

SECTION – EXERCISE SCIENCES

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THE INFLUENCE OF PLANTAR SHORT FOOT MUSCLE EXERCISES ON FOOT POSTURE AND GAIT PARAMETERS IN LONG-DISTANCE RUNNERS

Authors' contribution:

- A. Study design/planning
- B. Data collection/entry
- C. Data analysis/statistics
- D. Data interpretation
- E. Preparation of manuscript
- F. Literature analysis/search
- G. Funds collection

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Abstract

Aim. The aim of this study was to evaluate the influence of exercises of plantar short foot muscles on foot posture and gait parameters in long-distance runners.

Basic procedures. The study involved 48 long-distance runners aged 21-45 years. The runners performed short foot muscle exercises daily for 6 weeks. The Foot Posture Index (FPI-6) and gait parameters (G-walk) were measured twice: at baseline and after 6 weeks of exercises.

Result. Lower values of the Foot Posture Index (FPI-6) were observed. In the assessment of gait parameters, runners obtained lower cadence, walking speed, stride length and %stride length/height. Gait cycle duration was increased.

Conclusions. Exercises strengthening short foot muscles have beneficial effects on foot alignment by change of foot posture from slight pronation towards a neutral foot. Change of gait parameters may indicate improvement of motor control and shifting natural and comfortable walking speed towards lower values. The short foot muscle exercises should be included as part of the daily training programme of runners.

Introduction

Running is one of the most common forms of activity. Due to the easy accessibility and positive influence on physical condition, the popularity of this discipline is constantly growing. However, it can cause injuries and overloads, especially in the lower limbs [1]. Based on the results available in literature on the subject, it is estimated that from 27 to 70% of people running recreationally and professionally suffer trauma per year. Nearly 50% of injuries affect the knee joint. The most frequently reported complaint is the patellofemoral syndrome, followed by the ilio-tibial band syndrome, meniscus damage and patellar tendinitis. Almost 40% of the remaining injuries are in the foot, ankle and lower leg. The plantar fasciitis,

Achilles tendinitis, and medial tibial stress syndrome can be mentioned here. In contrast, damage above the knee joint accounts for less than 20% of all trauma suffered by runners [2].

During walking and running, there are three levels of movement within the lower limb: frontal, sagittal and transverse. During first contact with the ground, three phenomena occur: shock absorption, stabilization of the joints and flexible adjustment of the foot. Shock absorption is achieved by bending in the hip and knee joints and pronation in the ankle joint. This allows to reduce impact force. Pronation is a combination of dorsal flexion of the ankle, eversion of the rearfoot (calcaneus) and forefoot abduction, and occurs in the first half of the support phase while walking or running [2]. Pronation causes

some degree of relaxation between the tarsal bones, and then other mechanisms stabilizing the arches of the foot, which facilitates the adaptation of the foot to the ground and increases its elasticity [3]. This is especially important for long-distance runners, as they are exposed to long-term loads. Research indicates that pronation is a favourable phenomenon in running, provided that it does not go beyond the physiological limits and is not continued after the middle support phase is over [4].

Both posture of the foot inclining towards excessive pronation or supination are indicated in the literature as a risk factor for injury [5, 6]. The type of the foot determines its mobility and affects the kinematics of the lower limb joints. The reduced longitudinal arch of the foot is associated with its greater mobility than in the case of pes cavus [7-9]. In most cases, injuries in people with flat feet are the result of greater susceptibility to tissue damage associated with exceeding physiological ranges of motion [10] or incorrect compression of the subtalar and transverse talar joint [11]. On the other hand, in people with an elevated foot arch, lower mobility rate can be observed, which predisposes to injuries associated with weakening cushioning mechanism and increasing pressure on the plantar surface of the foot while walking or running [12, 13].

Analysis of foot posture is an important element in the comprehensive assessment of runners. The most commonly used diagnostic methods include orthopaedic, anthropometric, plantoconturographic or functional examination methods [14-16]. However, one of the more easily available and simple to use tools is the Foot Posture Index, which provides comprehensive foot assessment in all areas, including the plantar and dorsal surfaces of the foot. It has wide clinical application in assessing the risk of injuries in athletes [17, 18]. The test is carried out in static conditions – in a standing position, however, research indicates the existence of a strong relationship between the final result of the test and the mobility of the rearfoot during gait [20]. Analysing individual parts of the FPI-6, the largest correlations with the results of the dynamic study occur in the evaluation of the medial longitudinal arch of the foot and the assessment of the calcaneus in the frontal plane [21].

Comparing kinematics of the lower limbs during gait in people with a neutral foot and with a tendency to pronation, greater mobility during the support phase in the second case can be observed. In particular, these differences are visible in the mobility of the calcaneus during propulsion. In the frontal plane, a larger extent of the eversion and the total range of mobility of the rearfoot are observed [22-24]. Also, metatarsus and forefoot mobility in people with a lowered longitudinal arch is increased and lasts longer than in the case of a neutral foot [22-25].

Dynamical stability is a key element during movement [26]. Resistance to exogenous and endogenous disturbances of balance is a prerequisite for proper gait. The vestibular organ, the sight organ and the sensorimotor system are responsible for the control of stability. The latter is created by skin and deep sensory receptors, particularly from the plantar surface of the foot and the area around the ankle. Therefore, the correct distribution of foot load is an element affecting dynamic stability control and is a condition for proper gait [27].

In dynamic conditions, such as walking or running, stability allows to continue the functional movement, despite the occurring external and internal destabilizing forces. Dynamic stability analysis should take into account the changing moments of muscle strength and changes in the position of body segments in space [28]. Studies to date indicate that the measurement of the variability value in terms of kinematics and temporal-spatial parameters can be used to estimate dynamic stability control [29, 30]. It is assumed that increasing the variability of these parameters, and thus reducing the repeatability of individual strides, reduces stability. The variability of these parameters depends on the speed of walking, which may suggest the influence of speed on stability [31, 32]. Gait speed may depend on many factors – among others, on the age, height or strength of lower limb muscles. These factors affect maximal gait speed in particular [33]. When moving at a comfortable (natural) speed, the variability of the temporal-spatial and kinematic parameters of walking is the smallest, and, thus motor-control ability is the largest [34]. Both walking at higher and lower speeds increases the variability of its parameters [32, 35, 36]. There are, however, scientific reports indicating an improvement in dynamic stability while walking at a slower speed, despite the increase in its variability. Researchers suggest that the neuromuscular control system is more effective in controlling exogenous and endogenous balance disturbances during slow gait than in the case of movement at higher velocities [34, 37].

Individuals who practice long-distance running are exposed to long-lasting loads, which is why shock absorption during running and walking is a key mechanism in this group. The correct posture of the foot is a contributing factor [4]. The results of previous studies by the authors, as well as the works of other authors, indicate that foot posture is beneficial for exercise of the short plantar muscles of the foot surface [38-40]. There are no reports in the literature on the relationship between changes in foot posture under the influence of exercises with dynamic stability and changes in the gait pattern. The aim of this study was to assess the impact of short foot plantar exercise on foot posture and gait parameters in people practicing long-distance running at an amateur level.

Material and methods

1. Description of the study group

48 people (17 women and 31 men) aged from 21 to 45 years (32.5 ± 6.81), regularly engaging in long-distance running at an amateur level, took part in the study. The respondents ran from 20 to 100 kilometres per week (average $42.19 \text{ km} \pm 18.54 \text{ km}$). Runners were qualified for testing after meeting the inclusion criteria and taking the exclusion criteria into account. The following inclusion criteria were adopted: age within the range of 20–45 years, regular running training with weekly kilometre amount of not less than 20 km and consent to participate in the research. In contrast, the exclusion criteria were: age below 20 years or over 45 years, lack of consent to participate in research, lack of regular running training (less than 20 km weekly), deformations within the foot or injuries to the musculoskeletal system 6 months prior to testing.

The study participants performed exercises activating the short muscles of the plantar surface of the feet for 6 weeks. During this time, the runners performed their current running training, which was monitored by the researchers and did not change throughout the duration of the experiment. Measurements of selected parameters were performed before the start of training and after six weeks of exercise. Each runner was instructed on the purpose and course of the study and expressed his/her written consent to participate in the project. Prior to the study, the approval of the Bioethics Committee at the Regional Medical Chamber in Krakow was obtained for conducting the medical experiment (No. 40/KBL/OIL/2015 dated 15 April 2015). The study was registered in the Australian and New Zealand Clinical Trials Registry (ANZCTR) international database for clinical trials.

2. Research tools

2.1. The Foot Posture Index (FPI-6)

The Foot Posture Index is used for comprehensive and multi-levelled assessment of the feet. It consists of six parts, evaluating the various elements of the fore- and rearfoot:

- 1) Talar head palpation,
- 2) Supra and infra lateral malleolar curvature,
- 3) Inversion/eversion of the calcaneus,
- 4) Prominence in the region of the talonavicular joint,
- 5) Height and congruence of the medial longitudinal arch,
- 6) Abduction/adduction of the forefoot on the rear foot [19].

Each of these elements is evaluated on a scale from -2 to +2. Negative values indicate supination and positive values demonstrate pronation. The neutral position of the foot is classified as 0. The total sum of points allows for overall assessment of foot posture according to the following classification:

- from -12 to -5 points – foot with increased supination,
- from -4 to -1 points – foot with light supination,
- from 0 to +5 points – neutral foot,
- from +6 to +9 points – foot with light pronation,
- from +10 to +12 points – foot with increased pronation [19].

Studies conducted by Oleksy et al. [19] indicate that this tool is characterized by high repeatability of measurements for the same researcher. The value of the measurement repeatability coefficient R between the first and second test for all evaluated parameters was from 0.89 to 0.96.

2.1.1. Talar head palpation assessment

The talar head was examined by touch on the lateral and medial sides. It was the only measured based on palpation assessment and not visual evaluation [19].

2.1.2. Supra and infra lateral malleolar curvature observation

The researcher observed the supra and infra lateral malleolar curvature. Those which are correct should be equal. In the foot with increased supination, the supra lateral malleolar curvature is more concave than infra curvature. In the case of pronation, the opposite occurs. [19].

2.1.3. Inversion/eversion assessment of the calcaneus

Inversion/eversion assessment of the calcaneus. This measurement was based on visual assessment of calcaneus in the frontal plane. Angular measurements were not required [19].

2.1.4. Prominence assessment in the region of the talonavicular joint

In the neutral foot, the surface of the skin in this area is flat. This area becomes curved if the head of the talus is adducted, which occurs in the case of pronation. When the foot is in supination, the TNJ area is concave [19].

2.1.5. Height and congruence assessment of the medial longitudinal arch

Assessing the medial longitudinal arch of the foot, its height and posture were taken into account. In the neutral foot, the curvature of the arch is relatively even and resembles a segment of the circumference of a circle. When the foot is in pronation, the arch is lowered and flattened in the medial part. However, in the case of supination, the curvature is more acute in the rear part [19].

2.1.6. Abduction/adduction assessment of the forefoot on the rear foot

The researcher assessed the forefoot position by looking at the long axis of the heel from the back. In the neu-

tral foot posture, the forefoot is noticeably even on both sides of the heel. In the case of pronation, lateral toes are more visible, and in supination – the medial ones [19].

2.2. BTS G-walk motion sensor

The BTS G-Walk motion sensor (G-Sensor®, BTS Bioengineering S.p.A., Italy) was used to assess temporal-spatial parameters, motion symmetry, propulsion and pelvic movements. The belt along with the motion sensor was placed at the height of the fifth lumbar vertebra. The tool is a portable system for functional motion analysis, using three-axis accelerometers, magnetic field sensors and gyroscopes. The assessment of trunk movements allows the assessment of individual components of the gait pattern [41-43]. The test results indicate high repeatability of measurements using accelerometers (the intra-class correlation coefficient of ICC ranged from 0.7 to 0.97) [44].

For the needs of the present study, the “Gait” protocol was used, which determined the gait pattern based on a special algorithm analysing heel and toe detachment as well as normalizing acceleration and pelvic angles during the gait cycle.

During the test, consisting of walking a 70-meter section, the following parameters were obtained:

- speed;
- cadence (strides/min);
- step and stride length;
- step width;
- gait cycle duration;
- support and swing phase duration;
- single and double support phase duration;
- symmetry index;
- propulsion;
- pelvic mobility.

Data from the device were transferred to a computer via Bluetooth [45].

3. The set of exercises

Each study participant received a set of exercises activating the short plantar muscles of the feet. After the first test, the runners were taught how to perform the exercises correctly. In addition, they received instructions in writing.

The set included several exercises that were performed daily by the subjects, including their performance under the control of a physiotherapist once a week. The exercise programme included progression in the form of increased load and level of difficulty. The following tools were used: a tennis ball, a sensorimotor cushion and a tape. In each exercise, the runners paid attention to the even loading of three foot support points (head of the first and fifth bones of the metatarsus and the heel). Exercises were performed barefoot.

3.1. Exercises

Vele’s Forward Lean – consisted of maximal forward inclination from a standing position, with arms along the trunk, keeping the body in one line and not detaching the heels from the ground [46,47].

Reverse Tandem Gait – consisted of walking backwards, setting one foot after the other. First, the metatarsus was loaded and then the heel was added [46, 47].

Short Foot Exercise – they consisted in shortening the foot in the anterior-posterior dimension by bringing the metatarsal bone heads towards the heel, and then – in shortened foot position – clamping the three support points. The toes remained relaxed during this time, and the foot rested on the ground. Increasing the level of difficulty consisted in changing the position. The first exercise was performed while seated, the second was performed in a standing position, while in the third exercise, a half-squat was additionally performed [46, 47].

Exercises on the sensorimotor cushion – the set included several exercises in a single and double standing position. The exercises with the Thera-band type tape – strengthening the muscular-ligamentous apparatus around the ankle joint, took the movements of flexion and extension and pronation and supination with resistance into account.

4. Statistical analysis

Statistical elaboration was performed using the STATISTICA 12.0 PL programme. Normality of variable distribution was checked using the Shapiro-Wilk test. ANOVA was used to assess the significance of differences among studied variables in the evaluation of gait parameters, while in the case of the Foot Posture Index (FPI-6), the non-parametric Wilcoxon test was used. Differences were considered statistically significant if the test probability level was lower than the adopted level of significance ($p < 0.05$).

Results

1. Foot Posture Index (FPI-6)

After 6 weeks of exercise, lower values of the Foot Posture Index (FPI-6) were observed. These changes were statistically significant regarding all the components of the indicator within the left (Fig. 1) and right foot (Fig. 2). A statistically significant change was also observed as a result of the overall FPI-6 index. In the first examination, the median value was 6 in the left foot and 5 in the right one. After the implemented training session, these values decreased to 2 in the left foot ($p = 0.00000$) and to 2 in the right one ($p = 0.00000$).

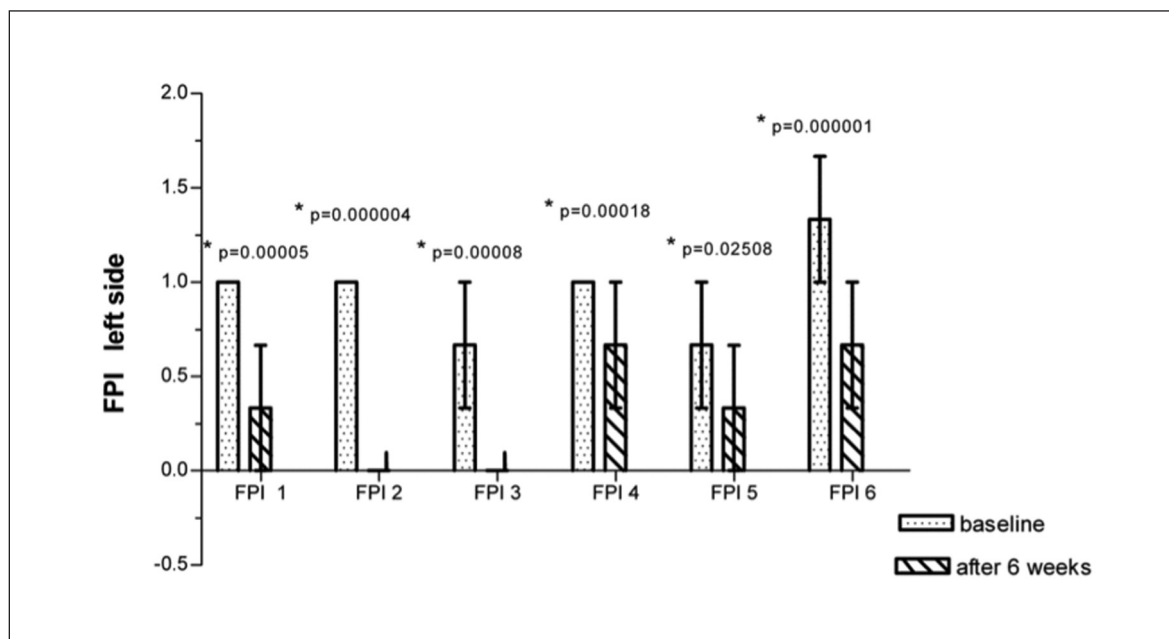


Fig. 1. The Foot Posture Index – results at baseline and after 6 weeks of exercising for the left lower limb. Values are expressed by median +/- quantile range

FPI 1 – Talar head palpation; FPI 2 – Supra and infra lateral malleolar curvature; FPI 3 – Inversion/eversion of the calcaneus; FPI 4 – Prominence in the region of the talonavicular joint; FPI 5 – Height and congruence of the medial longitudinal arch; FPI 6 – Abduction/adduction of the forefoot on the rear foot

p * between baseline and 6th week

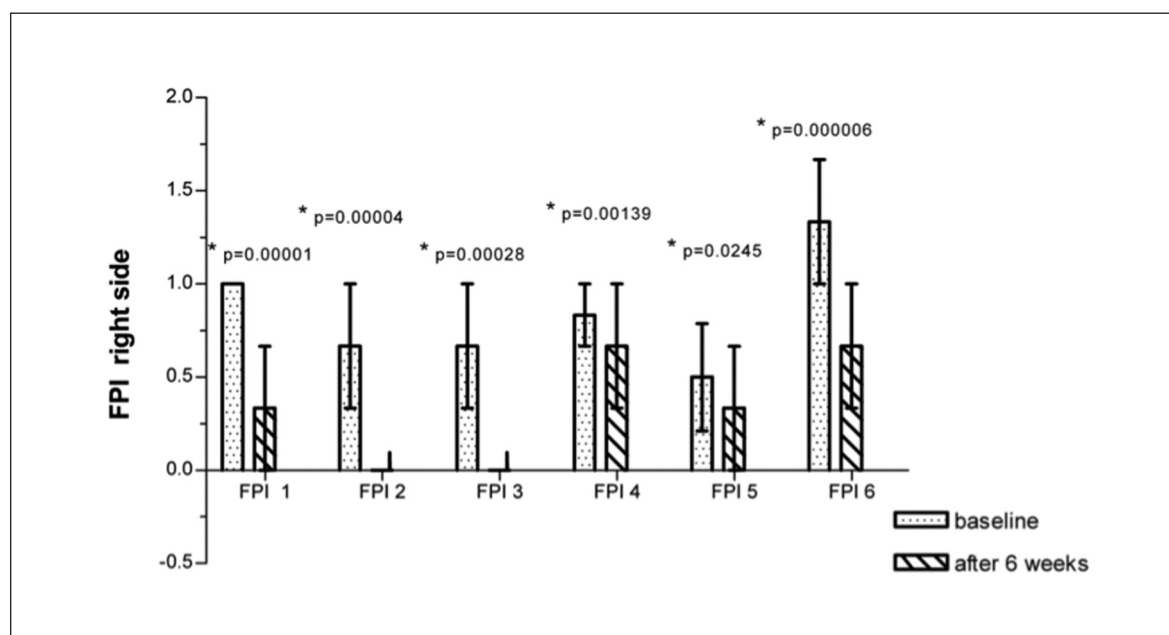


Fig. 2. The Foot Posture Index – results at baseline and after 6 weeks of exercising for the right lower limb. Values are expressed by median +/- quantile range

FPI 1 – Talar head palpation; FPI 2 – Supra and infra lateral malleolar curvature; FPI 3 – Inversion/eversion of the calcaneus; FPI 4 – Prominence in the region of the talonavicular joint; FPI 5 – Height and congruence of the medial longitudinal arch; FPI 6 – Abduction/adduction of the forefoot on the rear foot

p * between baseline and 6th week

2. G-walk inertial sensor

After 6 weeks of training, the runners obtained statistically significantly lower cadence, walking speed, stride length and stride length/height in the assessment of temporal-spatial gait parameters (Tab. 1). Gait cycle duration significantly increased (for the left and right lower limbs) (Tab. 1). No significant changes were observed for other parameters (Tab. 1).

Discussion

The aim of the study was to assess the impact of plantar short muscle exercises on foot posture and gait

parameters in individuals practicing long-distance running at an amateur level. The results obtained indicate that the six-week training had a positive effect on the foot posture. The applied exercise programme also influenced the change of some of the temporal-spatial gait parameters. There are no reports in the literature on linking the change in the foot posture under the influence of exercise with dynamic stability and the change in gait pattern. This is the first work to undertake the topic.

Among many risk factors for injuries in runners, one group is those related to the foot. These include disorders of biomechanical or anatomical structure of the foot, reduced flexibility, muscular imbalance or weakened strength. As external factors, the type of substrate

Table 1. Change of gait parameters after 6 weeks of exercises

Parameters	Baseline	6 th week	* <i>p</i>
Cadence [strides/min]	116.42 +/- 10.56	114.18 +/- 9.26	0.028171
Speed [m/s]	1.30 +/- 0.19	1.24 +/- 0.23	0.019630
Stride length [m]	1.34 +/- 0.17	1.30 +/- 0.18	0.022088
Stride length/height [%]	80.66 +/- 20.07	76.31 +/- 16.13	0.006880
Gait cycle duration L [s]	1.04 +/- 0.10	1.06 +/- 0.10	0.018043
Stride length L [% stride length]	50.71 +/- 1.45	50.53 +/- 1.67	ns
Support phase duration L [% gait cycle]	63.69 +/- 3.22	63.52 +/- 2.63	ns
Swing phase duration L [% gait cycle]	36.31 +/- 3.22	36.48 +/- 2.63	ns
Double support phase duration L [% gait cycle]	12.97 +/- 3.04	12.81 +/- 2.42	ns
Single support phase duration L [% gait cycle]	37.47 +/- 2.64	37.90 +/- 2.44	ns
Gait cycle duration R [s]	1.04 +/- 0.10	1.06 +/- 0.10	0.022126
Stride length R [% stride length]	49.29 +/- 1.45	49.48 +/- 1.67	ns
Support phase duration R [% gait cycle]	62.56 +/- 2.72	62.15 +/- 2.48	ns
Swing phase duration R [% gait cycle]	37.44 +/- 2.72	37.85 +/- 2.48	ns
Double support phase duration R [% gait cycle]	13.20 +/- 2.62	12.74 +/- 2.25	ns
Single support phase duration R [% gait cycle]	36.35 +/- 3.18	36.56 +/- 2.55	ns
Symmetry index	94.08 +/- 6.23	93.50 +/- 6.54	ns
Propulsion L [m/s ²]	7.19 +/- 1.94	6.74 +/- 1.95	ns
Propulsion R [m/s ²]	7.15 +/- 1.95	7.10 +/- 2.17	ns
Pelvic flexion-extension – Symmetry index	16.73 +/- 48.35	18.55 +/- 53.34	ns
Pelvic flexion-extension – range L [°]	2.49 +/- 0.97	2.23 +/- 0.73	ns
Pelvic flexion-extension – R range [°]	2.49 +/- 0.92	2.23 +/- 0.70	ns
Pelvic lateral flexion – Symmetry index	96.87 +/- 7.02	98.15 +/- 1.90	ns
Pelvic lateral flexion – L range [°]	7.26 +/- 2.62	7.80 +/- 2.38	0.046617
Pelvic lateral flexion – R range [°]	7.37 +/- 2.64	7.88 +/- 2.43	ns
Pelvic rotation – Symmetry index	92.83 +/- 15.11	96.21 +/- 6.60	ns
Pelvic rotation – L range [°]	8.45 +/- 3.44	8.03 +/- 2.93	ns
Pelvic rotation – R range [°]	8.51 +/- 3.33	8.07 +/- 2.94	ns

**p* – between baseline and 6th week

ns – not statistically significant

L – left lower limb

R – right lower limb

and footwear can be mentioned [48]. An unfavourable factor is the foot posture inclining both towards excessive pronation and supination [5,6]. It is connected with the influence of foot posture on its mobility and kinematics of the lower limb joints [7-9]. Pronation is a combination of dorsal flexion of the ankle, eversion of the rearfoot (calcaneus) and forefoot abduction, and occurs in the first half of the support phase while walking or running [2]. Proper foot pronation is a mechanism that provides shock absorption and adaptation to the unevenness of a surface [49]. In the case of excessive pronation, greater mobility in the support phase can be observed. In particular, these differences are visible in the mobility of the calcaneus during propulsion. In the frontal plane, a larger extent of eversion and the total range of mobility of the rearfoot are observed [22-24]. Also, metatarsal and forefoot mobility is increased [24, 25] and lasts longer than in the case of a neutral foot [23]. Injuries in people with excessive pronation and reduced longitudinal arch of the foot related to this are most often the result of greater susceptibility to tissue damage due to exceeding physiological ranges of motion [10] or incorrect compression of the subtalar joint and transverse talar joint [11].

However, in people with elevated medial longitudinal arch and tendency towards supination, its smaller mobility can be observed, which predisposes to injuries associated with weakening the cushioning mechanism [12] and increasing pressure on the plantar surface of the foot while walking or running [13].

In this work, the Foot Posture Index (FPI-6) was used to assess foot posture and changes occurring under the influence of the training programme, assessing the six elements of the fore- and rearfoot. Using this made it possible to classify the foot into one of three types: neutral, pronating or supinating [19]. After six weeks of training, foot posture improved from pronation towards a neutral foot. These changes concerned the right and left foot, showing statistical significance within all assessed elements and the total score. In the authors' previous studies, in which the effectiveness of two types of exercises activating the plantar short muscles of the foot in long-distance runners was compared, the FPI-6 was also used. Similarly to the present work, improvement in the posture towards a neutral foot was observed [40].

There are also other reports in the literature regarding the use of the Foot Posture Index among people practicing long-distance running. Cowley and Marsden [50] assessed the change in this index and the height of the navicular bone of the runners who covered the half-marathon distance. The first measurement was carried out a week before the competition. The subjects were instructed not to perform training on that day. The second measurement took place after the runner crossed

the finish line. Researchers observed a reduction in the navicular bone of both feet after the run. The value of the FPI-6 index in the left foot significantly increased (on average by 1.7), and thus, the pronation level increased. In the right foot, this value increased slightly (by 0.3 on average).

Similar studies have been carried out by Escamilla-Martinez et al. [51] who assessed foot posture with the FPI-6 before and after a run at a moderate speed (3.3 m/s), sustained for sixty minutes. Pressure distribution measurements of the plantar foot on the surface were also conducted. The research involved a group of thirty regularly training men. The obtained results also indicate a tendency of the feet to change pronation after long-term loading in the form of a running training. The value of the FPI-6 index increased on average by two points in both feet. The pressure on the medial side of the heel and under the head of the second metatarsal bone increased, and the longitudinal arch of the foot decreased. The results obtained by the researchers confirm the necessity to use exercises activating internal foot muscles on the plantar side and strengthening the longitudinal arch of the foot in runners.

The efficiency of the foot muscles on the plantar surface of the feet was evaluated by Mulligan et al. [39], who studied the impact of Short Foot Exercise on the medial longitudinal arch and dynamic functions. A navicular drop test was used. After an eight-week training period, the researchers observed improvement – they recorded lower values for navicular bone descent after shifting to a standing position, and thus, a smaller range of pronation. Own research confirms these results. Although the navicular drop test was not used, similar parameters were assessed (prominence in the region of the talonavicular joint and talar head palpation). In both of them, statistically significant changes were observed with a visible tendency towards improvement from pronation towards a neutral position.

Jung et al. [38] also evaluated the effectiveness of exercises activating the short plantar surface of the foot, to exercises involving additional long flexors. The advantage of the Short Foot Exercise was demonstrated - the electromyographic activity of the toe abductor muscle was significantly higher, and the value of the arch angle of the foot was lower in comparison to the results obtained during the second exercise. The results suggest, therefore, that the Short Foot Exercises have a more beneficial effect on strengthening the toe abductor muscle, which is the largest of the internal muscles of the foot. The increase in its activity may contribute to the reduction of the medial angle of the longitudinal arch, and thus, to raising the arch of the foot. In our research, a significant change in this parameter, which is part of the FPI-6, was also observed under the influence of exercises.

The original training programme designed by the authors used in this study was aimed at activating the short plantar muscles of the foot with the smallest activity of external muscles. The Short Foot Exercises developed by Professor Janda are commonly known, consisting in shortening the foot in the anterior-posterior dimension by bringing the metatarsal bone heads towards the calcaneus, while the fingers maintain relaxed and the foot rests on the ground [38]. These exercises restore strength and proper muscle tone and strengthen the medial longitudinal arch of the foot, which increases the stability of the ankle [52, 53]. They also have a positive effect on proprioception and postural stability. It is recommended to do barefoot exercises in order to ensure as much stimulation of the sensorimotor system [54].

The sensorimotor system is, next to the eye and vestibular organs, one of the basic mechanisms responsible for controlling stability and restoring balance. The system is made up of skin and deep sensory receptors, especially from the plantar surface of the foot and around the ankle. Proper distribution of the load on the feet is therefore an element affecting the control of dynamic stability and is a condition for proper gait [27].

Stability is a key element during movement [26]. In dynamic conditions, such as walking or running, it allows an individual to continue the functional movement, despite the occurrence of external and internal destabilizing forces. Dynamic stability analysis should take into account the changing moments of muscle strength and changes in the position of body segments in space [28].

To estimate dynamic stability control, it is possible to measure the variability of gait kinematics and temporal-spatial parameters [29, 30]. The variability of these parameters is the smallest when walking at natural speed, comfortable for a given person. It is assumed that the increase in variability, which occurs in the case of faster and slower gait, is associated with a decrease in stability [31, 32]. Paradoxically, however, with age, a reduction in walking speed is very often observed [55]. In the elderly, the perception of sense organs that control the balance and stability of the posture is weakened – the organ of responsible for sight, the vestibular organ and the receptors of superficial and deep feeling [56]. It seems, therefore, that moving at a slower speed is aimed at improving the control of dynamic stability, which is in contradiction with the previously quoted assumptions about the variability of gait.

This paradox is explained in a paper by Dingwell and Marin [37]. The authors compared dynamic stability and variability of gait parameters depending on its speed. In this research, the starting point were scientific reports indicating the relationship between gait speed and its variability. Even earlier, Winter [35] observed that there is an individual variable and individual speed of movement,

at which energy expenditure and variability of gait parameters are the smallest. Oberg et al. [32, 36] assessed changes in selected parameters depending on the speed at which the examined person moves. Faster gait was associated with lengthening strides and increased ranges of motion in the knee and hip joints. However, lower walking speeds are accompanied by smaller ranges of motion in the joints and lower generated moments of muscle strength [57-59].

11 young, healthy individuals participated in the study by Dingwell and Martin [37]. Prior to the actual test, the preferred walking speed (PWS) was determined for each participant. The task of the subjects was to move on a mechanical treadmill at speeds at 60%, 80%, 100% 120% and 140% of PWS, respectively. Selected parameters were evaluated using the VICON system for three-dimensional motion analysis. It was observed that their variability was the smallest when walking at the speed preferred by the subject. This variability increased with the change of walking speed, both in the direction of lower and higher values.

Local dynamic stability was quantitatively determined using the Lyapunov method [60]. The results obtained by the authors indicate an improvement in dynamic stability during walking at a slower speed, despite the increase in its variability. Researchers suggest that the neuromuscular control system is more effective in controlling exogenous and endogenous balance disturbances during slow walking than when moving at higher speeds.

A similar study was conducted by England and Granata [34]. They assessed the variability of temporal-spatial and kinematic parameters of gait when moving at speeds corresponding to 20%, 40%, 60% and 80% of walking speed (V_f), calculated using the Froude number, taking the forces of inertia and gravity into account [61]. According to available studies, the natural and comfortable walking speed is $0.42 V_f$, while running is initiated at the speed of $0.70 V_f$ [62,63]. Local dynamic stability was determined, similarly as in Dingwell and Martin's study, using the Lyapunov method [60]. The results obtained in the England and Granata study confirmed that when moving at a comfortable (natural) speed, the variability of temporal-spatial and kinematic parameters of gait is the smallest. Both walking at greater and lower speeds increases the variability of its parameters. However, the authors suggest that dynamic stability may be poorly represented by the size of the variation in gait. Lyapunov's analysis indicated greater local stability of all joints at a lower speeds.

In this study, a change in some temporal-spatial parameters of gait was observed after the 6-week programme of exercises activating the short plantar muscles of the foot surface. In the second examination, significantly lower cadence, gait speed, step length and a lower value of

the index expressing the ratio of stride length to body height were recorded. The duration of the gait cycle significantly prolonged. Other parameters did not change significantly. Perhaps this is related to the conditions under which the measurements were carried out. Walking on a flat surface may not be a demanding task for healthy individuals. Hence, the lack of registered changes due to training in percentage distribution of the gait cycle phases or in propulsion.

According to the previously quoted research results of different authors, when moving at a natural speed, the variability of temporal-spatial parameters is the smallest. On the other hand, walking at both higher and lower speeds increases the variability of its parameters. In our research, runners walked more slowly, with a shorter steps and smaller cadence after the applied training. Thus, the preferred walking speed, comfortable for a given person, changed. No changes in the proportion of the swing or support phases indicate that the gait pattern remained the same as before the workout.

Slower gait is a common strategy to increase dynamic stability and reduce the risk of falling, especially in elder individuals. However, studies conducted by Hak et al. [64] indicate that, in this case, the reduction in gait speed is not important. The response to the balance disorder and the mechanism allowing its preservation is shortening step length, increasing cadence and step width.

Changes in gait parameters observed in our research may be the result of improved motor control. It can be assumed that the applied foot exercises, through their impact on proprioceptors, contributed to the improvement of the sensorimotor system as a mechanism ensuring control of dynamic stability. The improvement of foot posture in statics, visible in the form of the FPI-6 index value change, could also translate into improvement in motor control. Further research in this field is recommended.

The heterogeneity of the group – the age of the respondents ranged from 21 to 45 years, and their weekly training ranging from 20 to 100 km, may be indicated as a limitation of this study. Another factor was the lack of subjects with feet supination in the study group, and therefore, it was impossible to assess what changes in runners with this type of foot posture would be triggered by the applied training programme.

Persons who practice long-distance running are exposed to long-lasting loads, which is why this group has key mechanisms that absorb shock during running and walking. Correct foot posture is a contributing factor [4]. The results of our research confirm that the short plantar muscle exercises of the foot surface improve foot posture towards a neutral position. The applied exercise programme also influenced changes in some of the temporal-spatial parameters of gait. After the applied training programme, the runners walked slower, took shorter steps and their cadence decreased. The transfer of natural, comfortable gait for a given person towards lower values may be the result of improved motor control, obtained through the influence of the applied exercises on the sensorimotor system.

Exercising the short plantar muscles of the foot surface is crucial for athletes, especially those who are exposed to long-lasting loads. Unfortunately, these exercises are usually overlooked in athletes' training. Therefore, more attention should be paid to adequate and optimal involvement internal muscles of the plantar surface of the foot in runners. Further research is recommended regarding the impact of these exercises, taking differences in the foot posture and among athletes of other disciplines into account.

Conclusions

1. Lower values of individual components and the total result of the Foot Posture Index suggest that the applied short plantar muscle exercises of the foot surface cause a statistically significant improvement in their posture from pronation to a neutral positioning.
2. The observed changes in temporal-spatial parameters of gait in the form of a statistically significant reduction in its speed, cadence and step length, as well as lengthening the gait cycle, may indicate improvement in motor control and a shift of the comfortable natural walking speed towards lower values.
3. Based on the obtained results, performing exercises activating the short plantar muscles of foot surface is recommended as a permanent element of daily training in long-distance runners.

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