Research Paper: Comparing the Effects of Fatigue Caused by the Treadmill and Overground Running on the Pattern of Plantar Pressure Distribution

Shokoufeh Pakbaz[1*], Mehrdad Anbarian[2], Azar Aghayari[3]

1. Department of Physical Education, Faculty of Educational Sciences and Psychology, Garmsar Branch, Payam-e Noor University, Semnan, Iran.
2. Department of Sport Biomechanics, Faculty of Sports Sciences, Bu-Ali Sina University, Hamadan, Iran.
3. Physical Education Branch, Payam-e Noor University, Tehran, Iran.

Use your device to scan and read the article online

Citation Pakbaz Sh, Anbarian M, Aghayari A. Comparing the Effects of Fatigue Caused by the Treadmill and Overground Running on the Pattern of Plantar Pressure Distribution. Physical Treatments. 2018; 8(3):169-178. http://dx.doi.org/10.32598/ptj.8.3.169

http://dx.doi.org/10.32598/ptj.8.3.169

Article info:
Received: 12 Apr 2018
Accepted: 26 Aug 2018
Available Online: 01 Oct 2018

Keywords:
Treadmill, Overground, Plantar pressure, Fatigue, Footscan

ABSTRACT

Purpose: This study aimed to compare the effects of fatigue due to overground and treadmill running on the plantar pressure distribution pattern.

Methods: Twelve novice athletes (Mean±SD age=26.0±2.5 y, Mean±SD weight: 52.0±3.0 kg, Mean±SD height: 159.0±5.0 cm), without sports injuries over the past year, were selected. Overground and treadmill running created fatigue in the samples. Peak plantar pressure distribution, Center of Pressure, contact area, and impulse the samples were recorded using a footscan (Footscan Version 7 Gait 2nd generation software) pressure system during running before and after the fatigue protocol and analyzed with repeated measures ANOVA in SPSS v. 18.

Results: Peak plantar pressure on the second to fifth toe , the fourth and fifth metatarsal bones, and medial part of the heel significantly increased. The shift in the Center of Pressure of the foot was non-significant in all stages. The contact area at the second metatarsal and midfoot area shifted only before the fatigue protocol on overground running. Impulse at the second to fifth toe, first to fifth metatarsal, significantly increased in the ground running.

Conclusion: The results showed that fatigue due to treadmill running has different effects compared to fatigue due to overground running.

*** Corresponding Author:**
Shokoufeh Pakbaz, MSc.
Address: *Department of Physical Education, Faculty of Educational Sciences and Psychology, Garmsar Branch, Payam-e Noor University, Semnan, Iran.*
Phone: *+98 (918) 3188446*
E-mail: *shokuh.pakbaz2009@gmail.com*

Highlights

- There is a question of whether overground running differs from running on a treadmill.
- Twelve novice athletes were selected to compare the effect of running in these two types of the running surface.
- Their peak plantar pressure distribution, the center of pressure, contact area and impulse were recorded with repeated measures using a footscan.
- The results showed that fatigue due to treadmill running has different effects compared to fatigue due to overground running.

Plain Language Summary

Sports injuries are a serious problem in both recreational and competitive sports, so predicting risk factors for sports injuries is essential. The goal of this current study was an analysis of plantar pressures after using two different surfaces (treadmill versus overground) in two different tested conditions (before and after the fatigue). The study participants took six series of tests as pretests. The time between the treadmill test and the overground test was 7 days. Immediately after the fatigue protocol, 6 correct test series of proper running as posttests were taken. The results showed that fatigue due to treadmill running has different effects compared to fatigue due to overground running.

1. Introduction

The current study aimed at analyzing plantar pressure subsequent to the running over two different surfaces (treadmill versus overground) before and after fatigue. Running is one of the most popular sport activities. However, nobody knows for sure that treadmill running can replicate overground running conditions.

This is an important area of investigation for training and research, and scientific studies have controversies over this matter. Some scientific investigations have shown that in running on a treadmill, stride length and flight phase decreases, but cadence increases using a moderate tempo of 3.3 to 4.8 m/s compared to overground running. Yet other investigations have shown similarities between the treadmill and overground running as regards kinematic factors such as the angle of hip adduction, internal/external rotation of the hip, eversion of the ankle, and maximum rotation of the pelvis [1-4].

Sports injuries are a serious problem for both recreational and competitive sports. Predicting risk factors for sports injuries is essential. A useful assessment of potential risk for running is the load on the plantar areas of the body when using different substrates [5, 6]. Overuse and repeated loading on these areas can cause lower extremity injuries. Yet no study has compared load distributions on the plantar areas when using a treadmill versus overground running. Such comparative information could assist in predicting sports injury risk factors. [7, 8].

Over the last 30 years, distance running has become a popular activity partly because everyone can do it without special equipment. As a result, the prevalence of lower extremity injuries due to running has increased [9]. These injuries occur due to overuse or repeated micro trauma to muscles, tendons, and bones and submaximal loading on these body parts. However, there are many causes of running injuries. Some causes are already discovered, but some are still unknown [10-12].

Nowadays using treadmills is increasingly popular, so researchers are interested in comparing the biomechanical characteristics between treadmill and overground running. As mentioned above, studies have not resolved the question of whether the mechanics of running on a treadmill can replicate those of overground running [1, 3]. So far, studies have investigated issues such as the kinematic adaptations and kinetics of running, as well as neuromuscular adaptations and differences in the activities of various muscles under different substrates in running [3, 4, 13-15].

Studies indicate that a number of factors be considered when investigating treadmill versus overground running. Such factors may include stride frequency; contact time; kinematics of hip, knee, and ankle; activities of specific

Pakbaz Sh, et al. Comparing the Effects of Fatigue Caused by the Treadmill and Overground Running on the Pattern of Plantar Pressure Distribution. PTJ. 2018; 8(3):169-178.

muscles; the amount of energy consumed; pressures in the plantar areas; and shock reduction [2-4, 13, 16-19]. Moreover, these factors can be influenced by other elements in the running environment. How familiar the runner is to running on treadmills, variations in the speed of the treadmill between strides, air resistance, and efforts of the runner to establish a safe stable running position on the treadmill can all affect treadmill and overground running comparisons. Another important factor is running speed that produces biomechanical differences between running on different surfaces at certain speeds (for example, 3 to 5 m/s, but not 6 m/s). It also increases the differences proportional to increase in speed [2,18]. Thus, further studies are needed to consider different running speeds as an important factor in the measurement of biomechanical changes when running on a treadmill versus overground [20, 21].

An even more important factor is the effect of fatigue on the biomechanics of running. Such effects may start by a change in the angle of the runner's foot with the running substrate, then a change in the distribution of pressure at the plantar area, followed by a change in the reaction forces, or a change in the pattern of muscular activity and neuromuscular control depending on the running surface [13]. Plantar pressure is routinely used for the measurement and analysis of running on a treadmill or overground surface for the prevention of injury, increasing athletic performance, and designing new sports materials. Also, it can be easily used to analyze the effect of fatigue in running [6].

Running is one of the basic skills in most sports. Many researchers in different sports are interested in its biomechanical parameters so that many studies have so far examined the factors affecting the biomechanical parameters of running. According to the researchers, there are still many unknown factors influencing the biomechanics of running [21]. Previous studies have reported that running on different surfaces causes various biomechanical adjustments, and that is why the running surface is one of the fundamental aspects considered in running analyses [2].

Today, people use treadmill device more than ever and it has become a popular device. In investigational areas, the treadmill as a research tool has also become more popular [2, 4, 22] because of its many methodological advantages such as low space requirements, high reproducibility, control over weather conditions, speed, slope, and so on for researchers [2, 4, 22]. However, the results of studies on the treadmill are controversial, and questions arise whether fatigue caused by running on the treadmill or on the ground has different effects on the distribution of plantar pressure in running.

2. Materials and Methods

The study sample comprised 12 beginner volunteer sportswomen, aged 26 to 29 years. Their demographic information was as follows: Mean±SD age of 26.0±2.5 years, Mean±SD weight of 52.0±3.0 kg, and Mean±SD height of 159.0±5.0 cm. The study subjects were selected from female students of Bu-Ali Sina University in Hamedan City, Iran. $P<0.05$ were considered significant. This research wad quasi-experimental design. We applied the controllable restrictions, including age, gender, and familiarity with the methods. However, due to the nature of the study, controlling all the factors influencing variables was not possible, but all possible efforts

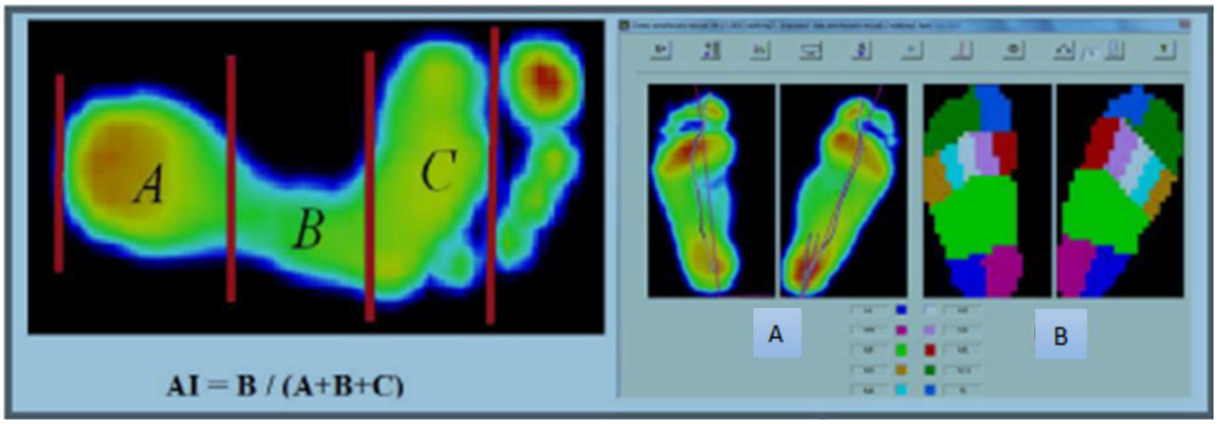

Figure 1. Determine the arch of the foot

Left picture represents calculation of foot arch index. Right picture (A) represents pressure on the sole of the foot; (B) represents 10 anatomical areas of the foot.

were made to reduce variations and provide the same conditions for all participants after being informed of the research procedure, the subjects presented written informed consent to participate in tests.

The participants did not show any abnormalities (assessment by New York test) or lower extremity musculoskeletal injury or disease for the past year. These data were self-reported. We used the New York test and posture screen to evaluate the physical conditions of the participants [15]. A digital scale of BS 100 (Sahand Company, Iran) was used to measure height and weight of the subjects; the accuracy of the scale was 0.1 kg and that of the height 1 cm.

Because of the pressure on the foot and its contact with the ground (back, middle, front of the foot), regardless of the toes, the foot Arch Index (AI) was calculated. Based on the foot arch index, there are three general classifications for foot structure (Figure 1).

Foot ring: AI≥21%

Foot with a normal arch: 28%≥AI≥21%

Flat foot: 28% AI≥21%

AB/AI=A+B+C

We used the footscan® advanced, hi-end system, and Gait software (2009) (made in Belgium) to measure the direction of the Center of Pressure (COP). The obtained information from this system includes various contact areas of the foot, maximum pressure on the foot, impulse, loading rate, and COP. It can be used to display the COPx (the rate changes in pressure center) moment by moment and change of plantar pressure.

The training protocol

This study was carried out in Bu-Ali Sina University of Hamedan, Sports Biomechanics Lab at the same time of the day for two tests. To register the rate changes in Center of Pressure (COPx), a footscan device of 1068 mm length, 418 mm width, and 8192 sensors with a sampling frequency of 500 Hz, and a treadmill made in China (Polar Model) were used. A 30 m long running track was determined, and the footscan device was located within 20 m of the track longitudinally.

In order to become familiar with the technique, the subjects were asked to run at normal speed for 2 to 3 min on the device so that the foot can make contact with the device properly when the main test with the device was run for the right foot (heel-toe). The participants had to run 30 m barefoot at the desired speed and pass the device so that one leg (the subject's leg contact with the screen in the pre-test and post-test) came into contact with the footscan device. Six correct and acceptable tests of running on the treadmill/overground pre-test and post-test were collected from each subject. If the foot did not hit the screen, the test would be rejected.

The participants were asked to do a warm-up activity for 15 minutes before exercise on both surfaces. Before the test, the subjects were asked to run on heel-toe. Six series of correct tests as pre-tests were collected. Then, the subjects ran on a treadmill with a 0-degree slope for about 30 minutes at a speed of 3-4 m/s. Every 5 minutes, the fatigue of the subjects was investigated by the Borg scale. Immediately after the treadmill test, 6 test series of running were performed as the post-test (heel-toe). Running time was 3 to 4 seconds on footscan. The time between the treadmill test and the overground test was 7 days. The subjects ran on the ground about 30 minutes at a speed of 3-4 m/s, and immediately after the fatigue protocol, 6 correct test series of proper running as post-test (heel-toe) were performed. Each participant used the same shoes for both tests.

The Shapiro-Wilk test was used for normally distributed data. To analyze the obtained data, the repeated measures ANOVA was performed to determine the differences before and after the fatigue by setting $\alpha \leq 0.05$. For a comparison of the conditions before and after fatigue in treadmill running and overground running, we used the Bonferroni test in SPSS v. 18.

3. Results

The Research hypothesis based on the pattern of distribution of plantar pressure caused by fatigue was confirmed running on the treadmill and the ground. The results showed that plantar pressure distribution were significantly different between running on a treadmill and on the ground (G×T) in the fourth and fifth toes of the foot (P=0.012), the fourth metatarsal (P=0.004), the fifth metatarsal (P=0.004), and the inside of the heel (P=0.008). The plantar pressure distribution pattern of running on the ground was significantly different prior to fatigue and after fatigue in the fourth and fifth toes of the foot (P=0.007), the first metatarsal bone (P=0.006), the fourth metatarsal area (P=0.007), and the midfoot bottom (P=0.001) (Table 1).

The Research hypothesis based on the pattern of COP caused by fatigue was not confirmed running on the

Table 1. The Mean±SD of plantar pressure in N/m² in 10 areas of the foot (Meta stands for metatarsal area)

Peak Plantar Pressure	Pre-Fatigue	Post-Fatigue		P		
		Treadmill (TR)	Overground (GR)	Pre×GR	Pre×TR	GR×TR
Toe 1	8.41±2.22	8.81±2.43	8.54±1.40	1.00	1.00	1.00
Toe 2-5	2.80±0.84	2.69±0.85	2.86±1.13	0.007*	1.00	0.012*
Meta 1	7.26±2.58	7.61±1.5	9.41±2.33	0.006*	1.00	0.03**
Meta 2	9.82±2.15	10.37±2.03	12.54±3.40	0.05**	0.56	0.13
Meta 3	10.06±2.77	10.21±2.32	12.09±3.44	0.1	1.00	0.2
Meta 4	7.35±2.11	6.82±1.61	10.01±2.80	0.007*	0.68	0.004*
Meta 5	4.13±1.48	3.59±1.11	5.57±1.93	0.01*	0.44	0.004*
Midfoot	3.64±1.10	3.45±1.19	6.01±1.42	0.001*	1.00	0
Heel medial side	13.12±3.35	12.01±3.42	14.54±3.79	0.48	0.25	0.008*
Heel lateral side	11.87±2.86	11.15±3.34	14.1±3.30	0.04**	0.9	0.02**

* P≤0.01; ** P≤0.05

PHYSICAL TREATMENTS

treadmill and the ground. To test this hypothesis, according to the footscan results and previous research, the running support phase was divided into three phases: the foot kick, the mid-phase of support, and the progress phase. The pattern of change in plantar pressure of running prior to fatigue and after fatigue on the ground and treadmill was not significantly different in any of the above phases (Table 2).

The Research hypothesis based on the pattern of contact percentage of different areas of the foot (contact areas) caused by fatigue was confirmed running on the treadmill and the ground. The results showed that the percentage of different foot contact areas with the ground was not significantly different between running on a treadmill and running on the ground (G×T) and before fatigue to after fatigue in the various parts of the foot. However, in the midfoot area, the difference was significant (P=0.006) just before the fatigue compared to after fatigue on the ground running (Pre×G) (Table 3).

The Research hypothesis based on the pattern of foot impulse caused by fatigue was confirmed running on the treadmill and the ground. The results showed a significant difference between running on a treadmill and on the ground (G×T) regarding the total pressure pattern for a specific area of the runner's foot sole. These areas include the fourth and the fifth toes (P=0.005), the first metatarsal area (P=0.009), the second metatarsal area (P=0.003), the third metatarsal area (P=0.024), the fourth metatarsal area (P=0.002) and the fifth metatarsal (P=0.002).

The pattern of total pressure for a specific area of the foot sole of the runner on the ground before fatigue was significantly different from after fatigue total pressure. These areas include the fourth and the fifth toes (P=0.004),

Table 2. The Mean±SD of changes in the Center of foot Pressure (COP) in 10 areas of the foot (Meta stands for metatarsal area)

COP	Pre-Fatigue	Post-Fatigue		P		
		Treadmill (TR)	Overground (GR)	Pre×GR	Pre×TR	GR×TR
Contact	-4.96±6.96	-7.04±6.75	-5±6.82	1.00	0.91	0.86
Midstance	-3.13±4.90	-3.80±5.04	-4.07±5.44	0.85	1.00	1.00
Propulsion	5.72±7.36	5.33±5.46	3.46±5.25	0.35	1.00	0.17

PHYSICAL TREATMENTS

Table 3. Mean±SD of the contact percentage of different areas of the foot (contact areas) in 10 plantar areas (Meta stands for metatarsal area)

Contact Areas	Pre-Fatigue	Post-Fatigue		P		
		Treadmill (TR)	Overground (GR)	Pre×GR	Pre×TR	GR×TR
Toe 1	13.77±2.02	13.59±2.35	13.91±2.60	1.00	1.00	0.94
Toes 2-5	16.13±1.53	16.36±1.79	17.09±2.22	0.47	1.00	0.46
Meta 1	11.48±1.95	11.39±1.59	10.98±1.75	0.74	1.00	0.30
Meta 2	9.96±1.25	10.28±1.28	10.83±1.57	0.06	0.46	0.14
Meta 3	8.58±0.97	8.61±0.97	9.12±1.13	0.33	1.00	0.05*
Meta 4	8.83±0.94	8.94±0.93	9.58±0.67	0.03*	1.00	0.01**
Meta 5	9.02±2.2	9.37±1.90	9.87±1.53	0.12	0.96	0.35
Midfoot	31.03±7.25	31.95±8.61	33.86±7.93	0.006**	0.36	0.04*
Heel medial side	14.60±1.43	14.12±1.47	14.32±1.40	1.00	0.15	1.00
Heel lateral side	12.93±1.13	12.55±1.17	12.87±1.41	1.00	0.21	1.00

*P≤0.05; **P≤0.01

PHYSICAL TREATMENTS

the first metatarsal area (P=0.001), the third metatarsal area (P=0.004), the fourth metatarsal (P=0.002), the fifth metatarsal (P=0.006), and the midfoot area (P=0.001). The pattern of total pressure for a specific area of the sole of the runner's foot on a treadmill before fatigue was significantly different from after fatigue only in the second metatarsal area (P=0.024) (Table 4).

4. Discussion

There is a debate on whether fatigue due to running on the treadmill or on the ground has different effects on the distribution of plantar pressure. The results show that fatigue caused by running on the ground and on the treadmill has different effects on the distribution of plantar pressure in running. One of the main study

Table 4. Mean±SD of the total pressure, in a special area under the foot impulse (Meta stands for metatarsal area)

Impulse	Pre-Fatigue	Post-Fatigue		P		
		Treadmill (TR)	Overground (GR)	Pre×GR	Pre×TR	GR×TR
Toe 1	0.98±0.35	1.07±0.33	1.08±0.13	1.00	1.00	1.00
Toes 2-5	0.36±0.1	0.36±0.1	0.05±0.14	0.004*	1.00	0.005*
Meta1	0.78±0.33	0.87±0.24	1.13±0.3	0.001*	0.49	0.009*
Meta 2	1.07±0.28	1.2±0.31	1.6±0.52	0	0.024**	0.003*
Meta 3	1.09±0.36	1.15±0.34	1.53±0.55	0.004*	0.38	0.024**
Meta 4	0.77±0.31	0.73±0.22	1.19±0.45	0.002*	1.00	0.002*
Meta 5	0.4±0.17	0.35±0.12	0.6±0.25	0.006*	0.69	0.002*
Midfoot	0.29±0.13	0.29±0.12	0.51±0.16	0.001*	1.00	0
Heel medial side	0.8±0.29	0.83±0.35	0.99±0.35	0.29	1.00	0.26
Heel lateral side	0.63±0.21	0.62±0.26	0.73±0.26	0.46	1.00	0.06

* P≤0.01; ** P≤0.05

PHYSICAL TREATMENTS

limitations was that we neither know the level of motivation of each participant nor differences in each participant's fatigue level.

Because of extensive laboratory studies on the treadmill and using the results to evaluate the effects of fatigue, it seems that issues raised in the study have a prominent role in generalizing the findings of other studies. Many studies have shown that the speed of the treadmill belt decreases by about 5% during the heel strike phase. This could be the result of the vertical force exerted on the treadmill. Hong et al. reported that compared to running on the ground, running on a treadmill is associated with a significant reduction in the maximum force on the foot and the distribution of loads on different areas of the foot [1].

They suggested that perhaps one of the potential reasons for this increase is the rise in the speed of the treadmill belt at the end of the stance phase. Vertical force reduction is likely associated with an increase in the speed of the treadmill belt at the end of the stance phase. In this case, the energy is transferred to the runner from the belt. In addition, in running on a treadmill, the runner can reach the speed of running on the ground with a lower driving force, and this would reduce the load on the feet in running on the treadmill.

Many studies have shown that fatigue changes in the pattern of pressure and force on the foot and its different areas by changing the mechanics of running. Nagel et al. (2008) showed that fatigue caused by long-distance running would change the distribution of plantar pressure for runners [14]. The results showed that the maximum amount of pressure and impulse on the runners' metatarsal areas would increase and in the area of the toes would reduce. Those results are very consistent with the results of this study. These results also reflect the transfer of load from the toes to the metatarsals that makes the area prone to damage from fatigue and stress fracture.

Alfuth and Rosenbaum et al. showed that after fatigue caused by running 10 km on a treadmill, the load on the heels would reduce. According to them, this is caused by changes in the mechanics of running. To explain this, fatigue and modified control of the back calf muscles are mentioned to be the causes of the change [23]. This result contrasts with the results of the present study. Perhaps one of the reasons for this conflict is the fatigue protocol used in the study with different subjects having different fitness levels.

There are other findings showing a significant difference in plantar pressure distribution in a state of fatigue caused by running on the treadmill or overground. In fatigue from running on the ground, the plantar pressure on the areas of the second to fifth toes; the first, fourth, and fifth metatarsals; the middle of the foot; and the inner part of the heel were significantly greater than those pressures in running on a treadmill.

Garcia-Perez et al. studied the effects of fatigue from running on a treadmill and on the ground. The results showed that after fatigue caused by running on a treadmill the overall pressure on the foot areas would reduce compared to the fatigue of running on the ground. The decline in the pressure in the heel area, great toe, and internal metatarsals was significant [24].

The results of this study in the areas of the first metatarsal and heel were consistent with the results of the present study, but in the areas of the great toe, the second to the fifth toe, the middle of the foot, and the outer part of the foot, they are not similar. The inconsistency may be due to different equipment utilized to measure plantar pressure in that in the present study plantar pressure was measured on barefoot using a footscan screen. However, in Garcia-Perez et al. study, the measurement was carried out on the insole of the shoes worn.

The results showed that none of the fatigue conditions had an effect on changing the plantar pressure center. These results indicate no change in foot movement in the frontal plane while running. In comparison with previous studies, no studies investigated the effects of fatigue in running on the Center of Pressure. This study is the first research to focus on this issue. However, Hajilo et al. showed that local fatigue was caused by the extension of the leg due to the changes in the heading of the pressure center while walking [7].

The results showed that during the contact phase, the pressure center significantly moved outward and inward in the heading phase. The results of the study were not consistent with those of our study. Perhaps the reason for this discrepancy is the different protocols of fatigue and the variety of tasks performed when the pressure is recorded.

In their study on the kinematic parameters of fatigue caused by running on a treadmill, Koblbauer et al. showed that after fatigue (caused by running on a treadmill), the inversion-eversion and supination-pronation did not change, and the pattern was the same as before-fatigue conditions [17]. Christina et al. (2001)

in their study also showed that the leg eversion of the ground exercise-induced fatigue did not change [25]. Dierks et al. showed that the fatigue of running on the treadmill would increase the maximum angle eversion of the back foot [26].

Because the course of pressure center reflects supination and pronation patterns, and fatigue in this component does not have any effect in each case, the results of this study do not match the results of Dierks et al. [26]. The reasons for this disparity might be related to the control of running speed. In Dierks et al. study, the runners chose their running speed. Pronation and supination, however, are the movements performed in three different planes with different activities, and maximum pronation or supination can be obtained only by measuring inversion or eversion of the back part of the leg [26]. Therefore, fatigue has no effect on pronation or supination of the foot. This study is a functional study to examine the effect of fatigue caused by running on the course of pressure center and shows that fatigue has no effect on this component in running.

These results are consistent with the results of our study. The fatigue generated in this study causes changes in the displacement of the pressure center, and the changes from fatigue in both situations are the same. The results showed that the fatigue caused by running overground would increase the contact areas of the fourth metatarsal and midfoot. However, the fatigue caused by running on a treadmill has no effect on different contact area locations.

Fourchet et al. showed that the total contact area of the foot would increase after fatigue due to increase in the contact area of the midfoot [27]. Nagel et al. in their study on 200 subjects participating in a marathon race investigated the parameters of plantar pressure measurements. They reported that after the marathon the contact surface of the foot would increase [14]. The medial longitudinal arch has a flexible structure and if it changes about 10 mm in length, it will become completely flat. Also, its length changes 4 mm in the stance phase. This structure plays an important role in the reaction force transfer between the ground, foot, and body. It has been shown that the Navicular bone is into decline after fatigue and arch height is lower.

The reduction in the height of the medial longitudinal arch may be associated with a greater surface area of the area under the medial longitudinal arch that increases midfoot contact. A further finding of this study is the increased contact surface area of the fourth metatarsal in after-fatigue condition, which is justified according to previous studies indicating greater contact area of the foot after fatigue. Based on our results, the fatigue after running on the treadmill has no effect on different parts of the foot contact surface, and this effect was different from the one caused by fatigue after running overground.

Wu et al. studied the effects of fatigue after treadmill running on EMG and plantar pressure. Their results showed that after generating fatigue by running on a treadmill, foot surface areas are not subject to change in running post-fatigue [28]. Alfuth and Rosenbaum also showed that the fatigue caused by running on a treadmill had no effect on different parts of the foot contact surfaces [23]. These results are consistent with the results of this study and reflect the impact of fatigue after treadmill running on different areas of the foot contact areas [29].

The results showed that the impulse applied to the second and fifth toe areas, the first to fifth metatarsals, and the midfoot after fatigue caused by running overground increased significantly, and the situation in other areas had not changed. The fatigue after running on a treadmill only increases impulses on the second metatarsal, and there is no significant effect in other areas. Due to the increasing impulse on the smaller toes and metatarsal area, the fatigue of running on a treadmill has increased forefoot loading.

Previous studies have shown that fatigue increases forefoot and metatarsal loading. Toe flexor fatigue, by reducing the functional capacity of the muscle, causes load transmission and impulse to the metatarsal. The Weist et al. study showed that fatigue increased the impulse applied to all parts of the foot, except for the small toes [30]. These results with respect to the metatarsal area are consistent with the findings of our study but inconsistent with regard to the area of small toes and heel area, and perhaps this is because of different measuring means of the load on the foot areas. In our study, the footscan device was used on barefoot, but in Weist et al. study, the measurement system was used with shoes. The results show that the fatigue caused by running on a treadmill increases the impulse applied to the second metatarsal area.

This may be due to toe flexor muscle fatigue and a defect to control the movements of the toes and the load distribution exerted on this area. The results of this study showed that the fatigue caused by running on a treadmill and on the ground had different effects on the foot impulse of the study runners.

Regarding the results of this paper, running on different surfaces, in repeated steps and continuous running produce different reactions, and the repetition of reactions causes different behaviors at the end of the protocol. As it was observed in this study, fatigue caused by two different running surfaces had different effects that could be due to different responses to various contact surfaces. Caekenberghe et al. reported that adaptation to different running surfaces would occur under different circumstances, and people reacted differently at every level.

The results show that fatigue caused by on the ground or on the treadmill running has different effects on the distribution of plantar pressure. In general, plantar pressure distribution in the after-fatigue condition of running on the ground was greater than that in the after-fatigue caused by running on the treadmill. Biomechanically, there are differences between running on a treadmill and running on the ground. Different running surfaces (on the ground and on the treadmill) create different effects in terms of fatigue.

Ethical Considerations

Compliance with ethical guidelines

After being informed of the research trends, the subjects presented written informed consent to participate in tests.

Funding

The present paper was extracted from the MSc. thesis of the first author, in Department of Physical Education, Faculty of Educational Sciences and Psychology, Garmsar Branch, Payam-e Noor University.

Authors' contributions

All authors contributed in designing, running, and writing all parts of the research.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors thank Ms. Connie Allison, Geneva, New York, for editing this article.

References

[1] Hong Y, Wang L, Li JX, Zhou JH. Comparison of plantar loads during treadmill and overground running. Journal of Science and Medicine in Sport. 2012; 15(6):554-560. [DOI:10.1016/j.jsams.2012.01.004] [PMID]

[2] Pinnington HC, Lloyd DG, Besier TF, Dawson B. Kinematic and electromyography analysis of submaximal differences running on a firm surface compared with soft, dry sand. European Journal of Applied Physiology. 2005; 94(3):242-53. [DOI:10.1007/s00421-005-1323-6] [PMID]

[3] Riley PO, Dicharry J, Franz J, Della Croce U, Wilder RP, Kerrigan DC. A kinematics and kinetic comparison of overground and treadmill running. Medicine and Science in Sports and Exercise. 2008; 40(6):1093-100. [DOI:10.1249/MSS.0b013e3181677530] [PMID]

[4] Tillman MD, Fiolkowski P, Bauer JA, Reisinger KD. In-shoe plantar measurements during running on different surfaces: Changes in temporal and kinetic parameters. Sports Engineering. 2002; 5(3):121-8. [DOI:10.1046/j.1460-2687.2002.00101.x]

[5] Dixon SJ, Stiles VH. Impact absorption of tennis shoe-surface combinations. Sports Engineering. 2003; 6(1):1-10. [DOI:10.1007/BF02844155]

[6] Savelberg HH, Vorstenbosch MA, Kamman EH, et al. Intra stride belt-speed variation affects treadmill locomotion. Gait and Posture. 1998; 7(1):26-34. [DOI:10.1016/S0966-6362(97)00023-4]

[7] Hajilu B, Anbarian M, Sepehrian M, Esmaeili H. [The effect of quadriceps muscle fatigue on foot plantar pressure distribution during stance phase of walking (Persian)]. Razi Journal of Medical Sciences. 2014; 21(121):1-8.

[8] Rosenbaum D, Engl T, Nagel A. Foot loading changes after a fatiguing run. Journal of Biomechanics. 2008; 2008(41):S109. [DOI:10.1016/S0021-9290(08)70109-X]

[9] Buist I, Bredeweg SW, Lemmink KA, Van Mechelen W, Diercks RL. Predictors of running-related injuries in novice runners enrolled in a systematic training program: A prospective cohort study. The American Journal of Sports Medicine. 2010; 38(2):273-80. [DOI:10.1177/0363546509347985] [PMID]

[10] Kram R, Griffin TM, Donelan JM, Chang Y H. Force treadmill for measuring vertical and horizontal ground reaction forces. Journal of Applied Physiology. 1998; 85(2):764-9. [DOI:10.1152/jappl.1998.85.2.764] [PMID]

[11] Schache AG, Blanch PD, Rath DA, Wrigley TV, Starr R, Bennell KL. A comparison of overground and treadmill running for measuring the three-dimensional kinematics of the lumbo-pelvic-hip complex. Clinical Biomechanics. 2001; 16(8):667-80. [DOI:10.1016/S0268-0033(01)00061-4]

[12] Tessutti V, Trombini-Souza F, Ribeiro AP, Nunes AL, Sacco-Ide C. In-shoe plantar pressure distribution during running on natural grass and asphalt in recreational runners. Journal of Science and Medicine in Sport. 2010; 13(1):151-5. [DOI:10.1016/j.jsams.2008.07.008] [PMID]

[13] Baur H, Hirschmüller A, Müller S, Gollhofer A, Mayer F. Muscular activity in treadmill and overground running. Isokinetics and Exercise Science. 2007; 15(3):165-71. [DOI:10.3233/IES-2007-0262]

[14] Nagel A, Fernholz, F, Kibele C, Rosenbaum D. Long distance running increases plantar pressures beneath the metatarsal heads: A barefoot walking investigation of 200 marathon runners. Gait and Posture. 2008; 27(1):152-5. [DOI:10.1016/j.gaitpost.2006.12.012] [PMID]

[15] Reinisch M, Schaff P, Hauser W, Rosemeyer B. Treadmill versus field trial. Movement analysis and pressure distribution in the athletic shoe. Sportverletzung Sportschaden: Organ der Gesellschaft fur Orthopadisch-Traumatologische Sportmedizin. 1991; 5(2):60-73. [DOI:10.1055/s-2007-993563] [PMID]

[16] Fellin RE, Manal K, Davis IS. Comparison of lower extremity kinematic curves during overground and treadmill running. Journal of Applied Biomechanics. 2010; 26(4):407-14. [PMID] [PMCID]

[17] Koblbauer IF, van Schooten KS, Verhagen EA, van Dieën JH. Kinematic changes during running-induced fatigue and relations with core endurance in novice runners. Journal of Science and Medicine in Sport. 2014; 17(4):419-24. [DOI:10.1016/j.jsams.2013.05.013] [PMID]

[18] Meeuwisse WH. Assessing causation in sport injury: A multifactorial model. Canadian Academy of Sport and Exercise Medicine. 1994; 4(3):166-70.

[19] Novacheck TF. The biomechanics of running. Gait and Posture. 1998; 7(1):77-95. [DOI:10.1016/S0966-6362(97)00038-6]

[20] Lavcanska V, Taylor NF, Schache AG, Familiarization to treadmill running in young unimpaired adults. Human Movement Science. 2005; 24(4):544-57. [DOI:10.1016/j.humov.2005.08.001] [PMID]

[21] Mercer JA, Vance J, Hreljac A, Hamill J. Relationship between shock attenuation and stride length during running at different velocities. European Journal of Applied Physiology. 2002; 87(4):403-8. [DOI:10.1007/s00421-002-0646-9] [PMID]

[22] Nigg BM, De Boer RW, Fisher V. A kinematic comparison of overground and treadmill running. Medicine and Science in Sports and Exercise. 1995; 27(1):98-105. [DOI:10.1249/00005768-199501000-00018] [PMID]

[23] Alfuth M, Rosenbaum D. Long distance running and acute effects on plantar foot sensitivity and plantar foot loading. Neuroscience Letters. 2011; 503(1):58-62. [DOI:10.1016/j.neulet.2011.08.010] [PMID]

[24] García-Pérez JA, Pérez-Soriano P, Llana S, Martínez-Nova A, Sánchez-Zuriaga D. Effect of overground vs treadmill running on plantar pressure: Influence of fatigue. Gait & Posture. 2013; 38(4):929-33. [DOI:10.1016/j.gaitpost.2013.04.026]

[25] Christina KA, White SC, Gilchrist LA. Effect of localized muscle fatigue on vertical ground reaction forces and ankle joint motion during running. Human Movement Science. 2001; 20(3):257-76. [DOI:10.1016/S0167-9457(01)00048-3]

[26] Dierks Tracy A, Davis Irene S, Hamill Joseph. The effects of running in an exerted state on lower extremity kinematics and joint timing. Journal of Biomechanics. 2010; 43(15):2993-8. [DOI:10.1016/j.jbiomech.2010.07.001] [PMID]

[27] Fourchet F, Luke K, Cosmin H, Heiko L, Redha T, Grégoire M. High-intensity running and plantar-flexor fatigability and plantar-pressure distribution in adolescent runners. Journal of Athletic Training. 2006; 50(2):117-125. [DOI:10.4085/1062-6050-49.3.90] [PMID] [PMCID]

[28] Wu WL, Chang JJ, Wu JH, Guo LY, Lin HT. EMG and plantar pressure patterns after prolonged running. Biomedical Engineering: Applications, Basis and Communications. 2007; 19(6):383-8. [DOI:10.4015/S1016237207000483]

[29] Weist R, Eils E, Rosenbaum D. The influence of muscle fatigue on electromyogram and plantar pressure patterns as an explanation for the incidence of metatarsal stress fractures. American Journal of Sports Medicine. 2004; 32(8):1893-8. [DOI:10.1177/0363546504265191] [PMID]

[30] Van Caekenberghe I, Segers V, Aerts P, Willems P, De Clercq D. Joint kinematics and kinetics of overground accelerated running versus running on an accelerated treadmill. Journal of the Royal Society Interface. 2013; 10(84):20130222. [DOI:10.1098/rsif.2013.0222] [PMID] [PMCID]