitation, 19(3), 81-85.

Catani, O., Cautiero, G., & Sergio, F. (2021). Medial displacement calcaneal osteotomy for unilateral adult acquired flatfoot: Effects of minimally invasive surgery on pain, alignment, functioning, and quality of life. Journal of Foot and Ankle Surgery, 60(2), 358-361. https://doi.org/10.1053/j.jfas.2020.11.003

De Blasiis, P., Caravaggi, P., Fullin, A., Leardini, A., Lucariello, A., Perna, A., Guerra, G., & De Luca, A. (2023). Postural stability and plantar pressure parameters in healthy subjects: Variability, correlation analysis and differences under open and closed eye conditions. Frontiers in Bioengineering and Biotechnology, 11, 1198120. https://doi.org/10.3389/fbioe.2023.1198120

De Blasiis, P., Fullin, A., Caravaggi, P., Lus, G., Melone, M. A., Sampaolo, S., De Luca, A., & Lucariello, A. (2022). Long-term effects of asymmetrical posture in boxing assessed by baropodometry. Journal of

Sports Medicine and Physical Fitness, 62(3), 350-355. https://doi.org/10.23736/S0022-4707.21.12040-7

de Souza Andrade, L., da Silva Almeida, I., Mochizuki, L., Sousa, C. V., Falk Neto, J. H., Kennedy, M. D., Quagliotti Durigan, J. L., & Mota, Y. L. (2021). What is the exercise intensity of Pilates? An analysis of the energy expenditure, blood lactate, and intensity of apparatus and mat Pilates sessions. Journal of Bodywork and Movement Therapies, 26, 36-42. https://doi.org/10.1016/j.jbmt.2020.12.007

Di Lorenzo, C. E. (2011). Pilates: What is it? Should it be used in rehabilitation? Sports Health, 3(4), 352-361. https://doi.org/10.1177/1941738111410285

Ding, J. (2023). Influence of Pilates training on physical coordination and stability of volleyball players. Revista Brasileira de Medicina do Esporte. https://doi.org/10.1590/1517-8692202329012023_0024

Duncan, R., Beckwith, J., & Betz, R. (2004). Management of lower extremity muscle contractures in cerebral palsy. Journal of the American Academy of Orthopaedic Surgeons, 12(2), 117-124.

Ekedahl, H., Jönsson, B., & Frobell, R. B. (2012). Fingertip-to-floor test and straight leg raising test: Validity, responsiveness, and predictive value in patients with acute/subacute low back pain. Archives of Physical Medicine and Rehabilitation, 93(12), 2210-2215. https://doi.org/10.1016/j.apmr.2012.04.020

Fayh, A., Brodt, G. A., Souza, C., & Loss, J. F. (2018). Pilates instruction affects stability and muscle recruitment during the long stretch exercise. Journal of Bodywork and Movement Therapies, 22(2), 471-475. https://doi.org/10.1016/j.jbmt.2017.05.010

Fullin, A., Caravaggi, P., Picerno, P., Mosca, M., Caravelli, S., De Luca, A., Lucariello, A., & De Blasiis, P. (2022). Variability of postural stability and plantar pressure parameters in healthy subjects evaluated by a novel pressure plate. International Journal of Environmental Research and Public Health, 19(5), 2913. https://doi.org/10.3390/ijerph19052913

Gajdosik, R. L., & Bohannon, R. W. (1987). Clinical measurement of range of motion: Review of goniometry emphasizing reliability and validity. Physical Therapy, 67(12), 1867-1872. https://doi.org/10.1093/ptj/67.12.1867

Gauvin, M. G., Riddle, D. L., & Rothstein, J. M. (1990). Reliability of clinical measurements of forward bending using the modified fingertip-to-floor method. Physical Therapy, 70(7), 443-447. https://doi.org/10.1093/ptj/70.7.443

Ivanenko, Y., & Gurfinkel, V. S. (2018). Human postural control. Frontiers in Neuroscience, 12, 171. https://doi.org/10.3389/fnins.2018.00171

Kloubec, J. A. (2010). Pilates for improvement of muscle endurance, flexibility, balance, and posture. Journal of Strength and Conditioning Research, 24(3), 661-667. https://doi.org/10.1519/JSC.0b013e3181c277a6

Lavie, C. J., Ozemek, C., Carbone, S., Katzmarzyk, P. T., & Blair, S. N. (2019). Sedentary behavior, exercise, and cardiovascular health. Circulation Research, 124(5), 799-815. https://doi.org/10.1161/CIRCRESAHA.118.312669

Magee, D. J. (2013). Orthopedic physical assessment (6th ed.). Elsevier Health Sciences.

Schober, P., & Cotton, R. E. (1951). Diagnosis of lumbosacral nerve root lesions by a new method of measurement of straight-leg raising. The Lancet, 257(6651), 116-119.

Manshouri, M., & Rahnama, N. (2015). Effects of Pilates exercises on flexibility and volleyball serve skill in female college students.

Mętel, S., & Milert, A. (2007). Joseph Pilates' method and possibilities of its application in physiotherapy. Rehabilitacja Medyczna, 11, 27-36.

Moffa, S., Perna, A., Candela, G., Cattolico, A., Sellitto, C., De Blasiis, P., Guerra, G., Tafuri, D., & Lucariello, A. (2020). Effects of hoverboard on balance in young soccer athletes. Journal of Functional Morphology and Kinesiology, 5(60). https://doi.org/10.3390/jfmk5030060

Muscolino, J. E., et al. (2003). Pilates and the "powerhouse"-I. Journal of Bodywork and Movement Therapies, 8(1), 15-24. https://doi.org/10.1016/S1360-8592(03)00057-3

Palermi, S., Massa, B., Vecchiato, M., Mazza, F., De Blasiis, P., Romano, A. M., Di Salvatore, M. G., Della Valle, E., Tarantino, D., Ruosi, C., & Sirico, F. (2021). Indirect structural muscle injuries of lower limb: Rehabilitation and therapeutic exercise. Journal of Functional Morphology and Kinesiology, 6(3), 75. https://doi.org/10.3390/jfmk6030075

Takakusaki, K. (2017). Functional neuroanatomy for posture and gait control. Journal of Movement Disorders, 10(1), 1-17. https://doi.org/10.14802/jmd.16062

Ten Berge, S. R., Halbertsma, J. P., Maathuis, P. G., Verheij, N. P., Dijkstra, P. U., & Maathuis, K. G. (2007). Reliability of popliteal angle measurement: A study in cerebral palsy patients and healthy controls. Journal of Pediatric Orthopaedics, 27(6), 648-652. https://doi.org/10.1097/BPO.0b013e3180dca15d

Tousignant, M., Poulin, L., Marchand, S., Viau, A., & Place, C. (2005). The Modified-Modified Schober Test for range of motion assessment of lumbar flexion in patients with low back pain: A study of criterion validity, intra- and inter-rater reliability and minimum metrically detectable change. Disability and Rehabilitation, 27(10), 553-559. https://doi.org/10.1080/09638280400018411

Uzun, A., & Demir, B. (2020). Effect of Pilates and reformer exercises on body composition. International Journal of Applied Exercise Physiology, 9, 2322-3537.

Vaquero-Cristóbal, R., Alacid, F., Esparza-Ros, F., Muyor, J. M., & López-Miñarro, P. A. (2015). The effects of 16-weeks Pilates mat program on anthropometric variables and body composition in active adult women after a short detraining period. Nutrición Hospitalaria, 31(4), 1738-1747.

Varangaonkar, V., Ganesan, S., & Kumar, K. (2015). The relationship between lumbar range of motion with hamstring flexibility among 6-12 years children from South India: A cross-sectional study. International Journal of Health & Allied Sciences, 4(1), 23-27. https://doi.org/10.4103/2278-344X.149243

Ward, M. M. (1991). Radiographic manifestations of ankylosing spondylitis. Seminars in Arthritis and Rheumatism, 21(4), 267-282.