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Acute effect of short foot exercise on dynamic stability and foot kinematic in trail runners

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Background. Trail runners face uneven terrains requiring optimal foot stability and postural control. The short foot exercise (SFE) may acutely enhance dynamic balance and foot arch height, potentially mitigating injury risk. This study aimed to evaluate the acute effects of the SFE on postural control and kinematics during a dynamic balance test in trail runners, considering the variations in the weekly training volumes of the participants.
Methods. Sixteen adult trail runners (mean age 36 ± 8.4 years; 50% male) with at least one year of trail running experience were evaluated. Dynamic balance was assessed using the Y-Balance Test (YBT), and foot kinematics were measured via the Arch Height Index (AHI) using a 3D motion capture system. Baseline measurements were taken, followed by an SFE protocol: the participants had to perform 12 repetitions of 5-second contractions, which they did in 3 sets with 2 minutes of rest between sets. Immediately afterward, YBT and AHI were reassessed.
Results. YBT showed significant improvements in all reach directions after the application of the SFE ($p < 0.05$). In contrast, no significant changes were observed in the AHI across reach directions ($p > 0.05$). However, subgroup analysis by weekly training volume revealed that participants with higher weekly volumes experienced a significant increase in anterior AHI (mean difference = -0.54 mm; 95% CI = -1.09 to 0.01; $p = 0.027$; effect size = 0.13). The SFE may acutely improve foot kinematics and dynamic balance in trail runners; however, these effects are influenced by the weekly training volume of the participants.

Acute Effect of Short Foot Exercise on Dynamic Stability and Foot Kinematic in Trail Runners

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Abstract

Background. Trail runners face uneven terrains requiring optimal foot stability and postural control. The short foot exercise (SFE) may acutely enhance dynamic balance and foot arch height, potentially mitigating injury risk. This study aimed to evaluate the acute effects of the SFE on postural control and kinematics during a dynamic balance test in trail runners, considering the variations in the weekly training volumes of the participants.

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Introduction

Trail running is an outdoor running discipline performed across diverse terrains, including mountains, deserts, native forests, tropical jungles, coastal areas, grassy plains, and arid regions (Scheer et al., 2020). In recent years, this sport has experienced remarkable growth in popularity, establishing itself as the leading all-terrain running discipline (Mocanu, 2015). Trail runners face various challenges, including significant elevation changes, diverse environmental and weather conditions, and uneven terrains (Mocanu, 2015; Scheer et al., 2020). While the physical health benefits of running are well-documented, navigating trails with heterogeneous surfaces increases the risk of injury (Matos et al., 2021; Viljoen et al., 2021). The ankle-foot joint complex is among the most frequently injured regions of the body, accounting for approximately 50% of injuries, characterized by ligament, or joint capsule injuries (Viljoen et al., 2021, 2022).

Trail running requires quick cognitive processing of the environment, the ability to respond to variations in the ground surface, obstacle avoidance, and positional adjustments of the foot in response to the terrain's elevations (Vincent, Brownstein & Vincent, 2022). To maintain postural control in this type of activity, runners use anticipatory and reactive strategies in response to obstacles on the roads(Vincent, Brownstein & Vincent, 2022). The short foot exercise (SFE) has been used to improve postural control in various demanding motor tasks by contracting and activating the intrinsic foot muscles (IFM)[7]. The IFM are a subset of the central foot system that play an important role in static and dynamic posture, helping to improve movement control, stabilization, and foot flexibility during stance phase[8]. They allow for the absorption of impact energy, enhance the dynamic alignment of the foot, support the medial longitudinal arch (MLA) of the foot, and provide plantar proprioceptive feedback (Kelly et al., 2014; McKeon et al., 2015). The most important element of foot function is the MLA, as postural demands increase, the IFM stabilize the foot, directly improving the posture of the foot arch via significant changes in the length and height of the MLA (Kelly et al., 2012, 2014; Mulligan & Cook, 2013). These foot arch changes can be compared through validated clinical kinematic methods such as the Arch Height Index (AHI), which is used to evaluate changes in MLA in static and dynamic tasks (Uhan et al., 2023). In recent years, it has been demonstrated that foot training with the SFE provides benefits in static and dynamic postural control in healthy young individuals, people with flat feet, and even those with ankle instability. The SFE improves the muscle strength of the IFM, consequently, achieving adequate support of the medial longitudinal arch (Lynn, Padilla & Tsang, 2012; Mulligan & Cook, 2013; Kim & Kim, 2016; Lee & Choi, 2019; Moon & Jung, 2021). Furthermore, it has been demonstrated that training this musculature reduces the risk of injury by 2.2 times compared to a control group of recreational runners (Suda et al., 2022). The authors of this study point out that with greater foot strength, the runner may sustain longer distances without developing a running-related injury, as the SFE acts as a protective factor against lower limb injuries. To the best of our knowledge, no studies have explored the benefits of strengthening the intrinsic foot musculature in trail runners.

Training workloads are also central to the development of injuries for runners (Drew & Finch, 2016). It has been proposed that higher training loads lead to higher injury rates (Gabbett, 2016; Soligard et al., 2016), and if these weekly training workloads increase rapidly, the athlete faces a high risk of injury (Gabbett et al., 2016). Training for more than 5.4 hours per week, including competition hours, is associated with a higher risk of injury in individual sports (Hartwig et al., 2019). Furthermore, in team sports, an additional hour of weekly training has been found to increase the risk of injuries in young athletes, with ankle sprains being among the most common injuries (Giroto et al., 2017). However, if training workloads are applied progressively, they can foster resilience in athletes, resulting in lower injury rates and performance optimization (Gabbett, 2016).

Foot stability, directly modulated by the intrinsic foot muscle, may play an important role in motor tasks requiring dynamic postural control or movements that demand more effort, such as climbing slopes, accelerating, decelerating, or jumping (Besomi et al., 2018). However, the potential acute effects of the short foot exercise on dynamic postural control and foot kinematics have not yet been investigated as a possible strategy for injury prevention in trail runners. Furthermore, the influence of weekly training volume on foot stability and kinematics in trail runners remains unknown. This study aimed to evaluate the acute effects of the short foot exercise on postural control and foot kinematics during a dynamic balance test in trail runners, considering the participants' varying weekly training volumes. We hypothesize that the short foot exercise will immediately enhance dynamic balance and increase the arch height index of the foot in trail runners. Furthermore, we anticipate that runners with higher weekly training volumes will exhibit a greater improvement in arch height index and perform better on the dynamic balance test compared to those with lower training volumes.

Material & Methods

Study design

This was a quasi-experimental study. Dynamic balance measurements were taken before and after the application of the short foot exercise using the Y-Balance Test (YBT) in the anterior, posterolateral, and posteromedial directions. Additionally, foot kinematics were assessed through the arch height index during the YBT performance.

Participants

A non-probabilistic convenience sampling was conducted, resulting in a sample of 16 volunteers. The sample size was determined using G*Power software (version 3.1.9.7; Franz Faul, University of Kiel, Kiel, Germany) based on an effect size of 0.66 in the SFE, an alpha error of 0.05, and a power of 0.80, which were calculated from data from a previous study (Lynn, Padilla & Tsang, 2012). To recruit participants, every running club in the city of Valdivia (Chile) was contacted by sending a form via email to identify potential participants. The club members answered questions regarding the study's inclusion and exclusion criteria. Those who met the criteria were invited by phone to participate in the study. The study included trail runners who were 18 years old or older, both female and male, who were registered and active in an official running club in Valdivia, with at least 1 year of experience in trail running, and who had completed a trail event of 10 km or more in the last year. Additionally, they had to accumulate a weekly distance volume of 20 km or more, with a training frequency of at least three times per week and a total of four hours of training per week (Besomi et al., 2018; Suda et al., 2022). Participants with functional lower limb injuries that prevented them from practicing trail running, such as fractures or ligament injuries, were excluded. Additionally, individuals undergoing physical therapy for strengthening the intrinsic foot muscles and ankle, or for specific balance rehabilitation, as well as those wearing minimalist footwear, were also excluded (Lynn, Padilla & Tsang, 2012; Suda et al., 2022).

Ethical approval

All participants received written and oral information about the project and gave informed consent, consistent with the Helsinki Declaration guidelines before participating in the study. The research protocol received approval from the Health Service Ethics Committee, Valdivia, Chile (N° 159).

Procedures

Participants were invited to the Human Movement Analysis Laboratory at the School of Kinesiology of the Universidad Austral de Chile. Before beginning the study, the principal investigator showed and explained the SFE and the YBT. The participants practiced familiarizing themselves with the study protocol. Data such as sex, age, weight, height, BMI, years of running experience, weekly training volume (days per hour of training), and weekly accumulated kilometers were recorded on a data sheet. The study, conducted in a single session lasting approximately 2 hours, began with measurements of leg length, knee width, and ankle width. Reflective markers were then placed on the ankle-foot segment to evaluate kinematics using infrared cameras (VICON model T10-S, Vicon, Oxford, UK). Subsequently, the participants performed the YBT before the foot intervention. As soon as the initial YBT evaluation was completed, the participants immediately performed the SFE protocol. At the end of the SFE protocol, the YBT was immediately performed again to assess the dependent variables (AHI, YBT).

Arch Height Index. For the evaluation of foot kinematics, a 3D motion capture system with 6 infrared cameras was used, with a capture frequency of 120 Hz. Reflective markers were attached to the skin using double-sided adhesive tape, and placed specifically on different bony segments, as shown in Figure 1. This allowed for the digital reconstruction and kinematic modeling of the ankle and foot using the Oxford Foot Model (Merker et al., 2015). Through this model, the researchers were able to calculate the AHI of the foot in millimeters and how it varies during motor activity in anterior, posterolateral and posteromedial directions. The AHI represents the kinematic changes that the MLA may undergo during a motor task (Uhan et al., 2023).

Insert Figure 1 near here

Y-Balance Test. Dynamic balance was assessed using the YBT (with an intrarater reliability coefficient ranging from 0.85 to 0.91) (Plisky et al., 2024), which was set up on the floor using adhesive tape in the anterior, posterolateral, and posteromedial directions. Cones placed at the start of each direction were pushed by the subject with the reaching foot. The distance reached was measured in centimeters. Before the official measurements, the participants were allowed to perform 6 practice trials for each reach direction to familiarize themselves with the test. During the official tests, the participants stood barefoot with the toes of the dominant foot (defined as the foot with which they would kick a ball) behind a previously marked line. While maintaining balance on one leg, the subjects attempted to push the reach indicator (cone) with the most distal part of the foot in the three directions, trying to reach the greatest possible distance. To improve the reproducibility of the test and establish a consistent protocol, a standard order was developed and used, which consisted of reaching in the anterior direction first, followed by a posterolateral, and finishing with the posteromedial reach. This sequence was repeated three times per direction. The test was considered invalid and had to be repeated if the subject failed to maintain the unipedal posture on the platform, failed to maintain contact of the reaching foot with the reach indicator, used the reach indicator to maintain balance, or could not return the reaching foot to the initial position (control position) (Plisky et al., 2024). Once each round was completed, the distance reached was recorded, and results were normalized using the following formula:

$$\% \, Normalized \, reach \, distance = \frac{reach \, distance \, (cm)}{leg \, length \, (cm)} \times 100$$

Short Foot Exercise. The participants familiarized themselves with the SFE to understand the specific muscle contraction they needed to perform. The exercise consisted of the participants sitting with their feet flat on the ground and performing a voluntary and conscious contraction of the IFM of the dominant foot. The participant attempted to bring the metatarsals of the foot toward the heel and the heel toward the metatarsals without generating flexion of the metatarsophalangeal joints. The SFE was applied immediately after completing the YBT. The participants had to perform 12 repetitions of 5-second contractions, which they did in 3 sets with 2 minutes of rest between sets (Lee, Cho & Lee, 2019). Once the protocol was completed, the YBT evaluation was immediately repeated to measure the dependent variables after the application of the SFE.

Statistical analysis

The study sample was analyzed according to sex, age, weight, height, BMI, accumulated kilometers, years of practice, and weekly training volume, using Percentages, frequencies, and standard deviations. To determine data distribution and variance homogeneity, the Shapiro-Wilk test and Levene's test were used, respectively. The paired sample t-test was used to compare pre and post the application of the SFE Subsequently, a two-factor repeated measures analysis of variance (ANOVA) (time: pre and post SFE application; training volume: low and high) was performed. Participants who practiced less than 5.4 hours of training per week were considered to have a low training volume, while those who practiced 5.4 hours or more (Hartwig et al., 2019) were considered to have a high training volume. . Consequently, four groups were created for analysis. Multiple pairwise comparisons were applied using Bonferroni-corrected t-tests to determine if there were significant interactions between factors. Additionally, the effect size (ES) was calculated based on Cohen's d and was reported as no effect (0 to 0.19), small effect (0.20 to 0.49), moderate effect (0.50 to 0.79), or large effect (0.80 or greater) (Fritz, Morris & Richler, 2012). For all analyses, a p-value < 0.05 was utilized. IBM SPSS software version 29.0.1.0 for Windows (SPSS Inc, Chicago, IL, USA) was used for statistical analysis, while GraphPad software version (10.2.1.395) was used for graphing the results.

Results

Table 1 presents the demographics, anthropometrics, and running variables of the study sample. Study sample characteristics were also divided according to the training volume of the participants.

******Insert Table 1 near here***

Arch Height Index

There were no statistically significant differences pre and post-SFE in the anterior [mean difference (MD) = -0.17mm; CI 95% = -0.59 to 0.26; $p = 0.199$], posterolateral (MD = 0.02 mm; CI 95% = -0.76 to 0.79; $p = 0.480$) and posteromedial (MD = 0.07mm; CI 95% = -0.69 to 0.82; $p = 0.428$) directions of the AHI of the foot. However, when categorizing by weekly training volume, ANOVA (pre and post-SFE x weekly training volume) revealed a significant interaction between the factors (df = 1; $F = 8.232$; $p = 0.012$) for the anterior reach direction of the AHI of the foot. The post-hoc analysis showed significant differences pre and post application of the SFE among participants with a high training volume (MD = -0.54 mm; CI 95% = -1.09 to 0.01; $p = 0.027$; ES= 0.13) as seen in Figure 2, while no significant differences were observed among participants with a low training volume. No significant differences were observed for the posterolateral and posteromedial reach directions of the AHI ($p > 0.05$).

Insert Figure 2 near here

Y-Balance Test

There were significant differences pre and post SFE application in the anterior (MD = -1.9%; CI 95% = -3.0 to -0.7; $p = 0.002$; ES= 2.21) posterolateral (MD = -2.6%; CI 95% = -5.4 to 0.3; $p = 0.037$; ES= 5.32) and posteromedial (MD = -5.2%; CI 95% = -8.3 to -2.0; $p = 0.002$; ES= 5.88) directions of the YBT. Furthermore, when categorizing by weekly training volume, ANOVA (pre and post-SFE x weekly training volume) revealed a significant interaction between the factors (df = 1; $F = 12.377$; $p = 0.03$) for the anterior direction variable of the YBT. The post-hoc analysis showed significant differences pre and post application of the SFE among participants with a low training volume (MD = -2.4%; CI 95% = -4.4 to -0.4; $p = 0.018$; ES= 0.09) as seen in Figure 3, while no significant differences were observed among participants with a high training volume. No significant differences were observed for the posterolateral and posteromedial reach directions of the YBT ($p > 0.05$).

Insert Figure 3 near here

Discussion

In the present study, we investigated the acute effect of SFE on dynamic balance and foot kinematics among trail runners, as well as the influence of weekly training volume on the study variables. A significant improvement in the AHI of the foot was observed for the anterior reach of the YBT among participants with a high weekly training volume, while the percentage of anterior reach of the YBT increased significantly among participants with a low training volume. To our knowledge, no studies have analyzed the influence of SFE on the foot kinematics and balance of trail runners. These findings suggest a positive effect of SFE in improving the AHI of the foot and dynamic balance in the anterior reach among trail runners; however, training volume influences the observed changes.

The abductor hallux is one of the largest intrinsic muscles of the foot, and it contributes to the supination of the midtarsal joint against the pronation force of the ground reaction. In other words, it stabilizes and even increases the medial longitudinal arch (Jung et al., 2011). Evidence shows that the IFM, such as the flexor digitorum brevis, quadratus plantae, and especially the abductor hallux, exhibit greater intrinsic activation in response to increased postural demands. Consequently, during single-leg support, there is greater IFM activation to stabilize and prevent the collapse of the MLA (Jung et al., 2011; Kelly et al., 2012). Our study found that the SFE, which strengthens the IFM, improved the AHI of the foot, which represents the kinematic changes of the MLA, in the anterior reach of the YBT among participants with high training volume. This finding is consistent with prior literature that supports an association between high chronic training loads and better performance and physical condition (Gabbett, 2016), including in individual sports like running (Scrimgeour et al., 1986), provided that the training load is appropriate (Gabbett, 2016). An optimal load maximizes performance potential while simultaneously reducing the negative consequences of training, such as injuries, fatigue, or overtraining (Morton, 1997). Similarly, the load or frequency of the short foot exercise might influence foot mechanics and performance among trail runners, given that fatigue of the IFM is significantly correlated with greater navicular drop (Headlee et al., 2008). This is particularly relevant considering that participants with low training volume did not show changes in the AHI of the foot pre-and post SFE. Muscle activation plays a key role in foot dynamics, but postural control is equally essential (Méndez-Rebolledo et al., 2015; Saavedra-Miranda & Mendez-Rebolledo, 2016). Previous research has shown that the short foot exercise stimulates proprioceptors in the sole of the foot, increasing afferent input to the spinal cord. This, in turn, enhances voluntary muscle activation and stability (Newsham, 2010). This would explain the significant changes in dynamic balance in all directions when comparing pre and post-SFE among the evaluated trail runners. However, when comparing according to training volume, only the subjects with low training volume showed significant improvements in the anterior reach of the YBT. These results contradict the previously described association of high loads with performance improvements (Gabbett, 2016). Our results can be interpreted based on the premise that individuals with lower weekly training volumes are less conditioned. Consequently, their initial adaptation to a functional test like the YBT may result in greater gains following training compared to those with more experience and higher weekly training volumes. For the latter group, the potential for improvement is smaller or occurs more gradually.

In the anterior reach of the YBT, the movement is performed in the sagittal plane along the mediolateral axis. The longitudinal arch of the foot plays a crucial role in maintaining unipedal stability within this axis (Jung et al., 2011). The IFM are fundamental for single-leg balance, as their activity is strongly correlated with mediolateral sway (Kelly et al., 2012). In our study, improvements were observed in both kinematics and dynamic balance during the anterior reach. Additionally, previous research indicates that asymmetries in the anterior reach results of the YBT are associated with a higher risk of non-contact injuries in collegiate athletes (Smith, Chimera & Warren, 2015). Therefore, our results support our hypothesis that the SFE can reduce the likelihood of non-contact injuries during running due to better neuromuscular and postural control. However, this hypothesis requires confirmation through longitudinal and prospective studies that evaluate injury incidence rates among a cohort of trail runners exposed to the SFE and a cohort exposed only to regular training.

Limitations of this study include that the SFE was performed in a sitting position, which may have influenced muscle recruitment. Previous research suggests that performing the SFE in a standing position elicits a greater maximum voluntary contraction of the intrinsic foot muscles compared to the sitting position (Choi et al., 2021). Additionally, the study sample was recruited by convenience, resulting in a small sample size, and it may not be representative of the general population of trail runners. Furthermore, the long-term effects of the SFE could not be assessed, and the study lacked a control group. Therefore, future research should include extended training and follow-up periods, as well as a larger sample size, to better evaluate the long-term impact of the SFE on trail runners.

This study opens a new line of research on trail runners. To our knowledge, it is the first study to measure the effect of the SFE on foot kinematics and postural control in this population. It provides relevant information for runners and sports personnel and indicates that the SFE could be useful as a pre-activation strategy to prepare the foot muscles for the perturbations and loads that trail running may present.

Conclusion

The SFE acutely improves the AHI of the foot in the anterior reach of the YBT in participants with high training volume, while runners with low training volume significantly improved their dynamic balance in the anterior reach. Therefore, the SFE can be useful before a race to activate the IFM and provide greater dynamic stability when practicing or competing in trail running. Although these results are promising, longitudinal and prospective studies are necessary to evaluate the injury incidence rates in a cohort of trail runners exposed to SFE training compared to a cohort exposed only to their usual training.

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Table 1 (on next page)

Demographic characteristics, anthropometry and variables associated with the practice of Trail Running (α).

(α) Values are presented by means, ± (Standard deviation) or percentages.

Table 1. Demographic characteristics, anthropometry and variables associated with the practice of Trail Running (α).

Variables	Trail Runners (n = 16)	Low training volume (n = 9)	High training volume (n = 7)
Male (n, %)	8 (50)	5 (55.6)	3 (42.9)
Female (n, %)	8 (50)	4 (44.4)	4 (57.1)
Age (year)	36 ± 8.4	38 ± 9.5	32.4 ± 6.5
Size (cms)	165.7 ± 7.1	165 ± 5.7	166.6 ± 9.0
Weight (kg)	66 ± 7.8	66.4 ± 7.26	65.3 ± 9.0
BMI (kg/m^2)	24.0 ± 1.7	24.3 ± 1.65	23.5 ± 1.7
Training volume (h x Training days / Week)	6.0 ± 1.9	4.7 ± 0.61	7.7 ± 1.5
Practice years (years)	3.5 ± 2.7	4.0 ± 3.07	2.9 ± 2.3
Weekly kilometers (km/week)	53.1 ± 17.7	47.8 ± 19.1	60 ± 14.1

(α) Values are presented by means, ± (Standard deviation) or percentages.

Figure 1

(Left) Markers on the foot shown from a medial view. (Right) Markers on the foot and ankle shown from a lateral view.

RMMA: Medial Malleoli, RHLX: Hallux, RD1M: 1 st Metatarsal, distal medial, RP1M: 1 st Metatarsal, proximal medial, RSTL: Sustaniculum Tali, RHEE: Heel, RCPG: Posterior end of the calcaneus, RPCA: Posterior calcaneus proximal, RLCA: Lateral calcaneus, RP5M: 5 th Metatarsal, proximal lateral, RD5M: 5 th Metatarsal, distal medial, RTOE: 2 nd Finger base, RANK: lateral malleolus.

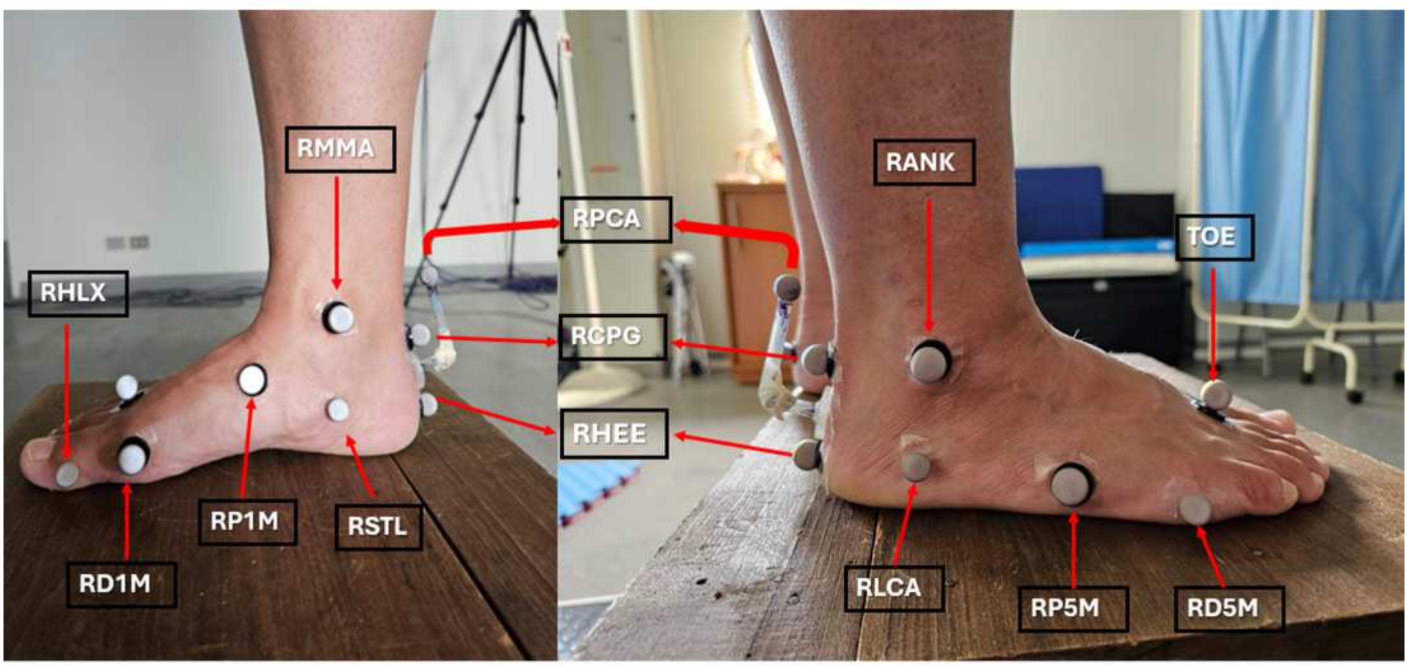


Figure 2

Post-hoc comparison of the Arch Height Index in the anterior reach of the Y-Balance Test between subjects with low and high volume training pre and post Short Foot Exercises application.

*$p < 0.05$.

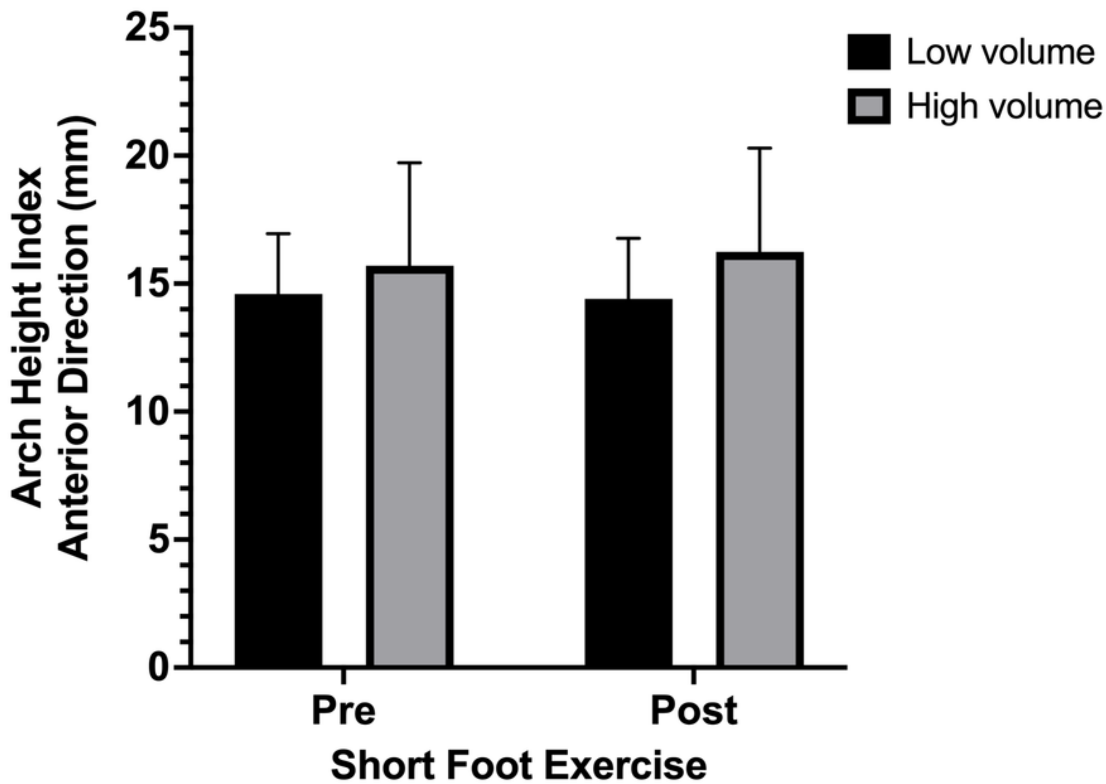
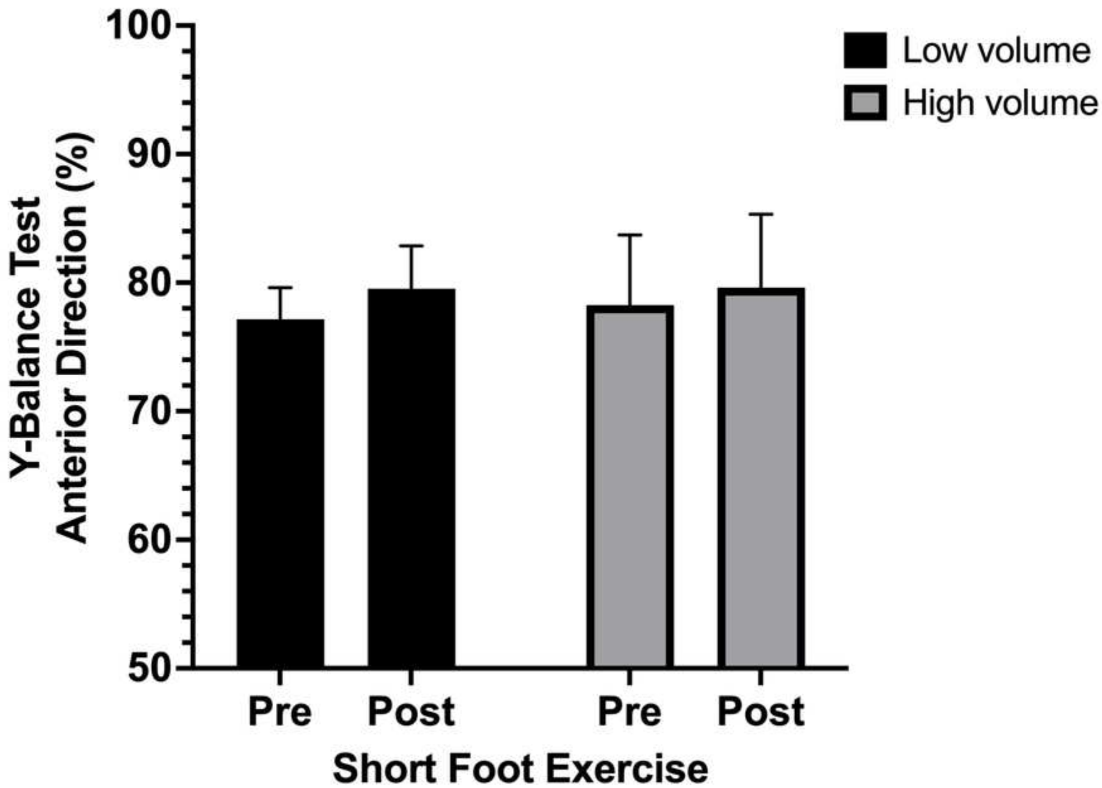

25
20
15
10
5
0
Arch Height Index
Anterior Direction (mm)
Low volume
High volume
Pre
Post
Short Foot Exercise

Figure 3

Post-hoc comparison of the percentage of reach in the anterior direction of the Y-Balance Test between subjects with low and high training volume pre and post Short Foot Exercises application.

*$p < 0.05$


100
90
80
70
60
50
Y-Balance Test
Anterior Direction (%)
Low volume
High volume
Pre
Post
Pre
Post
Short Foot Exercise