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Original Research

The Immediate Effect of the Use of Arch Support Insole on the Components of Ground Reaction Forces during Running in People with Functional Ankle Instability

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ABSTRACT

The amount and three-dimensional distribution of the ground reaction force during running are related to lower limb injuries. The shoe insole is effective in modulating the components of ground reaction forces. The aim of this study was to evaluate the effect of using Arch support insole when running on the values of ground reaction force, impulse, and loading rate during running in people with an ankle sprain. Ten healthy men and 10 soccer player with ankle sprain participated in this study. Using a force plate with a sampling frequency of 1000 Hz, the components of the ground reaction force during running in two conditions with and without insoles were measured. Then, the variables of the peak of the ground reaction forces, the time of reaching the peak of the ground reaction forces, the impulse, and the loading rate were extracted. Repeated measurement analysis of variance was used for intragroup comparison and a Multivariate ANOVA test was used for intergroup comparison with a significance level of 0.05 for statistical analysis. The experimental group had a greater vertical ground reaction force than that control group ($P = 0.01$). Using the insole had no effect on the value of the ground reaction forces ($P > 0.05$). Using insole increases the time to reach the peak of the vertical ground reaction force at the moment of heel contact with the ground ($P = 0.01$). The insole decreased the loading rate of the experimental group ($P = 0.023$). It seems that the insole used in the present study can possibly reduce the risk of lower limb injury due to the reduction of the values of the vertical loading rate and the vertical impulse.

Keywords: Ankle sprain, Ground reaction force, Loading rate, Insole

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INTRODUCTION

Ankle sprain is one of the most common injuries in various sports (1). Ankle sprains can become a serious disability as 40% of athletes develop dysfunction up to six months after the initial injury. (1-4). In addition to depriving a person of exercise, the injury imposes significant medical costs on society (5). In long term, ankle sprains may lead to chronic ankle instability, osteoarthritis, persistent disability, reduced quality of life, and reduced ankle joint function (6). Ankle sprain not only damages ligament structures but also damages the mechanical receptors in the capsules, tendons, and articular ligaments. (1,7). Disruption in these receptors leads to a decrease in proprioception, and poor balance of individuals (1,7). Various researchers have investigated the mechanism of ankle sprain injury. Garrik et al. (1977) introduced the mechanism of injury as inversion, plantar flexion, and internal rotation of the foot (8). So far, video analyses have shown that ankle sprains are the result of increased inversion and internal rotation with or without plantar flexion (9,11).

The magnitude and direction of the ground reaction forces are of clinical importance (12-14). The ground reaction force, as it passes through the outer part of the subtalar joint and the anterior part of the ankle joint, causes dorsiflexion and inversion of the ankle, which are neutralized by the contraction of plantar flexors and inverters (15). Increasing the loading rate is one of the important components in the occurrence of various damages (9,16). Researchers have reported that increasing the loading rate during running exposes, a person to fracture stress, patellofemoral pain, and plantar fasciitis (17,19). Therefore, reducing the ground reaction forces is considered a treatment strategy for these people. Since the load response of body tissues is time-dependent, the effect of the forces decreases with increasing time to reach the peak of ground reaction forces (18,20). Increasing the loading rate means reducing the ability of muscles and joints to absorb forces on the body (18,20).

Hoseini et al. 2020 reported that people with ankle sprains had a higher loading rate than the control group (21). Various factors affect the size of the components of the ground reaction forces, including the range of motion of the lower limb joints, motor strategies, the muscles contract, and the use of the insole. One of the ways to change the loading rate is to use suitable shoe insoles (20). The use of medical insoles is recommended to correct the biomechanical direction of the limb and to absorb shock. Various studies have examined the effect of medical insoles when running. For example, Mundermann et al. (2003) showed that insoles did not have a significant effect on the components of the ground reaction force (22). On the other hand, Perry et al. (1995) showed that the use of medical insoles increases the ground vertical reaction force (23).

O'Leary et al. (2008) stated that the use of insoles reduces the vertical ground reaction force and reduces the loading rate when running. (24). Eslami et al. (2009) also showed that the use of semi-rigid insoles while running reduces the peak values of the vertical ground reaction force by 5.5% and reduces the rear foot eversion by 40%, which is probably due to the flexibility of this type of insole (25). Wilkinson et al. 2018 showed that the insole reduces the vertical loading rate (26). Alamzadeh et al. 2019 showed that the insole increased the vertical ground reaction force when walking (27). Despite the fact that many studies have investigated the effect of insoles in different groups, so far, no research has been done to investigate the immediate effect of arch support insoles on ground reaction force components in people with ankle sprain when running. So, the purpose of this study is to investigate the immediate effect of arch support insole on the components of the ground reaction force in people with an ankle sprain.

MATERIAL AND METHODS

The present study is quasi-experimental and of laboratory type. In this study, 10 soccer players from Hamedan province were selected as a control group. Also, 10 soccer players with functional ankle instability were selected as the experimental group. Ten subjects were chosen in each group according to $\alpha = 0.05$, $\beta = 0.2$ (statistical power 80%) based on the power calculation method of Erdfelde et al 2007. The mean and standard deviation of age, height, and mass of the subjects in the control group were (22 ± 1.49 year), (174.8 ± 6.2 cm), and (74.4 ± 9.64 kg), respectively. Also, the mean and standard deviation of age, height, and mass of the subjects in the experimental group were (23 ± 1.63year), (173.4 ± 2.36 cm), and (76.3 ± 6.81 kg), respectively. Criteria for inclusion in the control group were having a normal musculoskeletal system, having a normal skeletal structure of the foot. Also, the inclusion criteria for the experimental group were: obtaining a score above 26 on the ankle function evaluation questionnaire, a history of severe sprains of the external ankle, a history of feeling ankle instability during the last 6 months, and also the exclusion criteria were: There is a difference of more than 3 mm between the length of the two lower limbs, history of surgery, and skeletal abnormalities. All subjects were right-handed and right-footed, which were measured by throwing the ball for

the hand and hitting the ball for the foot, respectively. Subjects were advised to refrain from strenuous physical activity for 48 hours prior to the test. Before doing the test, the purpose and method of the study were explained to the subjects after which they signed the consent form to participate in the study.
Subjects completed an ankle function evaluation questionnaire before entering the experimental group. In this questionnaire, 12 questions have been asked that the answers are scored based on the Likert scale with numbers from 0 to 4 and the maximum overall score of this tool is 48 and a score above 26 indicates the existence of ankle function limitation. (Ross et al. 2008) (28). The insole of the shoe used in this study was made according to the feet of individuals and by a technical orthopedist. The insole used in this research is of semi-rigid type (shore A 53, polypropylene) and the peak height of the internal length arc in this insole was 15 mm and its posting degree was 8 (Figure 1). Movement speed was calculated using four Vicon cameras and ligh-reflecting markers. A three-dimensional analyzer (Vicon (100Hz (Motion Lab Systems, Inc. 15045 Old Hammond Highway, Baton Rouge, LA 70816USA)) and four T-series cameras were used to record and analyze the kinematic information of running, for which the pelvis and limbs of the lower left and right were identified by 16 light-reflecting markers with a diameter of 14 mm. Using double-sided adhesive tape, markers were placed on the upper anterior and posterior-anterior iliac spine, upper right thigh, lower left thigh, the end of the thigh was mounted on the external epicondyle, the upper third of the right leg, the lower third of the left leg, the heel (on the shoe), the outer ankle, and the second metatarsal head (on the shoe) on both the right and left sides.
Using two Kistler force plates (Kistler AG, Winterthur, Switzerland) with dimensions (400 mm 2600 mm) ground reaction forces (GRF) in vertical (Fz), anterior-posterior (Fy), and internal-external directions (Fx) were measured while running. The sampling frequency was set to 1000 Hz. The two force plates were placed halfway along a 20-meter path so that the subject would take at least 5 steps before reaching the force plate. Before starting to record data, the force plate was first calibrated.
During running, GRF of both feet was recorded and the results of the dominant foot (injured foot) were used for analysis. Before performing the test, each subject ran on the laboratory surface for about 5 minutes to adjust to the test conditions. Then each subject ran 6 times at normal speed and their kinetic and kinematic information were recorded. In the present study, the type of shoe (ASICS design) was the same for all subjects and was selected according to their foot size.

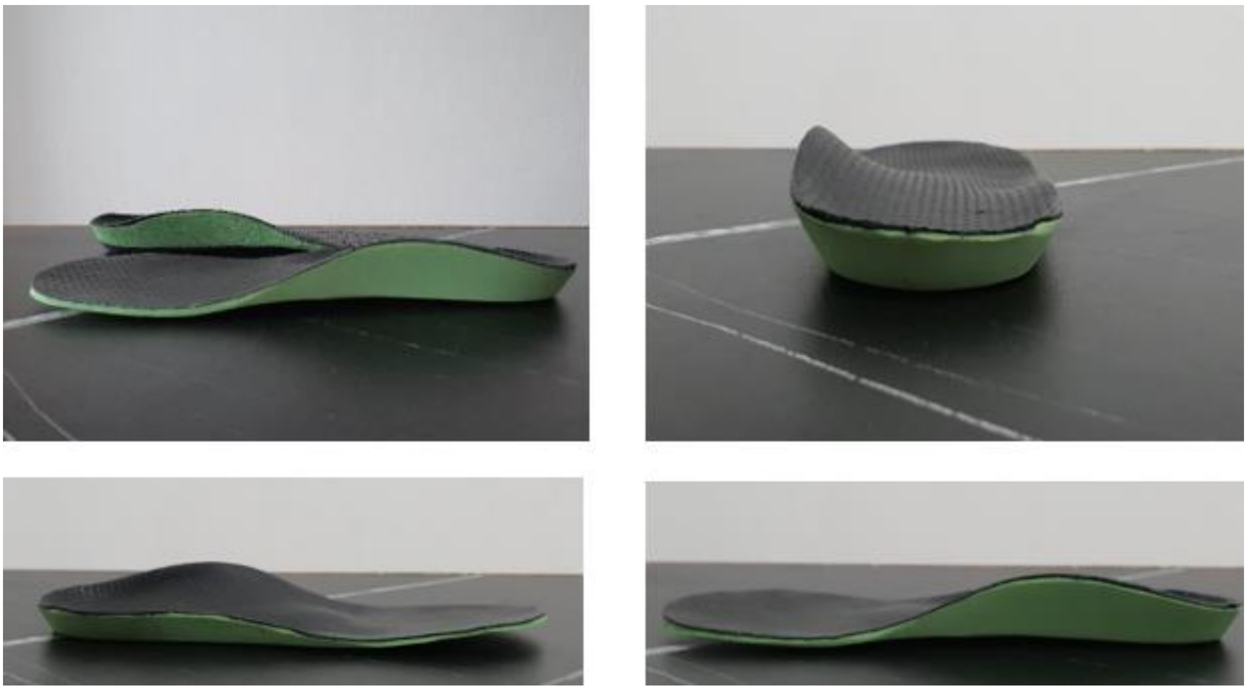

Fig1: Insole

Data processing

The obtained kinematic data were bused using Fourth order Butterworth low pass filter (zero lag) with a cutting frequency of 6 Hz. The obtained force plate signals were smoothed using a level 4 Butterworth low-pass filter with zero lag difference with a cut-off frequency of 20 Hz (16). Peak variables of ground reaction forces, impulse, and loading rate were measured. For GRF variables, three vertical components, three internal-external components, and two anterior-posterior components were extracted. For ground reaction forces, in the vertical direction, 3 points, including the value of the vertical force peak at the moment of initial contact (FzI.C), the middle phase of the establishment (Mid stance) (FzM.S), and the push-off phase (FzP.O), in the anterior-posterior direction of two peaks (forward (FyP.O) and brake (FyI.C)), and in the inward-external direction of 3 peaks (FxI.C, F FxM.S, and FxP.O) were calculated (Figure 2). All GRF forces were matched to individual weight and analyzed at the dominant foot.

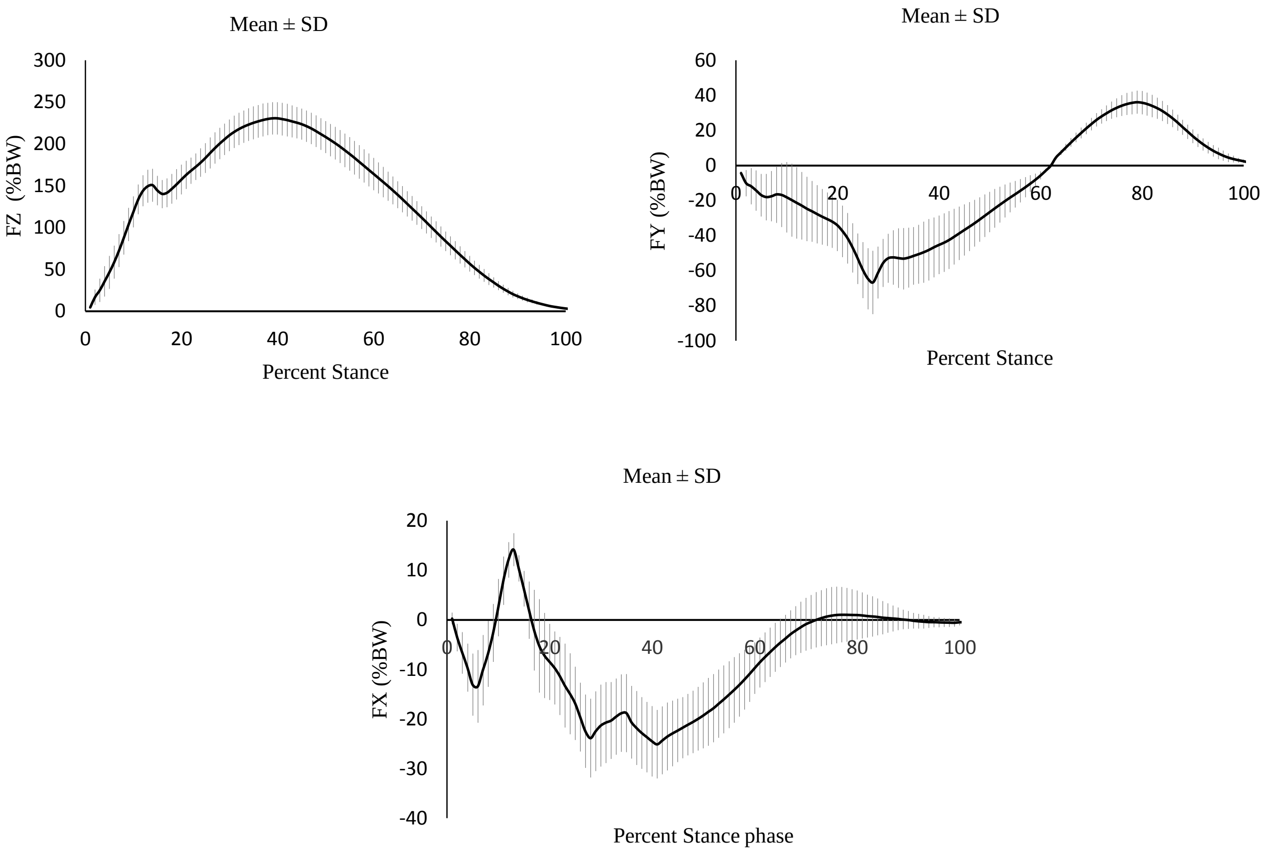

Figure 2: A time-normalized ensemble average traces of the ground reaction forces

The impulse was measured in three directions of x (Impx), y(Impy) and z(Impz). To calculate the impulse, trapezoidal integration was used (29).

$$\text{impulse} = \Delta t\left(\left(\frac{F1 + Fn}{2}\right) + \sum_{i=2}^{n-1} Fi\right)$$

The vertical loading rate is defined to be the initial part slope (Between the 20% point and the 80% point of the heel contact to the first peak of the vertical force-reaction of the ground) of the ground vertical reaction force curve (18).

$$\text{Loading rate} = \left[\!\left[\frac{\text{peak Fz(N)/body weight(N)}}{\text{time to peak Fz}}\right]\!\right]$$

Statistical method

The Shapiro-Wilk Test was used to check the normality of the data distribution. Regarding the normality of the data, repeated measures analysis of variance was used for intra-group comparison and Multivariate ANOVA test for intergroup comparison with a significance level ($P<0.05$) was used for statistical analysis. Statistical analysis was performed using SPSS software (version 19, SPSS Inc., Chicago, IL).

RESULTS

Table (1) shows the mean peak of the components of the matched ground reaction force Fx, Fy and Fz in both conditions with and without insole wear compared to healthy individuals.
It is noteworthy that the subjects in the experimental group with and without the use of insoles have a greater vertical reaction force than the control group at the moment of heel contact with the ground, and this difference is statistically significant (P = 0.01, P = 0.007). In the midstance phase, the experimental group with and without insole, showed a greater ground reaction force than the control group (P = 0.02, P = 0.006). There was no significant difference in other ground reaction forces between the groups.

Table 1. Mean and standard deviation of the normalized ground reaction force during running

BW%		Control	Experimental Group without insole	Experimental Group with insole	P value
Fz	Fz_1	108.47±15.43£	137.94±29.62¥	141.43±30.63§	£ vs ¥=0.01 £ vs §= 0.007
	Fz_2	101.93±18.09£	130.08±32.01¥	137.53±31.24§	£ vs ¥=0.02 ¥ vs §= 0.006
	Fz_3	192.54±25.5	200.97±24.39	201.83±25.70	NS
Fx	Fx_1	10.99±6.57	13.28±5.69	13.07±6.84	NS
	Fx_2	-20.64±3.57	-23.13±3.88	-22.05±6.65	NS
	Fx_3	2.08±1.49	2.49±2.62	1.54±1.05	NS
Fy	Fy_1	35.15±8.74	39.80±5.5	40.98±8.02	NS
	Fy_2	31.99±7.42	28.11±8.87	33.12±9.27	NS

Fz1: Vertical force at heel contact, Fz2: Vertical force at the mid stance, Fz3: Vertical force at propulsion phase. Fx1: Horizontal force at heel contact, Fx2: Force at the moment of foot flat, Fx3: Horizontal force at toe off, Fy1: Posterior reaction force (brake phase), Fy2: Anterior reaction force (propulsion phase).
NS: No Significant

Table (2) shows the average time to reach the peak of the ground reaction force components Fx, Fy and Fz in both conditions with and without insole wear compared to healthy individuals. As can be seen, the insole increases the time to reach the peak of the ground reaction force at the moment of heel contact, so that the values of TFz1 in the control group and the experimental group without insole were significantly lower than that in the experimental group with the insole (P = 0.01). The insole also increased the values of TFz2 and TFx2 in the experimental group (P = 0.04).

Table 1. Mean and standard deviation of the time to peak (sec) of ground reaction force during running

		Control	**Experimental Group without insole**	**Experimental Group with insole**	**P value**
TFz	TFz_1	0.049±0.008£	0.047±0.006¥	0.057±0.007§	£ vs ¥=0.01 ¥ vs §= 0.01
	TFz_2	0.06±0.007£	0.057±0.0061¥	0.064±0.007§	¥ vs §= 0.04
	TFz_3	0.15±0.016£	0.12±0.016¥	0.12±0.013	£ vs ¥=0.002
TFx	TFx_1	0.051±0.034	0.043±0.008	0.052±0.013	NS
	TFx_2	0.15±0.032£	0.12±0.021¥	0.15±0.025§	£ vs ¥=0.01 ¥ vs §= 0.01
	TFx_3	0.32±0.073	0.32±0.07	0.29±0.05	NS
TFy	TFy_1	0.09±0.011£	0.07±0.01¥	0.08±0.01	£ vs ¥=0.02
	TFy_2	0.28±0.06	0.23±0.03	0.23±0.03	NS

Fz1: Time to peak of Vertical force at heel contact, Fz2: Time to peak of Vertical force at the mid stance, Fz3: Time to peak of Vertical force at propulsion phase. Fx1: Time to peak of Horizontal force at heel contact, Fx2: Time to peak of Force at the moment of foot flat, Fx3: Time to peak of Horizontal force at toe off, Fy1: Time to peak of Posterior reaction force (brake phase), Fy2: Time to peak of Anterior reaction force (propulsion phase).
NS: No Significant

The results of impulse have been presented in Fig.2. As seen, the experimental group with and without insole have lower vertical impulse than the control group (p=0.01).

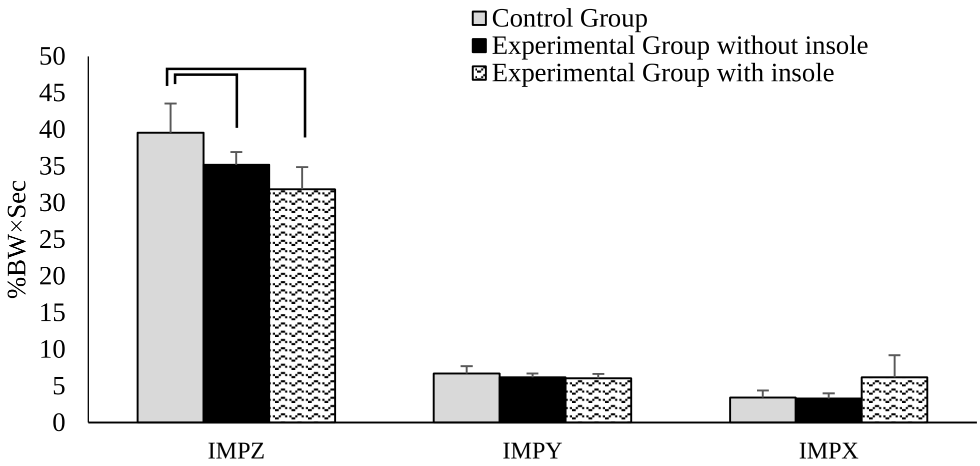

Fig 2. Impulse value in stance phase of running

The results related to the loading rate are summarized in Fig. 3. As can be seen in this diagram, the experimental group without insole has a higher loading rate than the control group (P = 0.023) and the experimental group with the insole (P = 0.002).

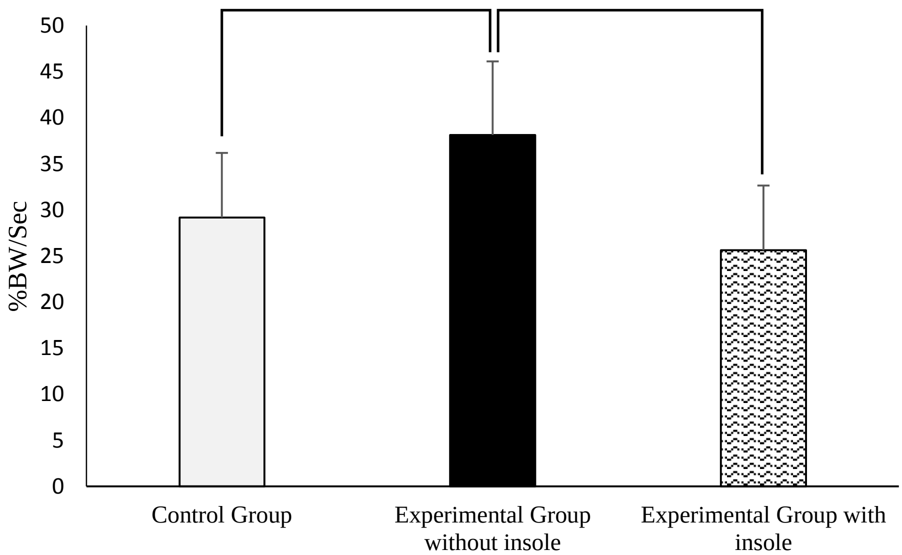

Fig 3. Loading rate in stance phase of running

Discussion

This study aimed to investigate immediate effect of the use of Arch Support medical insole on the peak of ground reaction forces and the time to reach them, impulse, and loading rate during running in people with ankle sprain compared to the healthy group. Running speed, shoes and the surface on which running takes place are external factors affecting the components of the ground reaction forces. Osama et al. 2021 Showed that the type of shoe changes the range of motion of the lower limb joints. They showed that wearing the shoe increases the range of motion of the plantar flexion of the ankle and decreases the eversion moment of the ankle (30). Since the running speed was controlled by motion analysis cameras in two conditions with and without insoles and between groups and also, the type of shoes and the surface of running were considered the same for the two groups, it can be said that these cases were controlled and as a result, the research was not effective. The results of this study showed that a group of people with ankle sprain have a higher vertical

ground reaction force at the moment of heel contact with the ground. These results are consistent with the research of Hoseini et al. 2020 (21).
At the moment of heel contact with the ground, the optimal activity of the muscles on the one hand and the range of motion of the lower limb joints, on the other hand, reduce the ground reaction force in different people. Various studies have examined the biomechanical components of people with ankle sprain when walking and running. Their results show that ankle sprain changes the parameters of muscle activity, kinematics, and joint kinetics compared to controls. Hopkins et al. 2012 showed that in people with an ankle sprain, the activity of the tibialis anterior muscle was significantly higher than the control group (31). Oatis et al. 2009 showed that increasing the activity of the tibialis anterior muscle increases the risk of external ligament sprain due to invertor torque (32). Increased activity of the tibialis anterior muscle increases ankle supination at the moment the foot hits the ground (32). Morley et al. 2010 showed that people with excessive supination have a greater ground reaction force during activities such as walking (33).
Increased ankle supination during walking and running increases the pressure on the outer edge of the foot and shifts the center of pressure to the outside of the sole. To compensate for this mechanism and prevent further damage to the ankle sprain, the activity of the peroneus longus muscle must be increased. Increased activity of peroneus longus causes proper placement of the ankle at the moment of heel contact with the ground (34). Various studies have shown that in people with functional ankle instability, the amount of activity and time of activity of the fibularis longus muscle is significantly less than healthy people (34). One of the reasons for the increase in vertical ground reaction force when the heel is in contact with the ground is a change in the movement pattern of the ankle because people with ankle instability have a disorder of the deep sensory system of the ankle joint (1,7), it seems that in this group of people a disorder of the deep sensory system, dysfunction of the invertor and evertor muscles Also, changing the range of motion of the lower limb joints increases the vertical ground reaction force at the moment of heel contact with the ground (1,7). The results of this study showed that the use of insoles increased the ground reaction force of the experimental group. These results were same with the results of Majlisi et al. (1397) (35). Also, the results of this study showed that in the conditions of using the insole, the component of the ground reaction force on the medial-lateral plane did not show a significant change. These findings are consistent with the results of Miller et al. (1996) who reported that insole has no effect on the amount of internal-external ground reaction force. They attributed this finding to the insensitivity of the force plate in the face of small forces (36). Since there is an inverse relationship between the loading rate and the time to reach the peak of ground reaction forces, increasing the time to reach the peak of reaction forces reduces the loading rate of ground reaction forces (18).
These results are in line with the results of Angel et al. 2014 (36). Since the loading rate is one of the effective factors in the incidence of various types of lower limb injuries (9,16), reducing the amount of this variable due to the use of insoles can be a special treatment to reduce other injuries, including knee problems. Increasing the transmission time reduces the effect of force, thus reducing the damage to tissues (20). The results of this study showed that the insole reduces the vertical impulse. One of the influential factors in the impulse is the time of force application. It seems that the use of the insole increases the force transmission time, so reducing the impulse seems reasonable. The insole used in the present study can reduce the risk of lower limb injury by reducing the amount of vertical load and impulse. One of the limitations in this research is the study of men, and due to the differences between women and men, the generalization of these results to the whole society is difficult.

CONCLUSION

It seems that the insole used in the study can possibly reduce the risk of lower limb injury due to the reduction of the values of the vertical loading rate and the vertical impulse. In addition, the use of the insole increases the time to reach the peak of the vertical ground reaction force at the moment of heel contact.

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تاثیر استفاده فوری از کفی Arch support بر مولفه‌های نیروهای عکس العمل هنگام دویدن در افرادی با بی ثباتی عملکردی مچ پا

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مقدار و نحوه توزیع سه بعدی مولفه‌های نیروی عکس‌العمل زمین هنگام دویدن با آسیب‌های اندام تحتانی مرتبط است. کفی کفش در تعدیل مولفه‌های نیروهای عکس‌العمل زمین موثر است. هدف از این مطالعه بررسی اثر استفاده از کفی Arch support هنگام دویدن در مقادیر نیروی عکس‌العمل، ایمپالس، و نرخ بارگذاری هنگام دویدن در افرادی با عارضه اسپرین مچ پا بود. ۱۰ مرد سالم و ۱۰ فوتبالیست با عارضه اسپرین مچ پا در این مطالعه شرکت نمودند. با استفاده از یک صفحه نیرو (۱۰۰۰ هرتز) مولفه‌های نیروی عکس‌العمل زمین هنگام دویدن در دو شرایط با و بدون کفی اندازه‌گیری شد. سپس متغیرهای اوج نیروهای عکس‌العمل زمین، زمان رسیدن به اوج نیروهای عکس‌العمل، ایمپالس، و نرخ بارگذاری استخراج شدند. از آزمون آماری آنالیز واریانس اندازه های تکراری برای مقایسه درون گروهی و از آزمون Mulivariate ANOVA برای مقایسه بین گروهی با سطح معناداری (P<۰/۰۵) جهت تحلیل آماری مورد استفاده قرار گرفت. گروه تجربی نیروی عکس العمل بزرگتری نسبت به گروه کنترل داشتند (P=۰/۰۱). کفی تاثیری در اندازه نیروهای عکس العمل نداشت (P>۰/۰۵). کفی باعث افرایش زمان رسیدن به اوج نیروی عکس العمل عمودی زمین در لحظه تماس پاشنه با زمین شده است (P=۰/۰۱). کفی باعث کاهش در نرخ بارگذاری گروه تجربی شده است (P=۰/۰۲۳). به نظر می‌رسد، کفی مورد استفاده در پژوهش حاضر با توجه به کاهش مقادیر نرخ بارگذاری عمودی، و ایمپالس عمودی احتمالاً می‌تواند ریسک آسیب اندام تحتانی را کاهش دهد.

واژه های کلیدی: اسپرین مچ پا، نیروهای عکس العمل زمین، نرخ بارگذاری ، کفی