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ORIGINAL

Analysis of the Plantar Pressure on the Flat and Slope Walking by Insole Type

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Objective: The purpose of this study is to provide biomechanical basis data for the analysis of the maximum vertical ground reaction force, the maximum plantar pressure, the average plantar pressure, and the contact area according to the type of the insole through the insole insertion type foot pressure gauge.

Method: In the treadmill, the slope was set at 10%, the first type A was worn at a walking speed of 3.5 km / h, and then walking was carried out using B, C, and D types. Data from 20 boots with consistent walking were extracted and plantar pressure data were collected and analyzed.

Results: Functional insole was more effective than conventional insole for maximum vertical ground reaction force, maximum plantar pressure, average plantar pressure, and contact area at 10% of treadmill ramps.

Conclusion: In this study, D-type insole supports the cushion in the middle part and supports the heel cup with hardness in the hind part, so that it is the most effective insole by lowering the plantar pressure and dispersing it more widely.

Keywords: Slope, Plantar pressure, Flat, Slope walking, Functional insole type, GRF

INTRODUCTION

In modern society, the development of transportation means that the opportunity to walk or run decreased significantly, resulting in scarce physical activity. As a result, the incidence of many lifestyle diseases such as diabetes, obesity, hypertension, and cardiovascular disease is increasing, hence personal and social interest in health have risen. Therefore, the importance of aerobic exercises such as walking, running, and climbing to prevent and improve lifestyle diseases is increasing (Oh, 2008). Walking is the most comfortable and stable form of exercise. Walking is recommended as a means of rehabilitation and health promotion as well as mobility, especially good after the middle aged (Ha, 2013). It is also recommended for young people in their 20s and 30s these days. In daily physical training areas, aerobic exercise is a representative workout recommended for a healthy life because it reduces body fat, positively affects lipid metabolism and hypertension, increases maximum oxygen intake and cardiac output as well as having positive effects on cardiovascular and weight control (ACSM, 2006). Mountain climbing is the most popular among the outdoor sports due to the unique geographic feature of Korea; 63.7% of the country is mountainous which provides plenty of opportunities for hiking (Korea Forest Service, 2012). According to the previous study on the different angles of hip joint, knee joint, and ankle joint while walking, 10% inclination among the 0, 5, 10% inclined treadmill ramps showed the most significant changes in joint angles. This suggests that 10% inclined ramp enabled more exercising while walking and proposes that walking on a slope is necessary to improve leg muscular strength (Yoon, Lee, & Kim, 2001). Walking is a method of movement that involves using two legs alternately, with at least one foot touching the ground all the time (Whittle, 1990). With regard to walking ability, the shoes inserted with an insole or an aid have been developed to enhance the dispersion effect in most of the plantar pressure and to emphasize effective features similar to normal gait patterns in motion analysis and electromyogram (EMG). Although the products introduced by each manufacturer are diverse in design, the nature of the effects seems to be similar such as inducing correct gait, providing gait stability, relieving pain and restoring joint function (Song, Lee, Back, & Park, 2008). Wearing a customised insole while walking or long-term standing makes it possible to relieve pain and shock due to higher pressure by distributing the pressure exerted on the specific part of the foot to the entire foot evenly (Jung et al., 2010). In addition, the slide caused by sudden walking environment changes like ramps and stairs may cause major injuries in the workplace and everyday life (Kim, Wen, & Lee, 2001).

An insole should be made of soft texture to prevent injury from external shocks (Lim & Lee, 2002). In the biomechanical evaluation of the functional insole types, when the patient with injured rear foot did not use the insole in which the entire sole of the foot is on the ground, the stride and the walking speed decreased while the support time of

Table 1. Measuring instrument

Section	Items	Model	Usage	Company
Measuring instrument	Body composition analysis	X-Scan PLUS II	Physical characteristics	JAWON
	Foot pressure	Pedar-X	Plantar pressure, pressure center measuring travel path	Novel
	Digital videocamera	GK-2 NTSC	Walking motion picture shooting	Canon
Data processing	Plantar pressure analysis	Pedar-x Recorder	Pressure data analysis	Novel
	Laptop	Xnote LPG1	Data analysis	LG Electronics

left and right foot are extended which affects the power of ankle joint and hip joint. The walking posture is restored with the functional insole. Therefore, the insole that increased the contact area of the middle part of the foot effectively reduced the foot pressure according to the foot pressure analysis on the contact area of the insole based on the three dimensional finite element model (Kim, Cho, Jung, Kim, & Chung, 2010).

This study was to analyze the advantages and disadvantages of using an insole on foot pressure for flat and slope treadmill walking and to provide basic data about the effects on maximum vertical ground reaction force, maximum plantar pressure, average plantar pressure and contact area.

Therefore, the purpose of the study is to provide foundational biomechanical data for walking on flat and ramps by analyzing the maximum vertical ground reaction force, maximum plantar pressure, average plantar pressure, and contact area according to the types of insole with an insole inserted plantar pressure measuring instrument.

METHODS

1. Subjects

The subjects of this study were 13 male students in their 20s studying in S University located in B City. The range of the age was 22.77 ± 1.88 years old, 173.92 ± 4.39 cm in height, 76.88 ± 9.01 kg in body weight, 252.62 ± 9.67 mm in left foot length, 253.00 ± 9.21 mm in right foot length and the average shoe size was between 250 and 270 mm with the normal foot shape and hind landing type without any injury of the lower limb for the past year. In order to minimize the variability of shoe size, the subjects who had the same foot size as the shoe size were selected. In addition, those with a normal foot shape, in which the sensor operates sequentially during the walking cycle, were selected with a plantar pressure measuring instrument while those with low-arched foot or high-arched foot were excluded. Before the experiment began the purpose and effect of the study were fully explained to the subjects and they voluntarily signed the agreement.

2. Measurements

The measuring instrument of the study are shown in (Table 1). The body composition analyzer was used to determine the physical characteristics and body composition of the subjects before participating in the experiment. The foot pressure measuring instrument measured plantar pressure and followed the changes in pressure center movement pathway while a digital video camera was used to analyze the walking motion.

3. Insoles for experiment

As shown in (Figure 1), all insole used in the experiment is a product of famous companies in Korea. Existing insole of type A is the insole that is inserted in hiking shoes from a renowned T company in Korea. The functional insoles of B, C, D types are manufactured by a famous F company specialized in insole production. The type B, FH603 Arch Hard Insole has general cushioning and shock absorbing function. In particular, with some hard wedge in the arch part it can reduce foot fatigue with the distributed weight to prevent arch deformation of the foot. The type C, FH801 Arch Dynamics Insole, is another functional insole that has the function of foot fatigue and pain relief through the support of the foot, and it improves the cushion and the feeling of grip and corrects the metatarsal and excessive inward/ outward movement of feet to induce the proper body alignment. FH902 Arch Orthotics Insole of the type D is designed to help the outer arch support by raising the outer sole during walking and landing motions. It helps to support the external arch and stabilizes the metatarsal to maintain the neutrality of the metatarsal to prevent internal rotation.

4. Measurement method

The treadmill was set to flat and 10% of the slope. The experiment was executed after warming up and practicing enough to walk in natural motions and speed; the walking speed in this experiment was 3.5 km / h, which was slightly slower than the average walking speed of an adult. It was calculated based on the previous study of Kim and Kim (2007) in which the adult group walked at the standard speed of 1.5 m / s whereas the obese people group walked at self selected speed of 1.3 m / s.

We used the Existing Insole first followed by the order of FH603 Arch Hard, FH801 Arch Dynamics and FH902 Arch Orthotic. The experiments were performed twice for one minute each and sampled data on 20

Figure 1. Existing insole, FH603 Arch hard, FH801 Arch dynamics, FH902 Arch orthotics

steps out of one consistent walking. The subjects took one minute break between measurements. Once an error occurred during the experiment, we continued after fixing and re-checking the device. The procedure of the experiment was as follows: the subject wore the shoes in the order of the Existing Insole, FH603 Arch Hard, FH801 Arch Dynamics, FH902 Arch Orthotic, walked on flat ground, took five minute break, and walked on sloped ground with the same order of insoles.

5. Statistical analysis

To measure the plantar pressure according to the type of the insole, we selected the one time period in which the walking motion was performed most naturally among the data measured two times per minute according to the experimental procedure, and 20 steps from each of the left foot and the right foot were chosen to collect the plantar pressure data for analysis. The measured data from the insole sensor of the Pedar-X system are divided into forefoot, middle foot and rear foot to determine mean foot pressure, maximum foot pressure, contact area and the maximum vertical ground reaction force; the maximum vertical ground reaction force was standardized by dividing the collected value by the weight of the subject. All data collected through the measurement was processed with Windows SPSS Version 23.0 (SPSS, Inc., Chicago, IL) after excluding or correcting the errors detected in the cleaning task on data input. For the final data set, the two-way repeated measure ANOVA was used to examine the difference of the variables according to the types of the insole on sloped treadmill walking. When there was a significant difference, Bonferroni method was used for post verification among groups. The statistical significance level for each data was set as α = .05.

RESULTS

1. Maximum vertical ground reaction force

Statistically significant differences were found in the interaction between the insoles and the slopes in the right middle foot (F = 3.510, p = .002) at the maximum vertical ground reaction force. The left forefoot (F = 40.311, p =. 001), the right forefoot (F = 48.886, p = .001), the left middle foot (F = 8.163, p = .006), the right middle foot (F = 29.671, p = .001), the right rear foot (F = 19.129, p = .001), the front side of left foot (F = 38.378, p = .001) and the front side of right foot (F = 20.554, p = .001) showed statistically significant difference according to the slopes. Statistically significant difference was found between the left rear foot (F = 3.936, p = 0.14) according to the insoles (A > D).

On the other hand, there was no statistically significant difference in the interaction between the insole and the slope in the forefoot, middle foot, rear foot, and the whole foot on the left and right. There was no significant difference in the left rear foot according to the slopes while no significant difference was found in either the left or right forefoot, middle foot, right rear foot and whole foot according to the insoles.

2. Maximum plantar pressure

At the maximum plantar pressure, the left forefoot (F = 4.543, p = .007**), the left middle foot (F = 3.473, p = .023*), the right middle foot (F = 3.809, p = .016*), the front side of left foot (F = 2.942, p = .042*) showed a statistically significant difference in the interaction between the insole and the slope. We found the statistically significant difference according to the slopes in the left forefoot (F = 19.014, p = .001), the right forefoot (F = 16.983, p = .001), left middle foot (F = 10.801, p = .002**), left rear foot (F = 6.760, p = .012*), right rear foot (F = 24.059, p = .001), the front side of left foot (F = 28.739, p = .001), and the front side of right foot (F = 22.881, p = .001).

On the other hand, there was no statistically significant difference in the interaction between the insole and the slope on the right forefoot, whole feet and left/ right rear foot. There was no significant difference according to the slopes in the right middle foot while no significant change according to the insoles was found in the left/ right forefoot, middle foot, rear foot and the whole feet.

Table 2. Maximum vertical GRF of flat and slope according to the type of insole (unit; N/kg)

Category	Insole type		Slope type: Flat	Slope type: Slope	F	p	Post-hoc
Fore foot	Left foot	A	6.23±0.52	6.87±0.83	Insole F=1.355 Slope F=40.311 Insole × Slope F=.996	.268 .000*** .403	
		B	6.20±0.46	6.59±0.84			
		C	5.85±0.41	6.38±0.64			
		D	6.16±0.44	6.48±0.63			
	Right foot	A	6.46±1.12	7.12±1.18	Insole: F=.917 Slope F=48.886 Insole × Slope F=.787	.440 .000*** .507	
		B	6.21±0.92	6.75±1.08			
		C	5.89±0.87	6.37±0.82			
		D	6.23±1.07	6.59±1.31			
Middle foot	Left foot	A	4.52±0.58	4.79±0.66	Insole F=.896 Slope F=8.163 Insole × Slope F=.523	.450 .006** .669	
		B	4.64±0.55	4.78±0.59			
		C	4.71±0.50	4.86±0.71			
		D	4.38±0.64	4.45±0.85			
	Right foot	A	4.51±0.81	4.80±0.77	Insole F=.508 Slope F=29.671 Insole × Slope F=3.510	.678 .000*** .022*	
		B	4.73±0.62	4.97±0.82			
		C	4.77±0.60	5.24±0.74			
		D	4.84±0.71	4.88±0.86			
Rear foot	Left foot	A	6.36±0.59	6.31±0.81	Insole F=3.936 Slope F=2.334 Insole × Slope F=.910	.014* .133 .443	A>D
		B	5.75±0.63	5.70±0.53			
		C	5.79±0.63	5.52±0.78			
		D	5.49±0.80	5.49±0.81			
	Right foot	A	6.37±0.70	6.00±0.77	Insole F=1.919 Slope F=19.129 Insole × Slope F=1.443	.139 .000*** .242	
		B	5.72±0.68	5.60±0.62			
		C	5.81±0.65	5.54±0.66			
		D	5.74±0.80	5.61±0.62			
Whole foot	Left foot	A	9.87±0.82	10.48±1.05	Insole F=1.740 Slope F=38.378 Insole × Slope F=.868	.171 .000*** .464	
		B	9.69±0.59	10.25±0.90			
		C	9.41±0.59	9.92±0.88			
		D	9.39±0.86	9.67±0.96			
	Right foot	A	9.62±1.36	10.52±0.99	Insole F=.313 Slope F=20.554 Insole × Slope F=1.917	.816 .000*** .139	
		B	9.94±0.67	10.34±1.03			
		C	9.35±1.40	10.27±0.70			
		D	9.87±0.63	10.06±1.12			

*Main effect: Insole, Slope

3. Average plantar pressure

Statistical analysis of average plantar pressure showed a significant difference in the interaction between the insoles and the slopes in the right midfoot (F = 3.820, p = .016*). The left forefoot (F = 1.261, p = .001), the right forefoot (F = 47.871, p = .001), the left middle foot (F = 8.429, p = .006**), the right middle foot (F = 23.222, p = .001), the right rear foot (F = 19.888, p = .001), the front side of left foot (F = 39.825, p = .001), the front side of right foot (F = 32.153, p = .001) showed a statistically significant difference according to the slopes. Also,

Table 3. Maximum plantar pressure of flat and slope according to insole type (unit; kPa)

Category	Insole type		Slope type: Flat	Slope type: Slope	F	p	Post-hoc
Fore foot	Left foot	A	297.50±57.35	336.73±81.19	Insole F=.683 Slope F=19.014 Insole × Slope F=4.543	.567 .000*** .007**	
		B	285.77±81.19	310.19±108.00			
		C	261.35±68.42	327.12±86.26			
		D	278.85±83.43	272.50±43.77			
	Right foot	A	319.42±82.83	337.88±79.12	Insole F=1.021 Slope F=16.983 Insole × Slope F=2.129	.392 .000*** .109	
		B	286.92±50.33	321.35±58.05			
		C	324.81±98.97	374.42±105.54			
		D	302.50±77.10	308.08±79.41			
Middle foot	Left foot	A	222.31±65.08	245.23±65.94	Insole F=1.444 Slope F=10.801 Insole × Slope F=3.473	.242 .002** .023*	
		B	212.16±71.17	222.50±68.97			
		C	189.62±53.10	223.08±59.53			
		D	187.11±74.60	180.77±57.53			
	Right foot	A	228.27±67.25	224.04±64.71	Insole F=.337 Slope F=2.947 Insole × Slope F=3.809	.799 .092 .016*	
		B	223.08±56.88	227.12±56.02			
		C	208.08±42.81	235.00±52.51			
		D	207.69±61.72	205.96±50.76			
Rear foot	Left foot	A	174.04±18.27	166.92±16.62	Insole F=2.584 Slope F=6.760 Insole × Slope F=.609	.064 .012* .612	
		B	159.23±15.12	154.62±16.48			
		C	154.62±19.28	148.27±21.95			
		D	162.12±20.89	161.35±23.75			
	Right foot	A	172.12±17.67	162.69±22.83	Insole F=1.168 Slope F=24.059 Insole × Slope F=1.915	.332 .000*** .140	
		B	164.62±20.91	154.38±17.33			
		C	162.69±24.91	147.31±20.35			
		D	168.85±25.83	166.35±22.95			
Whole foot	Left foot	A	301.92±57.59	340.77±81.51	Insole F=.380 Slope F=28.739 Insole × Slope F=2.942	.768 .000*** .042*	
		B	292.50±82.86	320.00±108.66			
		C	262.12±67.78	331.15±84.96			
		D	282.12±83.78	295.19±108.01			
	Right foot	A	326.35±79.59	347.73±68.52	Insole F=1.120 Slope F=22.881 Insole × Slope F=2.582	.350 .000*** .064	
		B	292.69±49.69	327.31±50.05			
		C	327.88±95.84	380.77±97.73			
		D	302.08±76.05	315.19±74.67			

*Main effect: Insole, Slope

there was a statistically significant difference in the left rear foot (F = 6.861, p = .001**) and in the right rear foot (F = 3.703, p = .018*) according to the insoles (A > B, C and D), (A > B).

On the other hand, there was no statistically significant difference in the interaction between the insoles and the slopes in the forefoot, rear foot, whole foot of left/ right feet as well as the left middle foot. No significant difference was shown according to the slopes in the left rear foot while left/ right forefoot, middle foot and whole foot did not show any statistically significant difference according to the insoles.

Table 4. Average plantar pressure of flat and slope according to insole type (unit; kPa)

Category	Insole type		Slope type		*F*	*p*	Post-hoc
			Flat	Flat			
Fore foot	Left foot	A	101.74±8.92	112.36±15.26	Insole *F*=.425 Slope *F*=32.791 Insole × Slope *F*=1.261	.736 .000*** .298	
		B	101.55±10.68	107.97±16.72			
		C	95.80±9.59	108.00±19.12			
		D	100.72±8.33	105.82±13.82			
	Right foot	A	104.81±13.32	115.55±14.18	Insole *F*=1.524 Slope *F*=47.871 Insole × Slope *F*=.850	.220 .000*** .473	
		B	100.79±10.77	109.61±12.93			
		C	95.87±11.93	103.90±12.41			
		D	101.11±12.87	106.54±16.05			
Middle foot	Left foot	A	54.45±10.13	57.59±10.92	Insole *F*=.570 Slope *F*=8.429 Insole × Slope *F*=.529	.638 .006** .664	
		B	55.77±9.54	57.49±9.87			
		C	56.60±9.31	58.41±10.48			
		D	52.41±8.59	53.27±10.78			
	Right foot	A	54.37±12.26	57.80±11.49	Insole *F*=.315 Slope *F*=23.222 Insole × Slope *F*=3.820	.814 .000*** .016*	
		B	57.17±9.65	59.50±10.41			
		C	57.28±9.07	62.92±10.71			
		D	58.33±11.60	58.39±10.69			
Rear foot	Left foot	A	123.51±10.60	122.06±12.58	Insole *F*=6.861 Slope *F*=2.640 Insole × Slope *F*=.841	.001** .111 .478	A>B, C, D
		B	111.10±8.00	110.37±9.28			
		C	111.95±9.70	107.10±14.99			
		D	105.88±10.63	105.57±10.25			
	Right foot	A	123.11±8.59	116.00±13.03	Insole *F*=3.703 Slope *F*=19.888 Insole × Slope *F*=1.600	.018* .000*** .202	A>B
		B	110.61±8.67	108.39±9.77			
		C	112.42±8.58	107.23±10.46			
		D	110.81±10.39	108.52±8.64			
Whole foot	Left foot	A	50.38±6.19	53.57±7.58	Insole *F*=.799 Slope *F*=39.825 Insole × Slope *F*=.767	.500 .000*** .518	
		B	49.55±6.39	52.28±6.68			
		C	47.91±5.64	50.72±6.64			
		D	47.82±4.87	49.36±6.46			
	Right foot	A	50.52±4.12	50.72±3.90	Insole *F*=.294 Slope *F*=32.153 Insole × Slope *F*=2.306	.829 .000*** .088	
		B	53.54±5.22	52.47±3.74			
		C	49.22±4.44	52.35±4.96			
		D	50.35±4.77	51.05±4.65			

*Main effect: Insole, Slope

4. Contact area

There was a statistically significant difference in the contact area according to the slopes in the left middle foot (F = 8.408, p = .006**) and the right middle foot (F = 23.226, p = .001).

On the other hand, there was no statistically significant difference in the interaction between the insoles and the slopes in the left/ right forefoot, middle foot, rear foot and whole foot. Neither was there a significant difference in the left/ right forefoot, rear foot and whole foot when walking on flat and sloped ground. However, there was no sta-

Table 5. Contact area between flat and slope according to insole type (unit; cm^2)

Category	Insole type		Slope type: Flat	Slope type: Slope	F	p	Post-hoc
Fore foot	Left foot	A	46.00±3.54	45.87±3.31	Insole F=.094 Slope F=.009 Insole × Slope F=1.419	.963 .924 .249	
		B	45.62±2.67	46.05±2.09			
		C	46.53±2.23	46.18±2.35			
		D	46.18±3.03	46.18±3.03			
	Right foot	A	45.97±3.26	46.20±3.11	Insole F=.008 Slope F=.417 Insole × Slope F=.467	.999 .521 .707	
		B	46.08±2.73	45.87±3.43			
		C	46.09±3.11	45.99±3.32			
		D	46.10±3.34	45.71±3.71			
Middle foot	Left foot	A	59.43±4.49	60.25±4.02	Insole F=1.697 Slope F=8.408 Insole × Slope F=.533	.180 .006** .662	
		B	61.06±4.11	62.44±3.42			
		C	63.06±3.70	63.64±3.58			
		D	59.98±6.30	60.44±5.89			
	Right foot	A	57.42±5.65	59.85±4.56	Insole F=2.385 Slope F=23.226 Insole × Slope F=1.029	.081 .000*** .388	
		B	61.35±4.44	62.29±4.23			
		C	62.30±4.17	63.50±3.20			
		D	59.48±5.02	61.52±4.02			
Rear foot	Left foot	A	39.48±2.02	39.48±2.02	Insole F=.000 Slope F=1.000 Insole × Slope F=1.000	1.000 .322 .401	
		B	39.48±2.02	39.48±2.02			
		C	39.48±2.02	39.48±2.02			
		D	39.48±2.02	39.48±2.02			
	Right foot	A	39.48±2.02	39.48±2.02	Insole F=.003 Slope F=.627 Insole × Slope F=1.124	1.000 .432 .349	
		B	39.48±2.02	39.48±2.02			
		C	39.36±1.98	39.48±2.02			
		D	39.48±2.02	39.45±2.00			
Whole foot	Left foot	A	132.81±10.57	132.08±10.32	Insole F=.400 Slope F=1.167 Insole × Slope F=1.002	.753 .285 .400	
		B	136.86±9.62	136.41±8.96			
		C	138.25±7.90	135.19±10.51			
		D	133.10±19.99	133.87±18.51			
	Right foot	A	131.64±11.73	131.98±9.84	Insole F=1.540 Slope F=2.935 Insole × Slope F=.789	.216 .093 .506	
		B	139.07±8.62	137.57±9.23			
		C	139.73±9.67	137.54±8.99			
		D	138.58±9.96	137.78±10.06			

*Main effect: Insole, Slope

tistically significant difference when using the functional insoles of B, C, and D type in the front side of left foot (A < D < B < C), the front side of right foot (A < D < C < B) when walking on flat ground, and the front side of left foot (A < D < B < C), the front side of right foot (A < C < B < D) when walking on slopes. Still the existing A type insole showed significantly narrower contact area compared to the functional insoles.

DISCUSSION

1. Maximum vertical ground reaction force

In previous studies, ground reaction force refers to the pressure from the ground as a reaction against the force when the body applies force through contact with the ground (Min, 2002).

The result of surface reaction force variable study (Jin & Shin, 2001) showed no statistically significant difference (t = 1.782) in maximum vertical force comparison between the general insole (1327.42 N) and the functional insole (1291.53 N) during walking. However, the average value of maximum vertical force was large with the general insole. According to the analysis of ground reaction force (Kim, 2016), the ground reaction force was significantly higher (t = -2.187, p = .036) when wearing normal shoes (.90 ± 3.18 N / BW) than wearing cushion shoes (.34 ± .72 N / BW). In other words, when wearing cushion shoes rather than general shoes, it is possible to reduce the impact on the feet from the ground during landing motions which shows that cushion shoes play a positive role in preventing injury. This study also found that the existing insole had higher ground reaction force value than the three functional insoles in the forefoot and rear foot.

In order to find the changes in angular velocity of each joint according to the inclination angles (Yoon, Lee, & Kim, 2001), the subjects walked on the treadmill at -5, 0, 5, and 10% of the slopes. This study showed a significant difference between 0% and 10% slopes in the knee joint angles when the knee is bended and straight. This makes it possible to predict that the motion of the lower limb during walking will be more frequent at a 10% slope. In other words, the movement of the lower limbs on a slope are more likely to occur. Therefore, the developed insoles should have a lot of cushions to reduce the ground reaction force. In the supporting study, when the cushion shoes are worn, the impact from the ground reaction force can be reduced in order to have positive effect for preventing injury.

At the maximum vertical ground reaction force, the existing insole showed the highest value while the functional insoles had relatively low ground reaction force. The C and D types of functional insoles which showed low values are considered to be the ideal insole types with cushions and supporting hard wedge.

2. Maximum plantar pressure

According to previous studies, the maximum pressure applied to each insole area in the stance phase is the maximum plantar pressure (Kim & Choi, 2007).

Choi (2013) suggested that the arch support or a functional insole plays a role in supporting the medial arch and decreases the maximum plantar pressure with increasing angle of the insole. According to this, it is considered that the effect of lowering the maximum plantar pressure can be seen when the insoles supporting the arches are worn.

Han (2008) analyzed the walking motions when walking on the flat and ramps. In the forefoot areas, the maximum force values in medial arch in the ramps and stair climbing increased compared to the flat, but there was no statistically significant difference. On the other hand, the maximum force value at the center of the forefoot decreased in the ramps and stair climbing compared to the walking on the flat ground. Especially, the maximum force value decreased significantly in the slope with a statistically significant difference. The maximum force value in the middle foot during the stairs and ramp climbing was lower than the maximum force value when walking on flat without any statistically significant difference. In the rear foot, the maximum force value decreased during the stairs and ramp climbing compared to the flat walking, but the difference was statistically significant. In this study, the maximum plantar pressure was the highest with the existing insole in all three parts of the feet while the functional insoles were generally similar.

In the case of maximum plantar pressure, the maximum plantar pressure of the type A insole was the highest in the middle foot during walking on the flat and slopes, hence cushioning or hard wedge insertion was required in the middle part. Therefore, the type D insole is considered to be the most ideal insole when walking on the flat and slopes because it supports the arch of the foot with hard rear foot that can reduce the maximum plantar pressure.

3. Average plantar pressure

In previous studies, the mean value of the pressure values applied to each insole area during the stance phase is an analytical item that indirectly evaluates the cumulative impact amount (Kim, 2002).

Kwak (1993) studied the effect of mid- to low- hardness of sneakers on the impact absorption and pressure distribution of the sole during running. He argued that a high value in the inner side of the foot area is considered unfavorable for stable walking because the pressure is concentrated on the inner side of the foot.

In the biomechanical evaluation study on functional insole types conducted by (Kim, Jo, Jeong, Kim, & Jeong, 2010), there was a significant difference in the average pressure between type 1 and type 3, type 2 and type 3. It was reported that the average plantar pressure changed according to the function of the insole; the pressure to the sole was remarkably smaller than type 1 which was for reducing fatigue when type 2 which is an insole designed for preventing shock and fatigue and type 3 which promotes blood circulation were worn.

Lee (2011) found a significant difference in the outer rear foot as a result of measuring the average pressures of different areas according to the angles of the corrective insole. In this area, the average pressure decreased from 143.23 kPa at 0°, 124.35 kPa at 5° to 123.66 kPa at 10° respectively. The post verification showed that the average pressure decreased at 5° and 10° compared to 0°.

Kim (2006) showed a significantly lower value at 38% in the middle foot but a higher value in the forefoot part. In the rear foot, when the streamlined rear balance shoes were worn, the feet were in contact with the ground from heel to toe gradually, so the pressure was low because of the wide contact area.

In the case of average plantar pressure, the value of the average plantar pressure was high in the forefoot and the rear foot with the existing insole. There was no significant difference between the existing insole and the functional insoles in the middle foot. Therefore, in the case of the average plantar pressure, the functional insole is regarded as the better insole than the existing insole since it absorbs the impact when walking and has a low plantar pressure value thanks to hard cushion or hard wedge structure.

4. Contact area

In previous studies, the contact area is the applied force per unit area and the pressure is the ratio of the applied force to the entire applied area. If the same force is applied, the pressure per unit area becomes smaller when applied to a larger area (Joo & Lee, 2001).

Lee (2011) studied the contact area on the different parts of a group according to the angles of the corrective insole and showed the significant difference (p = .001) in the inner third area of the middle foot. The area increased in the order of the following: 1.46 cm^2 at 0˚, 6.60 cm^2 at 5˚ and 7.71 cm^2 at 10˚. Scheffe's post verification showed that the contact areas increased at 5˚ and 10˚ compared to 0˚. This result is similar to the result by Lee (2010) which showed that the contact areas in the middle foot increased in the order of 1.16 cm^2 at 0˚, 4.83 cm^2 at 7˚ and 5 cm^2 at 3.5˚. This result implies that the contact area is widened by inserting the corrective insole on the inner part of the foot for the group, unlike the increase of the inner ground area which was smaller in the outer circumference. The contact area of the functional insole supporting the middle part is higher than that of the existing insole. Therefore, combined with the previous study results, the analysis found that the contact area of the type A insole was the lowest value while the contact area of the C type insole was the highest. And it had statistically significant effects on flat and slope walking. It was analyzed that the contact area was widened due to the cushion of middle part and rear part which is the key feature of type C insole.

CONCLUSION

In this study, we analyzed the plantar pressure of 13 male college students in their 20s when they walk on a treadmill which was flat or slope with the existing insole and three functional insoles. The study results were as follows;

In the case of maximum vertical ground reaction force, type C and D are regarded as the ideal functional insoles that support hard wedge with cushion and nice grip compared to the existing insole.

In the case of maximum plantar pressure, it was analyzed that the ideal type of insole for walking on the flat and slopes would be the type D because it supports the arch of the foot with high hardness in the rear foot to reduce the maximum plantar pressure.

In the case of average plantar pressure, the functional insoles are good with low plantar pressure because they have a cushion or hard wedge in the middle part that may absorb and evenly distribute the impact during walking.

The contact area of the functional insole supporting the middle foot was larger than that of the existing insole. The type C insole in particular showed wide contact areas in the middle and rear foot.

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