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Enhancing Foot Posture and Balance in Flexible Flatfoot: Short Foot Exercise, Balance Training, and Plyometrics Approach

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SUMMARY

Objective. The purpose of this study was to evaluate the effects of short foot exercise along with dynamic balance training and plyometric exercise training by using the navicular drop test on improving the foot posture and Y balance test for dynamic balance.

Methods. In this comparative study, 66 participants aged 18-30, using convenient sampling were randomly assigned to two groups: SFE group and plyometrics group (each n = 33). Evaluations included the Navicular Drop Test and the Y Balance Test. The SFE group performed short foot exercises with dynamic balance training, while the plyometrics group engaged in plyometric activities. Both groups participated in their respective exercises for 20 minutes, five days a week, over a span of 6 weeks.

Results. The Plyometrics group achieved significant improvements compared to the SFE group. Navicular drop decreased to 6.79 in Plyometrics and 8.45 in SFE. In the Y Balance Test, Plyometrics demonstrated better outcomes: anterior (104.82 *vs* 101.12), posteromedial (96.58 *vs* 93.30), and posterolateral (98.03 *vs* 95.85), all with P-values < 0.001, indicating superior reduction in navicular drop and enhanced dynamic balance.

Conclusions. According to this study, the plyometrics group is superior to the short-foot and dynamic balance exercise group. Plyometrics is more effective in reducing navicular drop and enhancing dynamic balance in people with flexible flatfoot.

KEY WORDS

Dynamic balance exercise; flexible flatfoot; navicular drop test; plyometric exercises; short foot exercise; Y balance test.

INTRODUCTION

The foot's arches play a crucial role in maintaining an upright posture, serving as levers that propel the body forward and assist in various movements like walking, running, and jumping. These arches are categorized into longitudinal and transverse arches, with the former further divided into medial and lateral sections. The medial longitudinal arch, more flexible and indicative of foot flatness, is supported by features such as endpoints, summits, and pillars. The heads of the first, second, and third metatarsals contribute to the front end, while the calcaneum's medial tubercle forms the posterior end. Acting as the keystone, the talus, with its superior articular surface, shapes the peak, while the pillar involves the talus, navicular, and cuneiform bones. Typically elevated 15-18 mm from the surface, a severely diminished medial longitudinal arch characterizes flatfootedness (1).

Flatfoot, or pes planus, is a common condition that has been documented throughout human history, with evidence tracing back to prehistoric times. Ancient records, including medical texts by figures like Galen and depictions in the art of Leonardo da Vinci, highlight its longstanding recognition. Historically, the primary treatment approach was con-

servative, primarily utilizing insoles, until the 19th century when surgical interventions became more prevalent. These surgeries, such as osteotomies, arthrodesis, arthrosis, and tendon lengthening and transfer, have evolved significantly. Despite centuries of study and treatment advancements, there remains no consensus on the best management practices for flatfoot, indicating the complexity and ongoing debates surrounding its treatment (2).

Flatfoot can be distinguished by the collapse of the medial longitudinal arch, hind foot eversion, and loaded forefoot abduction. Flatfoot also leads to a variety of musculoskeletal issues in the lower extremity, such as knee and hip pain. Foot posture problems, such as flat feet or high-arched feet, can induce lower body misalignment. Flat feet are the most common cause of knee problems among individuals. When the foot arch flattens on the ground, it causes a knock-off effect that causes the lower body to misalign. The flattened foot arch produces abnormal inward twisting of the shin and thigh bones (over pronation), putting stress on the knee joint and often causing pain. During the stance phase, the foot must adjust to the ground, absorb stress, and turn into a firm lever to propel the human body ahead through push-off. The efficiency of these tasks is strongly reliant on proper foot mobility, particularly subtalar pronation as well as supination. Pronation begins as soon as the weight is born and reaches its peak in midstance. The midtarsal joint releases during pronation, increasing foot flexibility to adjust to the underlying surface e and improve balance. Supination locks the midtarsal joint to improve foot stability and establish a strong lever for push-off (3).

Flat feet are more prevalent in children due to the elasticity of ligaments, and this condition becomes less common with age. Engaging the internal muscles of the foot, short foot exercises (SFE) are sensorimotor drills actively promoting the advancement of both the longitudinal and transverse arches (4). SFE involves shortening the foot's length by shifting the forefront of the initial metatarsal toward the heel without toe flexion. Through the specific involvement of the internal foot muscle (IFM) devoid of excessive triggering external foot muscles like the tibialis anterior and gastrocnemius, the short foot exercise (SFE) raises the MLA. When it comes to targeting the AbdH muscle, SFE is a more beneficial strengthening training than toe curl exercise (5).

Plyometric exercise involves swift and forceful combinations of both concentric and eccentric contractions. Individuals of all ages, including children and adults, can enhance various aspects such as balance, jumping ability, response speed, bone mineral density, enduring strength, muscle potency and power, energy generation, motor skills, and coordination through this dependable and effective workout (6). Following plyometric training, plyometric activities have shown a notable and statistically significant improvement in foot posture. This improvement is mainly due to the beneficial changes in mechanical characteristics brought about by plyometric activities, as well as the associated development in plantar flexor strength. The expansion of the foot's arch structure is intimately linked to the noted changes in foot posture (7).

Additionally, the study employed standard outcome measures, including the navicular drop test (NDT) to assess structural changes in the foot arch, and the Y balance test to evaluate dynamic balance and postural stability. These assessments enabled an objective evaluation of the exercises' influence on balance and arch improvement. Furthermore, this study undertook an extensive and meticulous review of the prevailing literature pertaining to the effectiveness of SFE in conjunction with balance training *versus* plyometric exercises for individuals with flexible flat feet, highlighting the then-existing gaps in knowledge and the need for further research.

MATERIALS AND METHODS

For this study, a cohort of 66 individuals diagnosed with flexible flatfoot was selected using convenient sampling. The study was approved by ISRB 03/ 033/ 2023/ ISRB/ SR / SCPT – date of approval: August 17, 2023. Subjects for this study were selected from individuals diagnosed with flexible flatfoot, aged between 18 and 30 years, and meeting specific inclusion criteria. Inclusion criteria encompassed individuals within the specified age group with clinically diagnosed flexible flatfoot, while exclusion criteria excluded those with rigid flatfoot or other significant foot deformities, severe osteoarthritis or other degenerative joint diseases affecting the lower extremities, history of neurological disorders affecting lower limb function, and acute lower limb injuries or fractures within the past three months. This sampling strategy aimed to ensure a representative sample for investigating the effectiveness of interventions for flexible flatfoot management. Through this approach, the study aims to contribute valuable insights into managing flexible flatfoot effectively.

Following informed consent, individuals meeting the inclusion criteria were recruited and assigned to either the SFE group or the plyometrics group (each n = 33). The study addressed the impact of two distinct exercise regimens on people with flexible flat foot. Both groups received treatment five days per week over a total of 6 weeks.

Participants in the SFE group received a structured inter-

vention consisting of short foot exercise and dynamic balance exercises for five days a week, for 6 weeks. The dynamic balance exercises included Single Leg Stance, Heel-Toe Walk, Tandem Stance, Clock Reach, Single Leg Stance with Eyes Closed, Heel Raises with Balance, Dynamic Lunge, Balancing on Uneven Surface, Tandem Walk, Tandem Stand with Arm Movement, Side Leg Raises, Standing on One Leg, Clock Hops, Single Leg Deadlift barefoot, Eyes Closed Tandem Stand, Dynamic Lunge with Rotation, Tree Pose, and Tandem Walk Eyes Closed, each performed 3 sets. Participants underwent plyometric exercise training, which included depth jumps, bounding, line hops, squat jumps, and ankle hops. Each session comprised 2 sets of 10 repetitions for each exercise, amounting to 20 minutes, conducted five days a week over a period of 6 weeks.

The Navicular Drop Test and Y Balance Test were utilized as outcome measures to gauge improvements in foot arch and balance among patients with flexible flatfoot. These tests assessed arch collapse during weight-bearing and dynamic balance, providing insights into the effectiveness of interventions.

Statistics

Statistical analysis was conducted to assess the significance of the observed differences in outcome measures between the two treatment groups. Paired t-tests were employed to compare pre- and post-treatment values within each group, allowing for an evaluation of the effectiveness of the interventions over time and Unpaired t-tests were then utilized to compare the post-treatment outcomes between two groups. Pre- and post-assessment data show significant improvements in foot posture and dynamic balance using NDT. The SFE group had a mean NDT decrease from 12.36 to 8.45 ($p < 0.0001$), while the Plyometrics group decreased from 12.82 to 6.79 ($p < 0.0001$). Pre- and post-assessment data of Y Balance Test show significant improvements in mean reach distances for both the SFE and Plyometrics groups ($p < 0.0001$). For the SFE group: anterior (Pre: 90.36, Post: 101.12), posteromedial (Pre: 81.06, Post: 93.30), posterolateral (Pre: 82.55, Post: 95.85). Similarly, for the Plyometrics group: anterior (Pre: 90.97, Post: 104.82), posteromedial (Pre: 81.30, Post: 96.58), posterolateral (Pre: 83.52, Post: 98.03).

The statistical analysis was performed by the same authors who conducted the research. This was done to maintain a cohesive understanding of the data and its implications within the context of the study. These statistical analyses offer compelling evidence supporting the effectiveness of the intervention in improving foot arch and dynamic balance in individuals with flatfoot, emphasizing the significance of integrating specific exercises into the treatment protocol for this condition.

RESULTS

The study participants underwent the prescribed interventions, with outcomes evaluated for both groups. Comparing post-intervention values between the SFE group and the Plyometrics group in the Navicular Drop Test: in the SFE group, the mean NDT value decreased to 8.45. Whereas in the Plyometrics group, the mean NDT value decreased to 6.79, as shown in **table I** and **figure 1**.

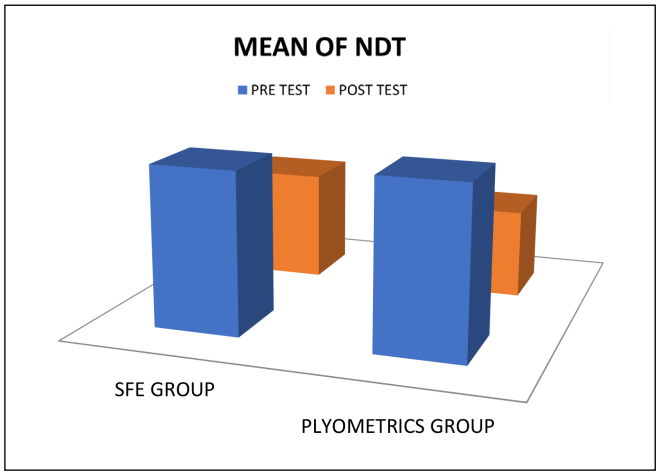

Figure 1. Pre- and post-test mean values of SFE group and plyometrics group for NDT (Navicular Drop Test).

Table I. Pre- and post-test values for SFE group and plyometrics group for Navicular drop test.

Group	Type of test	Mean ± SD	T-test	P-value
SFE group	Pre-test	12.36 ± 1.95	10.2123	< 0.0001
	Post-test	8.45 ± 1.09		
Plyometric group	Pre-test	12.82 ± 1.91	16.1643	< 0.0001
	Post-test	6.79 ± 1.11		

Table II. Pre- and post-test values for SFE group and plyometrics group for Y balance test.

Group	Localization	Test	Mean ± SD	T-test	P-value
SFE group	Anterior	Pre-test	90.36 ± 1.82	12.3283	< 0.0001
		Post-test	101.12 ± 4.44		
	Posteromedial	Pre-test	81.06 ± 2.37	17.5466	< 0.0001
		Post-test	93.30 ± 3.47		
	Posterolateral	Pre-test	82.55±2.20	18.1874	< 0.0001
		Post-test	95.85 ± 3.90		
Plyometrics group	Anterior	Pre-test	90.97 ± 1.33	31.0366	< 0.0001
		Post-test	104.82 ± 2.28		
	Posteromedial	Pre-test	81.30 ± 3.05	27.4648	< 0.0001
		Post-test	96.58 ± 2.73		
	Posterolateral	Pre-test	83.52 ± 2.06	32.3771	< 0.0001
		Post-test	98.03 ± 2.32		

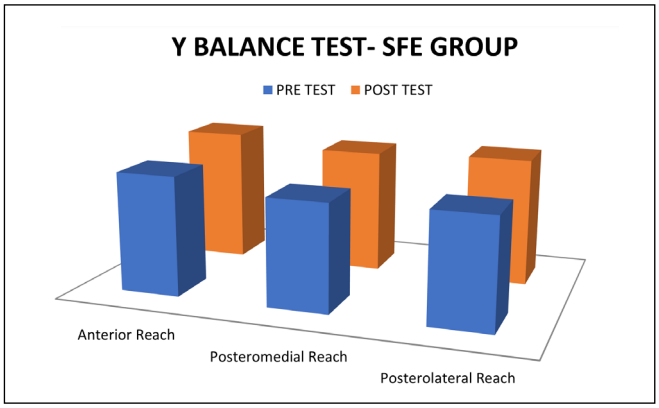

Figure 2. Pre- and post-test mean values of SFE group for Y balance test.

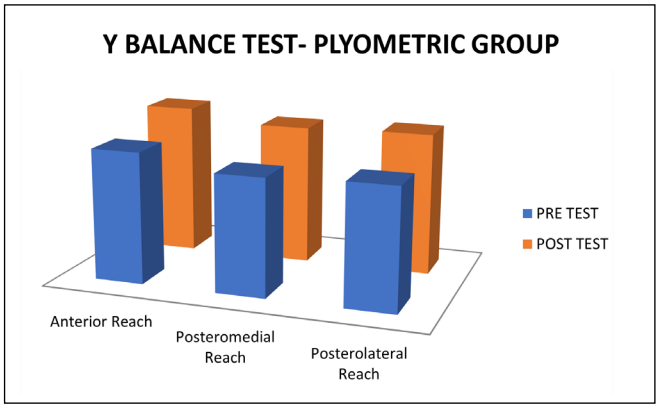

Figure 3. Pre- and post-test mean values of plyometrics group for Y balance test.

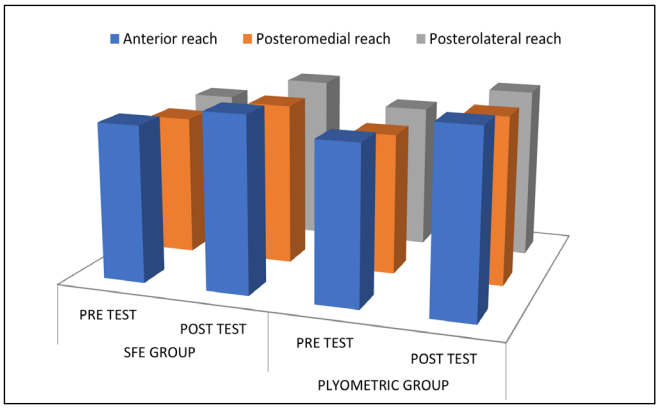

Figure 4. Pre- and post-test mean values of SFE group and plyometrics group for Y balance test.

Comparing post-intervention values between the SFE group and the Plyometrics group in the Y Balance Test: anterior – SFE group: 101.12, Plyometrics group: 104.82; posteromedial – SFE group: 93.30, Plyometrics group: 96.58; posterolateral – SFE group: 95.85, Plyometrics group: 98.03, as shown in **table II** and **figure 2-4**. Statistical analysis revealed a significant difference between the groups. The plyometrics group exhibited superior results in reducing navicular drop and enhancing dynamic balance, with P-values less than 0.0001.

DISCUSSION

The purpose of the study is to compare the short foot exercise (SFE) along with dynamic balance training and Plyometric ex-

ercises in improving the foot posture and dynamic balance in subjects with flexible flatfoot. The study consisted of 2 groups, SFE group, which received short foot exercise along with dynamic balance training, and plyometrics group, which received plyometric exercise training. Results showed that the plyometrics group showed significant improvement, particularly in navicular drop test (NDT) and Y balance test measures.

The study method included a comparative study design, recruiting 66 subjects diagnosed with flexible flatfoot by convenience sampling. Participants were randomly assigned to SFE group or Plyometrics group, with 33 people in each group. The duration of exposure for both groups was six weeks, and the results were assessed using the NDT and Y balance tests. Statistical analysis including paired t-test and unpaired t-test was used to assess the significance of differences between the two groups.

Statistical analysis revealed a significant difference in posttest values between the two groups, with the plyometric exercise group showing a greater effect on individuals with flexible flatfoot. The post-test mean values for the NDT were 6.79 ± 1.11 for plyometrics group, and 8.45 ± 1.09 for SFE group. For the Y Balance Test, the post-test mean values for the anterior, posteromedial, and posterolateral reaches were 104.82 ± 2.28, 96.58 ± 2.73, and 98.03 ± 2.32, respectively, for plyometrics group, and 101.12 ± 4.44, 93.30 ± 3.47, and 95.85 ± 3.90, respectively, for SFE group.

Flatfoot, also known as pes planus, is a condition characterized by the flattening or partial collapse of the arches of the feet. Although some people may not feel any pain or difficulties due to their flat feet, others may find it difficult, especially when it comes to balance. In order to distribute body weight and absorb shock during movement, the arches of the feet are extremely important. Overall stability and balance are affected when the foot's biomechanics are changed, as in the case of flatfoot, when the arches collapse or become less prominent (8).

Disproportioning the body weight is one of the main ways flatfoot impairs balance. Typically, when standing, walking, or engaging in other weight-bearing activities, the arches assist in uniformly dispersing the load throughout the foot. People with flat feet may have an unequal distribution of their weight, which puts more strain on specific parts of their feet. Having a stable and balanced posture can be more difficult to maintain due to the changing weight distribution that may impact the body's center of gravity.

Expanding on the results of prior research, Kamalakannan *et al.* carried out a study exploring the influence of plyometric exercises on the foot posture and functional activities of the lower limb. Similar to the present study, their research highlights the potential advantages of plyometrics in addressing issues related to flat feet. The results of Kamalakannan *et al.*'s study correspond with the current findings, demonstrating a favorable effect on the foot posture and functional abilities of the lower limb (1).

In strengthening the foot arch, they emphasized the importance of plyometric activities. Given its ability to strengthen the calf muscles – which are primarily responsible for arch elevation – they proposed that plyometrics may have a more potent effect. Plyometric exercises have the ability to function as a preventative measure by strengthening the calf muscles, which are essential for raising the arch, hence reducing the likelihood of more flatfoot-related injury (10).

Chaouachi *et al.* (2014) delved into the realm of plyometric training and its implications for balance performance in adults. Through meticulously designed experiments and systematic assessments, the researchers unearthed compelling evidence suggesting that the incorporation of plyometric exercises into a training regimen could lead to significant improvements in balance outcomes among adult individuals. The study likely scrutinized a diverse range of plyometric protocols, exploring variations in intensity, frequency, and duration to discern the optimal parameters for eliciting enhanced balance capabilities in the adult population (11).

Similarly, Unver *et al.* (2019) extended this line of inquiry with a specific focus on females. Recognizing potential gender-specific responses to plyometric training, Twist and colleagues sought to unravel the nuanced effects of this training modality on the balance performance of women. By meticulously designing their study and implementing rigorous testing protocols, they contributed valuable insights into how plyometric exercises could be tailored to meet the unique physiological and biomechanical characteristics of the female body, thereby maximizing the benefits for balance enhancement (12).

Arazi and Asadi (10) conducted a comprehensive review that yielded important findings. They showed that young athletes' muscle strength and balance ability were significantly improved after an 8-week program that included both land and aquatic plyometric exercise sessions (10).

Furthermore, Chaouachi *et al.* (2014) correlated our results by stating that, similar to the combined training program, plyometric training enhanced squat strength measurements, leaping abilities, and balancing. The quick stretch-shortening cycle that follows plyometric activity may be linked to the increase in balancing abilities. This cycle involves center of gravity movements in both vertically as well as horizontally directions, which may enhance postural control and equilibrium (11).

In addition, McKeon PO *et al.*'s data (2015) showed a noteworthy increase in the plantar flexors' strength, muscle ac-

tivity, and maximum voluntary contraction following plyometric activities. The notion that plantar flexor activity of the muscles increases significantly throughout the concentric stage of vertical leaps is corresponded by Ghaderiyan *et al.* (2016) (15, 16).

Further evidence that MLA and the plantar flexors are related was provided by Gross *et al.* (2011) who found that excessive fatigue of the plantar flexors promotes foot pronation and reduced its supination movement (17).

Ghaderiyan *et al.* (15) carried out a comprehensive study with the main goal of determining how a 12-week of rope jumping program affected postural control, static and dynamic balance in a particular population of boys with flat feet between the ages of 10 and 13. 450 male students made up a sizable sample size for the study.

After a preliminary screening procedure, thirty students were carefully selected and allocated at random to the control or experimental groups. The individuals in the experimental group, who were chosen for the rope jumping program, committed to a 12-week organized training schedule that included three 45-minute sessions per week. During this time, however, the control group did not engage in any structured exercises. Because of this contrast in activity levels, the researchers were able to identify and assess the particular impacts of the rope jumping regimen.

The impact of the rope jumping program was assessed using a multifaceted method by the researchers to measure many areas of the participants' physical ability. A customized foot scan instrument was used to quantify postural control. The stork stand balance test was used to measure static balance, and the Y balance test was used to assess dynamic balance. These evaluations gave researchers a thorough grasp of how the intervention affected several aspects of balance and postural control in the subjects of the trial.

Following the conclusion of the intervention and data analysis, the study produced impressive findings. Based on the comparison of the before and after tests data, the statistical results showed significant within-subject changes, with improvements in postural control, static balance, and dynamic balance highlighted. In addition, the program for rope jumping was shown to be effective, as seen by the significant interaction effects between SFE group allocations and testing times for all variables. These specific interventions are important for improving the physical well-being of this population, as seen by the improvements in postural control, static balance, and dynamic balance. As part of a comprehensive strategy to enhance balance and control of body posture in individuals with flat feet, the findings support the inclusion of rope jump activities (18).

The study carried out by Moon (5) involved 32 individuals who were flat-footed and were divided into two groups: the Sensory motor training alone and Sensory motor training combined with short foot exercises (SFE) group. The experiment was single-blinded and randomized controlled testing. Thrice a week during six weeks, each group participated in an eighteen-session SMT program. Through the evaluation of the H-reflex, static and dynamic balance, and the study sought to examine the effects of SMT *versus* incorporated SMT and SFE on stability in posture. The betterment of both static and dynamic balance was shown in the combined Sensory motor training and short foot exercises intervention as compared to SMT alone. This suggests that the combination method is more effective in improving postural stability in people with flat feet (19).

The integration of Sensory motor training with SFE led to significant improvements in muscle spindle functioning and proprioceptive feedback connected to the intrinsic foot muscles (IFM), according to the overall findings of a study conducted by Pabon-Carrasco M *et al.* in 2020 (20). A few studies discovered that the short foot exercise technique was beneficial after four to six weeks (21).

A study, carried out by Utsahachant *et al.* (21) aimed to compare the effects, after six weeks of training, of both SFE and SFEcombined with a lower limb training program to a control group that did not engage in any exercise. The study concentrated on intrinsic foot muscle control, static foot alignment and dynamic foot performance in individuals exhibiting flexible flatfoot. This included foot dynamics and the Center of Pressure Excursion Index in the stance phase of gait.

The forward foot propulsion, in the push-off stage of walking, can be improved with the use of the short-foot exercise and SFE combined with a lower limb training program. Furthermore, investigated was the enhancement of dynamic foot function, encompassing Medial Longitudinal Arch movement and Center of Pressure Excursion Index. More specifically, the SFLE program enhanced control over proximal muscles, which led to a higher shift in CPEI in the stance phase. These results suggested that both intervention programs might be used as a corrective treatment for people with flexible flat feet (22).

Of the six investigations, four reported improvements in the MLA using SFEs. More than five weeks of intervention duration showed MLA enhancement (23, 24) but fewer than five weeks of interventions showed no significant change (25). In a pilot study, Lynn SK *et al.* (2012) discovered that short-distance runners with high-arched feet exhibit superior dynamic balance and speed compared to individuals with low or neutral arch feet (26).

Ramachandran AK *et al*. (2021) study on plyometric exercise in the rehabilitation of athletes highlights the physiological responses and clinical applications of plyometric exercises. In the context of lower limb strength, plyometric training can significantly enhance the explosive strength of the lower limbs. The rapid stretch-shortening cycle involved in plyometric exercises helps improve muscle strength, power, and hypertrophy, which can contribute to better foot posture and overall locomotion (27).

Sabillah *et al*. (29) the study findings suggest that plyometric exercises, when combined with leg muscle strength training, play a significant role in enhancing the power and posture of the lower limb. This is supported by the observed increase in leg power due to the interaction between plyometric exercises and leg muscle strength (28).

A study conducted by Asadi aimed to assess the impact of plyometric neuromuscular exercises on the postural control performance of ten young male volleyball players (30).

According to the findings of the study by Stecco *et al*., the plantar fascia not only supports the longitudinal arch of the foot but also contributes to proprioception and peripheral motor coordination. Their research suggests that the relationship between the plantar fascia and the paratenon of the Achilles tendon implicates triceps surae structures in plantar fasciitis pathology. Therefore, interventions targeting these structures could be beneficial in managing flatfoot (8).

The findings of this study provide valuable insights into the efficacy of different intervention specifically, short-foot exercise along with dynamic balance training, and plyometrics in improving both balance and the arch of the foot, with a particular emphasis on individuals with flexible flat feet. The results suggest that both the interventions contribute positively to the enhancement of these parameters, aligning with existing literature on interventions for foot-related conditions. However, the study's data reveal that plyometric exercises stand out as the most effective and significant approach in addressing the challenges associated with flexible flat feet.

The observed improvements in balance and foot arch following short-foot exercise, dynamic balance training, and plyometrics underscore the versatility of these interventions in addressing the multifaceted nature of flexible flat foot conditions. Short-foot exercises, known for their focus on intrinsic foot muscle engagement, and dynamic balance training, emphasizing coordination and stability, have demonstrated positive effects. Yet, the standout efficacy of plyometrics suggests that the dynamic, explosive nature of these exercises may uniquely target and strengthen the neuromuscular components crucial for balance and arch support in flexible flat feet.

Limitations

The sample size was relatively small, and the study duration was limited to six weeks. The research employed convenience sampling, potentially introducing selection bias and restricting the generalizability of the sample. The study had a relatively short intervention duration of six weeks, which may not be sufficient to fully evaluate the effects of the interventions. The study did not collect proper follow-up data, which may limit the ability to assess the long-term effects of the interventions.

CONCLUSIONS

In conclusion, both short-foot exercise with dynamic balance training and plyometric exercises contribute significantly to improving foot posture and dynamic balance in individuals with flexible flatfoots. Plyometric exercises, with their focus on rapid and forceful movements, showed superiority, particularly in enhancing dynamic balance. These findings offer valuable guidance for healthcare professionals involved in the management of flexible flatfoot and underscore the importance of tailoring interventions to individual needs and characteristics.

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None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

VK: methodology, investigation, formal analysis, writing - original draft. KM: conceptualization, methodology, supervision, writing- review & editing.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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