STUDY ON THE BIOMECHANICAL CHARACTERISTICS OF FUNCTIONAL INSOLES ON THE FOOT OF ATHLETES DURING RUNNING

Guanghua ZHI*

Basic Teaching Department, Guilin University of Electronic Technology, Beihai 536000, China, dizhi1602@163.com

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STUDY ON THE INFLUENCE OF BIOMECHANICAL CHARACTERISTICS OF FUNCTIONAL INSOLES ON THE FOOT OF ATHLETES DURING RUNNING

ABSTRACT. Functional insoles can reduce foot injuries caused by running. In this paper, ten male volunteers from the Track and Field Department of Guilin University of Electronic Technology were selected as subjects to test the biomechanical characteristics of the foot, such as plantar pressure, impulse, and center line pressure distribution, when using normal insoles and shock-absorbing functional insoles made of latex, ethyl vinyl acetate (EVA), and conventional insoles. The results showed that the plantar pressure and impulse were mainly concentrated on the first toe, the middle of the metatarsal, and the lateral part of the heel. After using the shock-absorbing insoles, the average pressure and impulse of the first toe, second to fifth toe, lateral metatarsal, and lateral heel were significantly reduced, while the average pressure intensity and impulse of the medial metatarsal, middle metatarsal, and medial heel were significantly increased; the center line of pressure became longer and straighter, indicating that the running stability was improved.

KEY WORDS: insole, shock absorption, foot, biomechanics

STUDIU PRIVIND INFLUENȚA CARACTERISTICILOR BIOMECANICE ALE BRANȚURILOR FUNCȚIONALE ASUPRA PICIORULUI SPORTIVILOR ÎN TIMPUL ALERGĂRII

REZUMAT. Branțurile funcționale pot reduce leziunile cauzate de alergare la nivelul picioarelor. În această lucrare, zece voluntari de sex masculin de la Departamentul de atletism al Universității de Tehnologie Electronică din Guilin au fost selectați ca subiecți pentru a testa caracteristicile biomecanice ale piciorului, cum ar fi presiunea plantară, impulsul și distribuția presiunii pe linia centrală, la utilizarea branțurilor normale, a branțurilor funcționale care absorb șocurile, fabricate din latex, etilen-acetat de vinil (EVA) și a branțurilor convenționale. Rezultatele au arătat că a existat o concentrare preponderentă a presiunii plantare și a impulsului în zona halucelui, în zona centrală a metatarsienelor și pe partea laterală a călcâiului. După utilizarea branțurilor care absorb șocurile, presiunea și impulsul medii în zona halucelui, în zona ce cuprinde al doilea până la al cincilea metatarsian, în zona metatarsiană laterală și în cea laterală a călcâiului s-au redus semnificativ, în timp ce intensitatea medie a presiunii și impulsul în zona metatarsiană mediană, în centrul zonei metatarsiene și în zona mediană a călcâiului au crescut semnificativ; linia centrală de presiune a devenit mai lungă și mai dreaptă, ceea ce indică faptul că s-a îmbunătățit stabilitatea în timpul alergării.

CUVINTE CHEIE: branț, absorbția șocurilor, picior, biomecanică

ÉTUDE SUR L'INFLUENCE DES CARACTÉRISTIQUES BIOMÉCANIQUES DES SEMELLES INTÉRIEURES FONCTIONNELS SUR LE PIED DES ATHLÈTES PENDANT LA COURSE

RÉSUMÉ. Les semelles intérieures fonctionnelles peuvent réduire les blessures aux pieds pendant la course. Dans cet article, dix volontaires masculins du département d'athlétisme de l'Université de Technologie Électronique de Guilin ont été sélectionnés comme sujets pour tester les caractéristiques biomécaniques du pied, telles que la pression plantaire, l'impulsion et la répartition de la pression sur l'axe central, lors de l'utilisation de semelles intérieures normales, de semelles intérieures fonctionnelles, en latex et éthylène-acétate de vinyle (EVA), d'absorption des chocs, et de semelles intérieures conventionnelles. Les résultats ont montré qu'il y avait une concentration prédominante de pression plantaire et d'impulsion dans la zone de l'hallux, dans la zone centrale des métatarsiens et sur la face latérale du talon. Après avoir utilisé les semelles intérieures amortissantes, la pression et l'impulsion moyennes dans la zone de l'hallux, la zone du deuxième au cinquième métatarsien, la zone métatarsienne latérale et la zone latérale du talon ont été considérablement réduites, tandis que l'intensité de pression et l'impulsion moyennes dans la zone métatarsienne moyenne, le centre de la zone métatarsienne et la zone médiale du talon ont augmenté de manière significative ; la ligne centrale de pression est devenue plus longue et plus droite, ce qui montre que la stabilité pendant la course s'est améliorée.

MOTS CLÉS : semelle intérieure, absorption des chocs, pied, biomécanique

* *Correspondence to: Guanghua ZHI, Basic Teaching Department, Guilin University of Electronic Technology, Beihai 536000, China, dizhi1602@163.com.*

INTRODUCTION

In today's fast-paced life, people are paying more and more attention to health issues. As technology advances, more and more health products are being developed, and one of the products that have received much attention is functional insoles [1]. These insoles can provide targeted support and protection according to the biomechanical characteristics of people's feet, thus improving physical conditions and preventing sports injuries. The foot is a very important part of the body [2] and is responsible for supporting the body weight, balancing the body stability and cushioning the ground load and other functions; therefore, during sports, the foot is often subjected to large loads and pressures. During daily walking, the foot is exposed to multiple impacts, not to mention that running exposes the foot to approximately three times the impact of jogging [3]. With such frequent and large impacts, it is difficult for the foot's own shock-absorbing structure (mainly the arch) to fully compensate for the damage caused by the impacts. If the foot is not properly protected and supported, it will cause foot pain and affect human health. The role of insoles is to avoid direct contact between the foot and the sole, and at the same time, by virtue of its own material characteristics, relieve the pressure for the foot and play a role in absorbing sweat, thus improving the comfort of the shoe, and the pattern of the insole surface can also reduce the slippage between the sole and the foot [4]. In addition to the above-mentioned basic functions, functional insoles also have their own features, and shock-absorbing insoles are one of the functional insoles that emphasize shock-absorbing functions. Shock-absorbing functional insoles use the material and structure to improve the shock-absorbing performance, so as to provide sufficient support to the foot [5] and reduce the sports injuries caused during running. For functional insoles, He *et al*. [6] developed a smart insole with real-time monitoring of plantar pressure distribution through wearable sensor technology. The experimental results showed a 44% reduction in heel pressure after using the smart insole. Liu *et al*. [7] investigated the effect of orthotic insoles with medial arch support and heel cushion on postural balance in chronic stroke patients and found that orthotic insoles had a small but significant positive effect on improving postural balance in chronic stroke patients. Han [8] compared the biomechanical and clinical effects of three different insoles on rearfoot motion (RFM) and ankle moment parameters and found that insoles with arch support and cushioning were effective in reducing sports injuries. In this paper, ten male volunteers from the Track and Field Department of Guilin University of Electronic Technology were used to test the biomechanical characteristics of the foot such as plantar pressure intensity, impulse and center line distribution of pressure under normal insoles and shock-absorbing functional insoles.

EXPERIMENTAL

Subjects

In this paper, ten male volunteers were selected from the Track and Field Department of Guilin University of Electronic Technology, and their basic conditions are shown in Table 1. There were no significant differences in age, height and weight among the ten volunteers, and they were also in good health, with no serious sports injuries to the lower limbs, especially the feet, in the past six months. The shoe sizes worn by the volunteers were all 41. The volunteers were awake during the experiment and all gave informed consent.

Table 1: Basic information of male volunteers

	Age/years	Height/cm	Body weight/kg
Average value	20±1.1	170.3±1.1	62.1±1.1
P value	0.114	0.123	0.145

Equipment and Materials

The experimental equipment and materials included the Novel Pedar-X plantar pressure insole testing system [9] (Novel, Germany) used to test the biomechanics of the foot, stopwatch, treadmill (Yijian brand, model ELF, 0.3~4 m/s speed adjustable range), size 41 sports shoes of common brand, white board paper, marker, glue, carving knife, latex, and ethyl vinyl acetate (EVA) [10]. Among them, the plantar pressure insole testing system mainly consisted of insoles with 99 capacitive pressure sensors and a signal transmission box. The signal transmission box transmitted the collected plantar pressure data to the computer via wireless signals, and each insole then used 99 pressure sensors [11] to collect the distribution of plantar pressure. The sampling frequency of the pressure sensors was 50 Hz. The sampling positions constituted by the pressure sensors and their corresponding foot regions are shown in Figure 1. Area ① is the 1st toe region; area ② is the 2nd to 5th toe region; area ③ is the medial metatarsal region; area ④ is the middle metatarsal region; area ⑤ is the lateral metatarsal region; area ⑥ is the midfoot region; area ⑦ is the medial heel region; area ⑧ is the lateral heel region [12].

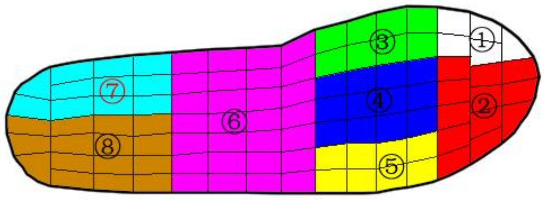

Figure 1. Schematic diagram of the sampling position of the pressure sensors and the corresponding plantar regions

The shock-absorbing functional insoles used in the experiments were all prepared independently, and the preparation process is as follows.

① A size 41 ordinary sports shoes insole with a hardness of 35 °ShA was selected.

② Structural design of shock-absorbing functional insoles: The design principle of the shock-absorbing functional insoles was to bond different materials of insoles at specific areas to achieve the shock-absorbing function. Its basic structure is shown in Figure 2. The light blue A area corresponded to the forefoot metatarsal area, which required a certain amount of rebound to improve the efficiency of movement; the yellow B area and the pink C area corresponded to the lateral and medial heel areas, respectively, which required a certain amount of shock absorption to reduce the impact of landing. The parameters of the material used in areas A, B, and C are shown in Table 2.

Table 2: Material-related parameters of the three regions

Area code	Materials	Hardness/°ShA	Thickness/mm
A	Latex	18	2
B	Latex	22	3
C	EVA	40	3

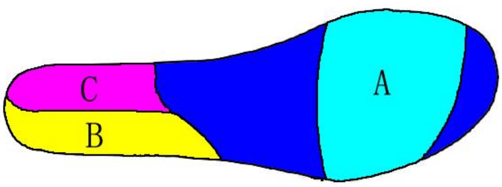

Figure 2. Basic structure of shock-absorbing functional insoles

③ Making the shock-absorbing functional insole: first, the structure shown in Figure 2 was drawn on the white board paper. Then, areas A, B and C were cut out as samples. Then, the same shapes were cut from the materials according to the samples and glued to the corresponding areas using glue. Air bubbles were avoided when gluing the functional insoles. After the glue had set, the glued edges were sanded with sandpaper [13].

Methods

Blank Experiment

First, the pressure insole of the plantar pressure testing system was placed into the corresponding sports shoes. The pressure insole was kept as close as possible to the sports shoe sole without sliding. After the volunteer put on the sports shoes, the pressure insole and the signal transmission box were connected using the connection cable (note the difference between left and right), and then the signal transmission box was fixed at the waist [14].

The volunteers warmed up before wearing the test system. After wearing, they ran on the treadmill at a speed of 3 m/s for 5 s, and the change in plantar pressure was recorded during the process. The test was conducted three times with a 6-minute interval between each test to ensure that the volunteers were rested.

Comparison Experiments

The volunteers also warmed up before the test and then replaced the original insoles in the shoes with the prepared shock-absorbing functional insoles. After that, the volunteers also ran on the treadmill at a speed of 3 m/s for 5 s to record the change in plantar pressure. The test was conducted three times, with each test interval of 6 minutes.

Statistical Analysis

SPSS software [15] was used to statistically analyze the collected data. The measurement data were expressed as mean ± standard deviation (X ± SD). Independent T-test was used to compare the two insoles. $P < 0.05$ indicates a significant difference, and $p < 0.01$ indicates a highly significant difference.

RESULTS AND DISCUSSIONS

As the right and left feet are symmetrical and the space of this paper is limited, only the right foot was used as an example. Table 3 shows the average pressure intensity of each area of the sole of the subject's right foot under the action of the two insoles. It was seen from Table 3 that the average pressure intensity distribution in the foot was greater in the 1st toe, the middle metatarsal and the lateral heel, especially in the middle metatarsal and the lateral heel. Due to the arch-shaped structure of the human foot arch, the pressure intensity borne by the foot is mainly concentrated in the upper and lower ends of the foot, i.e., the toes, metatarsals and heel area. The midfoot is located in the center of the foot arch, so the pressure intensity borne by it is small.

Table 3: Average pressure in each region of the right foot under the action of the two insoles

Plantar area number	Area name	General sports insoles/kPa	Shock-absorbing functional insoles/kPa	P value
①	1st toe	101.3±10.2	92.4±12.4	0.004**
②	2nd to 5th toe	42.2±11.4	38.6±12.6	0.001**
③	Medial metatarsal	66.5±11.3	75.4±11.2	0.000**
④	Mid-metatarsal	167.3±32.1	192.4±42.6	0.001**
⑤	Lateral metatarsal	61.35±12.8	44.7±12.4	0.002**
⑥	Midfoot	0.2±0.1	0.1±0.1	0.215
⑦	Medial heel	71.3±22.6	93.6±27.7	0.002**
⑧	Lateral heel	125.9±19.7	105.6±25.8	0.001**

In addition, except for the midfoot region, all other regions of the foot showed significant changes in average plantar pressure after using the shock-absorbing insoles. The average pressure intensity of the 1st toe, 2nd to 5th toe, lateral metatarsal and lateral heel showed a significant decrease, while the average pressure intensity of the medial metatarsal, mid-metatarsal and medial heel showed a significant increase. This indicated that the pressure on the toes and the medial and lateral metatarsals was directed to the mid-metatarsal and the pressure on the lateral heel was directed to the medial heel after the use of the shock-absorbing insoles. The overall distribution of pressure intensity was closer to the midline of the foot and relatively more balanced.

Table 4: Impulse of different areas of the right foot under the action of the two insoles

Plantar area number	Area name	General sports insoles/Ns	Shock-absorbing functional insoles/Ns	P value
①	1st toe	10.5±1.1	9.4±2.5	0.012*
②	2nd to 5th toe	7.9±2.3	6.8±2.7	0.001**
③	Medial metatarsal	12.1±2.2	16.9±2.8	0.001**
④	Mid-metatarsal	52.2±14.8	69.1±15.5	0.000**
⑤	Lateral metatarsal	10.6±2.9	9.6±2.1	0.025*
⑥	Midfoot	0.1±0.1	0.0±0.0	0.236
⑦	Medial heel	16.7±11.4	22.2±10.2	0.002**
⑧	Lateral heel	41.6±15.7	35.6±15.8	0.000*

Also taking the right foot as an example, Table 4 shows the impulse of different areas of the foot during the running process under the action of two kinds of insoles, i.e., the impact received by the foot during the running process. It was seen from Table 4 that the distribution of the impulse on the 1st toe, middle metatarsal and lateral heel were large, especially the middle metatarsal and lateral heel, and the distribution of the impulse was almost the same as the distribution of the average pressure intensity. The intensity of pressure is the pressure per unit area, and the impulse is the product of the applied force and the action time. In the same running time period, the amount of impulse on the sole of the same person is proportional to the pressure, so the distribution of the impulse on the sole of the foot was nearly consistent with the average pressure intensity.

As a result, the impulse of the 1st toe, 2nd to 5th toe, lateral metatarsal and lateral heel were significantly reduced, while the impulse of the medial metatarsal, mid-metatarsal and medial heel were significantly increased after the use of shock-absorbing insoles. The reason for this is also the guiding effect of the shock-absorbing insole on the plantar pressure, which makes the pressure intensity closer to the midline of the foot, i.e., the distribution of the pressure intensity is more balanced, so the distribution of the impulse, which is proportional to the pressure intensity, is more balanced.

In addition to the above two measures, the center line of pressure is also a measure of the distribution of plantar pressure. The center line of pressure is a trajectory curve formed by the movement of the center of pressure on the bottom of the foot over time, and its shape can reflect the stability of the foot during running. When running is stable, there will not be multiple pressure peaks at the same moment, and the center line becomes longer as time goes on; when running is unstable, the center line of pressure will be shifted and shortened.

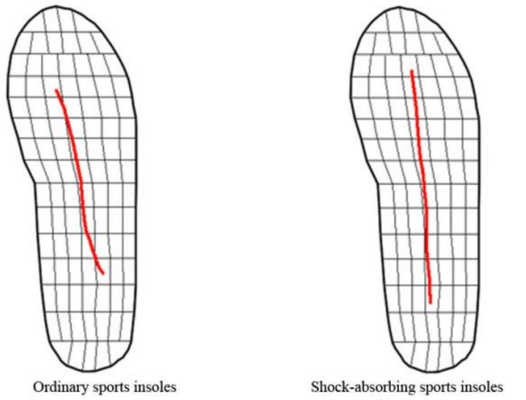

Figure 3. Distribution of the center line of pressure on the bottom of the foot after using the two kinds of insoles

In addition, the more balanced the pressure distribution on the foot during running, the flatter the center of pressure line will be along the direction of movement. Figure 3 shows the distribution of the center line of pressure after using the two types of insoles in one of the subjects during running. It was seen from Figure 3 that the center of the pressure line in the normal sport insole was shorter and had more lateral offset bending than the shock-absorbing sport insole, indicating that the subject was more stable during running with the shock-absorbing insole, and the pressure distribution in the foot was balanced.

CONCLUSION

In this paper, ten male volunteers from the Track and Field Department of Guilin University of Electronic Technology were selected as subjects to test the biomechanical characteristics of the foot such as plantar pressure, impulse and pressure center line distribution after using ordinary insoles and shock-absorbing functional insoles. The shock-absorbing functional insoles were prepared independently by latex, EVA, conventional insoles, etc. The experimental results obtained are summarized as follows. (1) The average pressure intensity and impulse of the 1st toe, mid-metatarsal and lateral heel were relatively greater. (2) The average pressure intensity and impulse of the 1st toe, 2nd to 5th toe, lateral metatarsal and lateral heel were significantly reduced, while the average pressure intensity and impulse of the medial metatarsal, middle metatarsal and medial heel were significantly increased after using shock absorbing insoles. (3) The center line of pressure on the bottom of the foot after using the shock-absorbing sports insole was longer and straighter along the direction of motion, indicating more stable running.

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