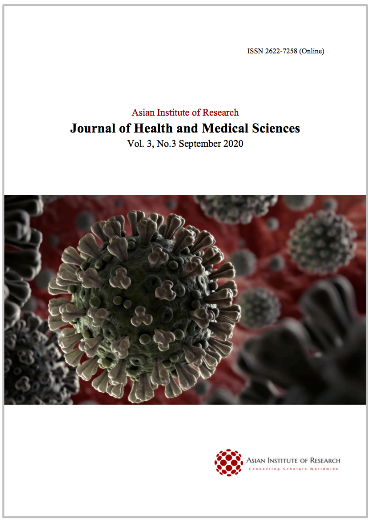

Journal of Health and Medical Sciences

Nakagawa, Kazumasa, Mitomo, Akari, and Takahashi, Yuko. (2020), Effect of a Foot Arch Exercise Program for High School Runners. In: *Journal of Health and Medical Sciences*, Vol.3, No.3, 329-337.

ISSN 2622-7258

DOI: 10.31014/aior.1994.03.03.128

Published by:
The Asian Institute of Research

The Asian Institute of Research
Journal of Health and Medical Sciences
Vol.3, No.3, 2020: 329-337
ISSN 2622-7258

DOI: 10.31014/aior.1994.03.03.128

Effect of a Foot Arch Exercise Program for High School Runners

Kazumasa Nakagawa[1,2], Akari Mitomo[3,4], Yuko Takahashi[1]

[1] Takasaki University of Health and Welfare, Faculty of Health Care, Department of Physiotherapy, Gunma, Japan
[2] Takasaki University of Health and Welfare, Graduate School of Health Care, Department of Physiotherapy
[3] Student of Takasaki University of Health and Welfare, Graduate School of Health Care, Department of Physiotherapy
[4] Gunma Sports Orthopaedics

Correspondence: Kazumasa Nakagawa, Department of Physiotherapy, Takasaki University of Health and Welfare, Takasaki, Nakaoruicho, 501, Japan. Tel: +81-27-352-1291. E-mail: nakagawa-ka@takasaki-u.ac.jp

Abstract
The short-foot exercise (SFE) has been used as a training method for the intrinsic muscles of the foot. The effectiveness of SFE is mostly reported in short-term interventions, with only a few reports of its sustained effects. The purpose of this study was to verify the effect of SFE training for 31 high school runners. All subjects were measured 3 times for 8 months, and underwent ankle stabilization training during the study period. During the first 3 months of the study period, one randomly selected group of subjects underwent SFE, and another group did not, the non-SFE group. Measurement items were pain, navicular drop (ND), modified star excursion balance test (mSEBT), ankle dorsiflexion angle and toe gripping force. A one-way analysis of variance with post-hoc Tukey's test was performed to evaluate differences between groups with multiple comparison analysis for each measurement. The number of physical problems in the SFE group was lower at the time of the second measurement (M2) but increased at the third measurement (M3). In the SFE group, the ND value was significantly decreased at the time of the M2 but was significantly increased at the M3. Toe gripping force showed a significantly larger value in the SFE group at the M3. It was suggested that the SFE was effective for ND and decreasing some pains. There are no studies referring to the sustainability of the effects of the SFE, so these results can be a reference for future investigation of this exercise.

Keywords: Short Foot Exercise, Medial Longitudinal Arch, Sports Injuries, Intrinsic Foot Muscles, Flat Foot, Modified Star Excursion Balance Test, Navicular Drop

1. Introduction

1.Background

The arch of the foot is important when considering foot function. In addition to the mechanical support by bones, joint capsules, and ligaments in the medial longitudinal arch (MLA), the functional support of muscles is very important in absorbing load shock (Hicks, 1954). In order to maintain MLA, the functions of the external foot muscles such as the tibialis posterior muscle and flexor pollicis longus muscle and the intrinsic muscles of the foot such as abductor pollicis longus are important (Pohl, Rabbito & Ferber, 2010). In order to maintain the MLA, the functions of both the extrinsic and intrinsic foot muscles are important (Pohl, Rabbito & Ferber, 2010). In particular, the intrinsic muscles play a critical role in the regulation of absorption and propulsion during dynamic activities (McKeon & Fourchet, 2015). Flatfoot is a common phenomenon caused by a decrease in the arch and excessive pronation of the foot, and is reported to cause overuse injuries and syndromes including plantar fasciitis, achilles tendonitis, hallux valgus, posterior tibialis tendon dysfunction, and patellofemoral pain syndrome (Pohl, Hamill & Davis, 2009, Ryan et al., 2009, Sherman, 1999, Tome, Nawoczenski, Flemister, & Houck, 2006). In terms of maintaining the MLA, when the function of the intrinsic muscles deteriorates, the extrinsic muscles may contract excessively to compensate, thereby increasing traction stress and causing impairments.

Running motion is one of many basic movements used when playing sports. Because running is not only for training athletes but also an easily engageable exercise for ordinary individuals, it has become very popular. Although running promotes positive psychological and physical effects, repetitive motions and other factors are often involved in the activity, frequently causing musculoskeletal disorders. These disorders are more pronounced among track and field athletes who are forced to run at higher levels. Indeed, reports have shown that chronic disorders were strongly associated with the motions involved in running (Zemper, 2005, Lysholm & Wiklander, 1987). Long-distance runners in particular often suffer from chronic pain in the lower limbs and other areas (Tschopp & Brunner, 2017, Dimeo, Peters & Guderian, 2004). Focusing on the arch of the foot, there are several studies of different aspects of the motions involved, such as an excessive ankle/foot pronation in the stance phase of running (Jam, 2006), the lowering of the MLA with navicular drop (ND) (Headlee, Leonard, Hart, Ingersoll, and Hertel, 2008), changes in rigidity of the plantar arches (Miller, Whitcome, Lieberman, Norton & Dyer, 2014), and the increase in impact and acceleration on the tibia during running (Crowell & Davis, 2011). Impaired function of the arch is also reported to be involved in shin splints (medial tibial stress syndrome), posterior tibial tendonitis and flatfoot, all of which can trouble track and field athletes (Pohl, Hamill & Davis, 2009, Newman, Witchalls, Waddington & Adams, 2013).

Because track and field athletes continuously apply load to their feet during running, exercises for training the intrinsic muscles may reduce the load on the extrinsic muscles, which in turn can then better maintain arch function (Sulowska, Oleksy, Mika, Bylina & Sołtan, 2016). Gooding et al. compared four exercises (the short-foot exercise, toes-spread-out exercise, first-toe-extension exercise, and second- to fifth-toe-extension exercise) for training the intrinsic muscles of the foot, and reported on the effectiveness of each exercise (Gooding, Feger, Hart & Hertel, 2016). One of the four exercises studied, the short-foot exercise (SFE), has been used in many studies as a training method for the intrinsic muscles of the foot (Jung, Koh & Kwon, 2011, Okamura, Knai, Hasegawa, Otsuka & Oki, 2019, Namsawang, Eungpinichpong, Vichiansiri & Rattanathongkom, 2019). The SFE selectively trains the abductor hallucis muscle, which is the largest of the intrinsic muscles and is highly active during loading. It holds the arch by contracting the abductor hallucis muscle during loading. It was reported that the SFE appeared to train the intrinsic muscles more effectively than the towel-curl exercise (Lynn, Padilla & Tsang, 2012), and there was preliminary evidence suggesting that SFE training may have value in statically and dynamically supporting the MLA (Mulligan & Cook, 2013). There are also reports that it contributes to reducing flatfeet (Okamura et al., 2020, Kim EK & Kim JS, 2016), varus sprains or foot instability (Lee E., Cho, Lee S., 2019), and knee problems such as patellofemoral pain syndrome (Lee, Yoon & Cynn, 2017). Although there are some negative reports about its effects (Haun, Brown, Hannigan & Johnson, 2020), it seems to be considered a general training method for the intrinsic muscles.

1.2 Purpose

The effectiveness of SFE is mostly reported in short-term interventions, with only a few reports of its sustained effects. This study provided an opportunity to give training to high school track and field athletes on ankle joints and foot arches with a focus on maintaining and improving arch function. The purpose of this study was to verify the effect of SFE training on the intrinsic muscles of the foot.

2. Method

2.1 Subjectss

An initial group of 49 high school runners were recruited, and then people who were unable to participate in all 3 measurements or be followed during the intervention period were excluded from the study. A total of 31 people (20 men and 11 women; mean age ± standard deviation: 15.6 ± 0.7 years; height: 164.9 ± 8.0 cm; weight: 52.5 ± 6.9 kg) were selected as subjects for this study. All subjects were informed about the purpose and procedures of the study and they provided written informed consent prior to participation. This study was approved by the Takasaki Health and Welfare University Ethics Review Committee (No. 2966).

2.2 Study Design

All subjects were measured 3 times for 8 months, the period between the first measurement (M1) and the second measurement (M2) were 3 months, and the period between M2 and the third measurement (M3) were 5 months. All subjects underwent ankle stabilization training during the study period. During the first 3 months of the study period, one randomly selected group of subjects underwent SFE for the purpose of activating the intrinsic muscles of the foot, and another group did not, the non-SFE group. The results of the 3 measurements in both groups were compared

2.3 Measurements

2.3.1 Pain

At the time of the M1, subjects were asked about any pain occurring during normal running movements in the last half year. In this study, pain was defined as that which caused the individual to miss practice or running for at least 1 day. At the time of the M2 and M3, the subjects were asked similarly about any pain they experienced.

2.3.2 Physical assessment items

2.3.2.1 Navicular drop (ND)

The height from the floor to the lower end of the navicular tuberosity (hereinafter referred to as the arch height) and the foot length from the posterior surface of the calcaneus to the tip of the toe were measured in the unloaded position and the loaded position. The non-loaded position was a sitting position with the hip and knee joints at 90° and no weight applied, and the loaded position was a forward squat with the measured limb forward and the lower leg advanced forward. The value obtained by subtracting the arch height at the load position from the arch height at the non-load position was calculated as ND.

2.3.2.2 Modified Star Excursion Balance Test (mSEBT)

As an evaluation of dynamic balance, the mSEBT was administered (van Lieshout et al., 2016). The maximum reach distance was measured by placing both hands on the lumbar region and performing a reach on one leg in three directions: front, inner back, and outer back. The measurement was performed three times in each direction, and the maximum value was divided by the leg length (distance from the most anterior end of the superior anterior iliac spine to the distal end of the malleolus) to calculate the reach rate. The average value of the measured values in each direction was extracted as data for analysis.

(3) Ankle dorsiflexion angle
Following the method of Bennell et al., a measurement of dorsiflexion was calculated from the inclination angle of the lower leg with respect to the horizontal line of the floor (Bennell et al., 1998). With the subjects' hip and knee joints flexed and loaded on the front leg, we placed the tilt angle meter on the front of the lower leg and measured the angle in the maximum dorsiflexion position. The measurement was performed twice in units of 1° and the average value was calculated.

(4) Toe gripping force
As in another study, toe grip was measured with subjects sitting barefoot with their knee position at 90° flexion and the ankle plantar dorsiflexion at 0° (Nakae, Murata, Kai, Soma & Satou, 2013). The measurement was made using a toe muscle-strength measuring device T.K.K. II 3364 (Takei Koki Co., Ltd.). We fixed the position of the foot by placing the toe on the bar and measured the toe grip force used to pull the bar. The measurement was performed three times on each side and the maximum value was used. The average value of the left and right measurement values was extracted as the data to be used in the analysis in this study.

2.4 Training routine

The ankle stabilization training carried out with both groups consisted of 8 types of training on an unstable plate. These exercises stabilize the ankle joint by stimulating the foot's extrinsic muscles and improve windlass function by stabilizing the hip joint. They consisted of ① heel raise on two legs (10 times), ② one-leg standing with the other leg backward (both sides, 10 seconds each), ③ one-leg standing with the other leg forward (both sides, 10 seconds each), ④ leg swing with one-leg standing (both sides, 10 seconds each), ⑤ one-leg heel raise with knee in an extended position (both sides, 10 times), ⑥ one-leg heel raise with knee in a flexed position (both sides, 10 times), ⑦ two-leg squats (10 times), and ⑧ one-leg squats (both sides, 10 times). Subjects chose between two types of unstable plates that had different levels of difficulty. Both groups conducted these exercises twice a week during the study period.

The SFE was performed only by the SFE group. With reference to the method of Jung et al., the subjects sat in a chair with hip and knee joints at 90° (Jung et al., 2011). They were guided to bring the first metatarsal head close to the heel without bending their toes and to hold this position for 5 seconds, then relax for 3 seconds. This was repeated for 5 minutes on each side (totally 10 minutes on both sides), and the effect was judged by the examiner palpating the abductor malleus of the toe during each exercise. When it was judged that sufficient contraction of the first toe abductor muscles was obtained without the toe flexor and tibialis posterior muscles contracting to compensate, the difficulty was adjusted by performing the same exercise in the standing position. The training was conducted 3 times a week for 3 months.

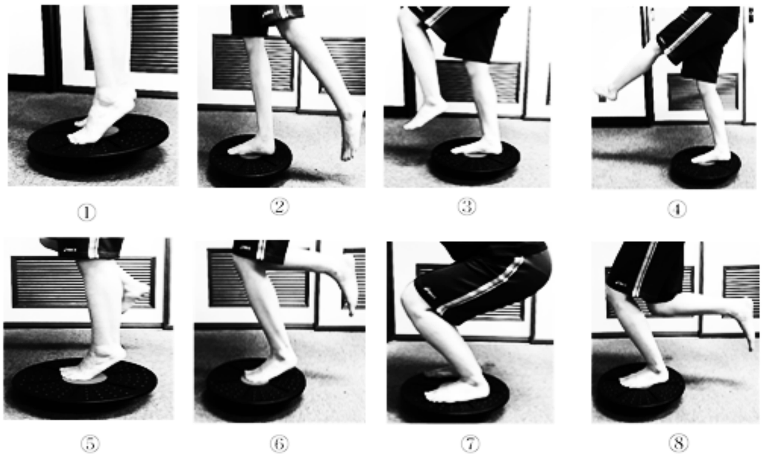

Figure-1 Ankle stabilization training program

① heel raise 1, ② one-leg standing 1, ③ one-leg standing 2, ④ leg swing
⑤ heel raise 1, ⑥ heel raise 2, ⑦ two-leg squat, ⑧ one-leg squat

2.5 Analysis

All measurement results were confirmed to be normally distributed, so a one-way analysis of variance (ANOVA) with post-hoc Tukey's test was performed to evaluate differences between groups with multiple comparison analysis for each measurement. All statistical analyses were conducted using SPSS 24.0J for Windows, with the significance level set at 5%.

3. Results

3.1 Pain

The number of incidents of pain at each measurement time is presented in Table 1. The number of physical problems in the SFE group was lower at the time of M2 but increased at the M3.

Table-1 The number of pains (physical problems)

		SFE Group (n=13)			Non-SFE Group (n=18)		
		1st	2nd	3rd	1st	2nd	3rd
Number		6	3	8	7	10	5
Contents	Upper thigh	0	0	1	1	2	1
	Knee joint	1	0	2	2	1	0
	Lower thigh	3	1	3	2	3	1
	Ankle joint	0	1	1	1	2	1
	Foot/Finger	2	1	1	1	2	2

SFE=Short Foot Exercise

3.2 Physical Assessment

Table 2 shows the results of the measurement and one-way ANOVA, and Table 3 shows the results of the post-hoc test. In the SFE group, the ND value was significantly decreased at the time of the M2 but was significantly increased at the M3, returning to the same level as the initial results. The mSEBT was significantly higher in the non-SFE group at the M2 but no other significant differences were observed. The ankle dorsiflexion angle was significantly larger in both groups at the time of the M2. Toe gripping force showed a significantly larger value in the SFE group at the M3.

Table-2 The results of the physical assessment values and the one-way ANOVA in each group

	SFE Group (n=13)				Non-SFE Group (n=18)			
	1st	2nd	3rd	p value*	1st	2nd	3rd	p
ND (cm)	0.83±0.52	0.57±0.41	0.73±0.38	0.029	1.12±0.72	0.80±0.38	0.90±0.44	0.185
mSEBT (%)	0.91±0.11	0.98±0.09	0.93±0.10	0.163	0.89±0.16	1.01±0.08	0.96±0.08	0.001
ADROM (deg)	40.2±3.5	50.7±4.4	46.5±3.4	0.004	42.9±3.1	53.4±3.2	47.6±3.2	0.002
TGF (kgf)	10.1±5.3	10.7±4.9	14.9±5.6	0.048	9.7±4.2	10.6±5.3	12.8±4.7	0.129

SFE=Short Foot Exercise, ND=Navicular Drop, mSEBT=modified Star Excursion Balance Test
ADROM=Ankle Dorsiflexion Range of Motion, TGF=Toe Gripping Force
Value: average±SD(standard deviation), * = one-way analysis of variance (one-way ANOVA)

Table 3 The results of post-hoc test in each group

	SFE Group (n=13)			Non-SFE Group (n=18)		
	1st-2nd	1st-3rd	2nd-3rd	1st-2nd	1st-3rd	2nd-3rd
ND	0.046 (0.11 - 0.65)	0.771 (-0.27 - 0.48)	0.039 (0.03 - 0.21)			
mSEBT (%)				0.001 (-0.14 - -0.04)	0.173 (-0.09 – 0.01)	0.078 (-0.004 - 0.10)
ADROM (deg)	0.003 (3.4 - 18.1)	0.092 (-0.8 - 13.5)	0.314 (-11.7 - 2.9)	0.001 (3.2 - 14.9)	0.363 (-2.5 - 9.1)	0.050 (-11.6 - 0.01)
TGF (kgf)	0.945 (-5.8 - 4.6)	0047 (-9.9 - -0.03)	0.034 (-9.3 – -0.99)			

SFE=Short Foot Exercise, ND=Navicular Drop, mSEBT=modified Star Excursion Balance Test
ADROM=Ankle Dorsiflexion Range of Motion, TGF=Toe Grip force
Value: p value (95% Confidence Interval)

4. Discussion

In this study, high school track and field athletes were selected as subjects for the purpose of validating SFE training. Benett et al. reported that ND in cross-country athletes in unloaded and standing positions were 3.6 ± 3.3 mm in healthy runners and 6.8 ± 3.7 mm in runners with injuries (Bennett et al., 2001). Since the arch height measurement in this study measures the ND in a state close to motion, the ND was calculated from the difference in arch height between the unloaded position and the loaded position in the knee flexion position, which tended to have a relatively large value. Pes planus was defined as ND exceeding 13 mm (Cote, Brunet, Gansneder & Shultz, 2005), so the subjects in this study were considered appropriate as an intervention target.

In the SFE group, the ND value significantly decreased three months after SFE was performed, indicating effectiveness from the viewpoint of reinforcement in the longitudinal arch of the foot. Uncer et al. reported that short-term intervention was effective for ND (Unver, Erdem & Akbas, 2019), and another study showed that the muscle activity of the abductor hallucis dorsi muscle was significantly increased during SFE training (Jung et al., 2011). In other studies, it has been suggested that the improvement of the arch through use of the SFE was effective for avoiding various injuries (Okamura et al., 2020, Lee, Yoon & Cynn, 2017, Kim EK & Kim JS, 2016). It was possible that the SFE intervention makes it possible to maintain the arch even under load. Although the generalization of the training effects in this study is speculative, the number of pain incidents increased in the non-SFE group at the time of M2 while the number of pain incidents in the SFE group decreased, suggesting the SFE was effective.

Of note, in the SFE group the value of ND at the M3 increased significantly compared with the M2, almost reaching the same level as the M1 and indicating the importance of continuing intervention to maintain improvements. Because the number of pain incidents reported at the time of the M3 was also increased, it is possible the pain was caused by the decline in arch function that earlier showed improvement. There are no studies referring to the sustainability of the effects of the SFE, so these results can be a reference for future investigation of this exercise. The ankle stabilization training carried out in both groups was also expected to effect improvement in the arch by improving the windlass function and strengthening the extrinsic foot muscles. In the non-SFE group, ND tended to decrease but no significant change was observed. Therefore, it is suggested that the combination of this training with the SFE focusing on the intrinsic muscles was more effective in improving the arch of the foot. The ankle dorsiflexion angle was significantly larger in both groups at the time of the M2, suggesting the mobility of the foot was improved by conducting the unstable-plate training.

Although previous studies reported changes in arch function leading to some balancing improvement (Birinci & Demirbas, 2017), no significant change was observed in mSEBT in the SFE group in this study. A significant improvement was observed in the non-SFE group, possibly because the training with the unstable plate improved the nerve-muscle coordination and postural control in the one-leg standing position. In this study, the value of mSEBT was calculated by taking the average value of all directions, but the characteristics in each direction could be measured in future studies.

The toe gripping force of the SFE group increased significantly at the time of the M3. It was reported that strengthening the toe flexor muscle group resulted in decreased ND, and as a result was effective in preventing hallux valgus (Yokozuka, Okazaki, Sakamoto & Takahashi, 2019). In this study, toe gripping force in the SFE group increased during the period when SFE was not performed, resulting in increased ND and increased pain. It was undeniable that extrinsic muscles were activated rather than intrinsic muscles, which might have been counterproductive from the perspective of injury prevention. In athletes performing repeated running movements, increased muscle output of the toes might cause a decrease in the rocker function of the foot and a decrease in shock absorbing function, resulting in an excessive load on the foot and lower limbs. It is expected that further verification will be needed in the future, including exploring the detailed mechanism of the toe and arch functions. There was also a report that the SFE consisted of movements that were difficult for subjects to picture, and that learning it was therefore difficult. Also worth considering is that the SFE in this study repeated movements for 5 minutes that did not involve any joint movements, so it could cause fatigue and poor concentration in long-term implementation. There are many reports that the training’s positive effect was increased by performing it in combination with other methods (Kim & Lee, 2020, Namsawang, Eungpinichpong, Vichiansiri & Rattanathongkom, 2019, Okamura, Kanai, Hasegawa, Otsuka & Oki, 2019, Jung, Koh & Kwon, 2011). It is necessary to devise training with regular measurements of effects and share that feedback. Beyond the exercises, there are many other factors that also affect foot problems, so it is necessary to consider not only physical functions, but also shoes, insoles and environmental factors (Miller et al., 2014). Furthermore, in athletics, running and practice routines differ between long-distance athletes and short-distance athletes, so there might be differences in intervention effects. However, the subjects of this study were both short- and long-distance athletes so no comparison could be made, and the group was too small for differences between men and women to be explored. In the future, it would be necessary to increase the number of subjects and examine the characteristics of each group in more depth.

Acknowledgments
There is no conflict of interest related to this study. I would like to thank the team coaches and supervisor, the measurement contributors, and most importantly the athletes who cooperated with the measurements for their patience and understanding throughout the study.

References

Bennell, K. L., Talbot, R. C., Wajswelner, H., Techovanich, W., Kelly, D. H., Hall, A. J. (1998). Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Australian Journal of Physiotherapy, 44(3),* 175-180. http://dx.doi.org/10.1016/s0004-9514(14)60377-9

Bennett, J. E., Reinking, M. F., Pluemer, B., Pentel, A., Seaton, M., Killian, C. (2001). Factors contributing to the development of medial tibial stress syndrome in high school runner. *Journal of Orthopedic & Sports Physical Therapy, 31(9),* 504-510. http://dx.doi.org/10.2519/jospt.2001.31.9.504

Birinci, T., Demirbas, S. B. (2017). Relationship between the mobility of medial longitudinal arch and postural control. *Acta Orthopaedics et Traumatologica Turcica, 51(3),* 233-237. https://doi.org/10.1016/j.aott.2016.11.004

Cote, K. P., Brunet, M. E., Gansneder, B. M., Shultz, S. J. (2005). Effects of pronated and supinated foot postures on static and dynamic postural stability. *Journal of Athletic Training*, *40(1),* 41–46.

Crowell, H. P., Davis, I. S. (2011). Gait retraining to reduce lower extremity loading in runners. *Clinical Biomechanics, 26(1),* 78-83. https://doi.org/10.1016/j.clinbiomech.2010.09.003

Dimeo, F. C., Peters, J., Guderian, H. (2004). Abdominal pain in long distance runners: case report and analysis of the literature. *British Journal of Sports Medicine, 38(5),* E24. https://doi.org/10.1136/bjsm.2003.007237.

Gooding, T. M., Feger, M. A., Hart, J. M., Hertel, J. (2016). Intrinsic foot muscle activation during specific exercises: a T2 time magnetic resonance imaging study. *Journal of Athletic Training, 51(8),* 644-650. https://doi.org/10.4085/1062-6050-51.10.07

Haun, C., Brown, C. N., Hannigan, K., Johnson, S. T. (2020). The effects of the short foot exercise on navicular drop: a critically appraised topic. *Journal of Sport Rehabilitation,* 1-6. https://doi.org/10.1123/jsr.2019-0437

Headlee, D. L., Leonard, J. L., Hart, J. M., Ingersoll, C. D., Hertel, J. (2008). Fatigue of the plantar intrinsic foot muscles increases navicular drop. *Journal of Electromyography and Kinesiology, 18(3),* 420-425. https://doi.org/10.1016/j.jelekin.2006.11.004

Hicks, J. H. (1954). The mechanics of the foot. II. The plantar aponeurosis and the arch. *Journal of Anatomy, 88(1),* 25-30.

Jam, B. (2006). Evaluation and retraining of the intrinsic foot muscles for pain syndromes related to abnormal control of pronation. *Advanced Physical Therapy Education Institute*, *21*, 1-8.

Jung, D.Y., Kim, M.H., Koh, E. K., Kwon, O. Y., Cynn, H. S., Lee, W. H. (2011). A comparison in the muscle activity of the abductor hallucis and the medial longitudinal arch angle during toe curl and short foot exercises. *Physical Therapy in Sport, 12(1),* 30-35. http://dx.doi.org/10.1016/j.ptsp.2010.08.001

Jung, D. Y., Koh, E. K., Kwon, O. Y. (2011), Effect of foot orthoses and short-foot exercise on the cross-sectional area of the abductor hallucis muscle in subjects with pes planus: a randomized controlled trial. *Journal of Back and Musculoskeletal Rehabilitation, 24,* 225-231. http://dx.doi.org/10.3233/BMR-2011-0299

Kim, E. K., Kim, J. S. (2016). The effects of short foot exercises and arch support insoles on improvement in the medial longitudinal arch and dynamic balance of flexible flatfoot patients. *Journal of Physical Therapy Science, 28(11),* 3136-3139. https://doi.org/10.1589/jpts.28.3136

Kim, J. S., Lee, M.Y. (2020). The effect of short foot exercise using visual feedback on the balance and accuracy of knee joint movement in subjects with flexible flatfoot. *Medicine (Baltimore), 99(13),* e19260. https://doi.org/10.1097/MD.0000000000019260

Lee, E., Cho, J., Lee, S. (2019). Short-foot exercise promotes quantitative somatosensory function in ankle instability: a randomized controlled trial. *Medical Science Monitor, 25,* 618-626. https://doi.org/10.12659/MSM.912785

Lee, J., Yoon, J., Cynn, H. (2017). Foot exercise and taping in patients with patellofemoral pain and pronated foot. *Journal of Bodywork and Movement Therapies, 21(1),* 216-222. https://doi.org/10.1016/j.jbmt.2016.07.010

Lynn, S. K., Padilla, R. A., Tsang, K. K. (2012). Differences in static- and dynamic-balance task performance after 4 weeks of intrinsic-foot-muscle training: the short-foot exercise versus the towel-curl exercise. *Journal of Sport Rehabilitation*, *21*(4), 327-333. http://dx.doi.org/10.1123/jsr.21.4.327

Lysholm, J., Wiklander, J. (1987). Injuries in runners. *American Journal of Sports Medicine, 15(2),* 168-171. https://doi.org/10.1177/036354658701500213.

McKeon, P. O., Fourchet, F. (2015). Freeing the foot: integrating the foot core system into rehabilitation for lower extremity injuries. *Clinics in Sports Medicine, 34(2),* 347-361. https://doi.org/10.1016/j.csm.2014.12.002

Miller, E. E., Whitcome, K. K., Lieberman, D. E., Norton, H. L., Dyer, R. E. (2014). The effect of minimal shoes on arch structure and intrinsic foot muscle strength. *Journal of Sport and Health Science*, *3*(2), 74-85.

Mulligan, E. P., Cook, P. G. (2013). Effect of plantar intrinsic muscle training on medial longitudinal arch morphology and dynamic function. *Manual Therapy, 18(5),* 425-430. https://doi.org/10.1016/j.math.2013.02.007

Nakae, H., Murata, S., Kai, Y., Soma M., Satou, Y. (2013). Comparison of the lower limbs muscular activity of toe grip and the toe-gripping strength in sitting upright position and the standing position. (in Japanese). *Japanese Journal of Health Promotion and Physical Therapy 3(1),* 11-14, https://doi.org/10.9759/hppt.3.11

Namsawang, J., Eungpinichpong, W., Vichiansiri, R., Rattanathongkom, S. (2019). Effects of the short foot exercise with neuromuscular electrical stimulation on navicular height in flexible flatfoot in Thailand: a randomized controlled trial. *Journal of Preventive Medicine and Public Health, 52*(4), 250–257. https://doi.org/10.3961/jpmph.19.072

Newman, P., Witchalls, J., Waddington, G., Adams, R. (2013). Risk factors associated with medial tibial stress syndrome in runners: a systematic review and meta-analysis. *Open access journal of sports medicine*, *4*, 229–241. https://doi.org/10.2147/OAJSM.S39331

Okamura, K., Fukuda, K., Oki, S., Ono, T., Tanaka, S., Kanai, S. (2020). Effects of plantar intrinsic foot muscle strengthening exercise on static and dynamic foot kinematics: a pilot randomized controlled single-blind trial in individuals with pes planus. *Gait Posture, 75,* 40-45. http://dx.doi.org/10.1016/j.gaitpost.2019.09.030.

Okamura, K., Kanai, S., Hasegawa, M., Otsuka, A. Oki, S. (2019), Effect of electromyographic biofeedback on learning the short foot exercise. *Journal of Back and Musculoskeletal Rehabilitation, 32(5),* 685-691. http://dx.doi.org/10.3233/BMR-181155

Pohl, M. B., Hamill, J., Davis, I. S. (2009). Biomechanical and anatomic factors associated with a history of plantar fasciitis in female runners. *Clinical Journal of Sport Medicine, 19(5),* 372-376. http://dx.doi.org/10.1097/JSM.0b013e3181b8c270

Pohl, M. B., Rabbito, M., Ferber, R. (2010). The role of tibialis posterior fatigue on foot kinematics during walking. *Journal of Foot and Ankle Research, 3(1),* 3-6. http://dx.doi.org/10.1186/1757-1146-3-6

Ryan, M., Grau, S., Krauss, I., Maiwald, C., Taunton, J., Horstmann, T. (2009). Kinematic analysis of runners with achilles mid-portion tendinopathy. *Foot and Ankle International, 30(12),* 1190-1195. http://dx.doi.org/10.3113/FAI.2009.1190

Sherman, K. P. (1999). The foot in sport. *British Journal of Sports Medicine, 33(1),* 6-13. http://dx.doi.org/10.1136/bjsm.33.1.6

Sulowska, I., Oleksy, Ł., Mika, A., Bylina, D., Sołtan, J. (2016). The influence of plantar short foot muscle exercises on foot posture and fundamental movement patterns in long-distance runners, a non-randomized, non-blinded clinical trial. *PLoS One, 11(6),* e0157917. https://doi.org/10.1371/journal.pone.0157917

Tome, J., Nawoczenski, D. A., Flemister, A., Houck, J. (2006). Comparison of foot kinematics between subjects with posterior tibialis tendon dysfunction and healthy controls. *Journal of Orthopaedics and Sports Physical Therapy,* 36(9), 635-644. http://dx.doi.org/10.2519/jospt.2006.2293

Tschopp, M., Brunner, F. (2017). Diseases and overuse injuries of the lower extremities in long distance runners (in German). *Zeitschrift für Rheumatologie, 76(5),* 443-450. https://doi.org/10.1007/s00393-017-0276-6.

Unver, B., Erdem, E., Akbas, E. (2019). Effects of short-foot exercises on foot posture, pain, disability, and plantar pressure in pes planus. *Journal of Sport Rehabilitation*, *29*(4), 436-440. https://doi.org/10.1123/jsr.2018-0363

van Lieshout, R., Reijneveld, E. A., van den Berg, S. M., Haerkens, G. M., Koenders, N. H., de Leeuw, A. J., van Oorsouw, R. G., Paap, D., Scheffer, E., Weterings, S., & Stukstette, M. J. (2016). Reproducibility of the modified star excursion balance test composite and specific reach direction scores. *International Journal of Sports Physical Therapy*, *11*(3), 356–365.

Yokozuka, M., Okazaki, K., Sakamoto, Y., Takahashi, K. (2019). Relationship between foot morphology and toe muscle strength in female university students. *Journal of Physical Therapy Science, 31(5),* 457-461. https://doi.org/10.1589/jpts.31.457

Zemper, E. D. (2005). Track and field injuries. *Medicine and Sports Science, 48,* 138-151. https://doi.org/10.1159/000084287.