GAIT CHARACTERISTICS AND PRESSURE DISTRIBUTION FOR BAREFOOT AND VARIOUS HEEL HEIGHT SHOES DURING WALKING

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This study was to identify changes in pressure distribution and temporal gait characteristics in barefoot, rubber-soled flat shoe (0 cm heel heights), 4.5 cm high-heeled pumps and 9 cm high-heeled pumps during normal walking. Using the Novel Pedar in-shoe system, data was collected over 30 steps for both right and left foot. Comparing MP (Maximum pressure) and MV (mean value) in eight masks (GT, OT, MM, MidM, LM, MA, LA and Heel) of the foot during walking in barefoot and various heel heights. We concluded that: (1) characteristics of pressure distribution in rubber-soled flat were similar to the barefoot in both left and right. (2) The bearing area of insole decreased with the heel height increasing, pressure at GT, MM and MidM increased significantly with the increasing of heel height, while LM and Heel decreased. (3) Pressure distribution of left and right foot was identical but not the temporal gait.

KEY WORDS: barefoot, high heels, shoes, gait, pressure, bearing area

INTRODUCTION: Study about foot pressure distribution and temporal gait characteristics were going deeper with people's daily closer attention to foot health. Some of these studies about types of shoes have been well controlled, comparing the changes in gait and pressure distribution that occur when wearing shoes as opposed to going barefoot. Soames and Clark [1] found that increasing heel height decreased peak pressures under the third, fourth and fifth metatarsal heads while it increased peak pressure under the first and second metatarsals. Some of this research has focused on gait changes and pressure distribution; few of them have studied the changes of pressure distribution, similarities and differences between left and right foot gait patterns during normal walking. Schwartz et al.(1964) shows that right and left foot gait patterns are not identical. The purpose of our study was two-fold: (1) to contrast pressure distribution at eight areas of foot during walking in barefoot, flat and high heels. (2) To identify the gait patterns and characteristics of pressure distributions of left and right foot during normal walking.

METHODS: Twelve healthy female volunteers, with an age range 20-25 years, mean 22.5 years, weight range 46-55 kg, and no history of foot or ankle musculoskeletal/neuromuscular trauma or disease. Three styles of shoes for the subjects to wear comfortably are both with size 36 and 37, one was rubber-soled flat shoe and two high heels were women's dress pumps, of 4.5 cm and 9 cm heel heights respectively, the two pumps were made by the same manufacturer and both of identical styles.

Using the Novel Pedar in-shoe system, data was collected for left and right foot over 30 steps and average over this period. The Novel-win analysis software was used to collect and analyze the data. The insoles were set to collect data with a 20 kPa pressure threshold (manufacture's instructions). Order of trials was: barefoot, flat, high heels 4.5 cm and high heels 9 cm. There was a 10min interval after each trial, all subjects repeated for three times. Bontrager et al(1997) defined a set of generalized masks for Pedar system comprising eight areas of the foot, after study the MMPP (Mean Maximum Pressure Picture) and MVP (Mean Value Picture) of foot pressure in our research, we defined the following eight masks for Pedar system in Figure 1.

(GT: great toe; OT: other toes; MM: medial metatarsal heads (1); MidM: middle metatarsal head (2,3); LM: lateral metatarsal heads(4,5); MA: medial arch; LA: lateral arch).

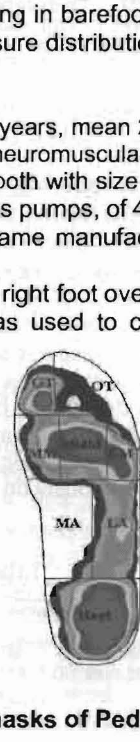

Figure 1 Eight masks of Pedar insole.

RESULTS:

Pressure distribution: The distribution of MMP (Mean Maximum Pressure) and MV (Mean Value) in barefoot, flat, high heels 4.5 cm and high heels 9 cm in eight Pedar masks are shown in Table 1 and Table 2. MMP shows the highest pressure that reached for each sensor at any time during data collection period, which provides a summary of the highest pressure reached over the entire surface of the insole. MV shows the average pressure recorded by each sensor during the contact phases of data collection period, calculated by summing the pressures for each sensor and dividing by the number of frames that the sensor loaded.

Data analysis indicated that the pressure distribution on eight masks of flat was similar to barefoot, but the value of each mask was lessened significantly except OT and MA. In both left and right foot, Maximum Pressure and Mean value under the LM in barefoot were significantly greater than that in any shoe (Table 1, Table 2). By increasing the heel height, the Max pressure on GT, MidM and MM increased significantly, but the Maximum Pressure on Heel, LA, MA, LM decreased obviously (Table 1). There was no significant difference between left foot and right fod of MMP and MV on eight masks ($p > 0.05$).

Table 1 MMP distribution in eight masks during walking (N/cm^2).

		Barefoot		Flat		Height 4.5 cm		Height 9 cm	
		L	R	L	R	L	R	L	R
Fore foot	GT	35.85(5.42)	36.96(6.98)	24.55(4.22)	25.15(3.05)	47.5(5.6)	46.1(5.02)	51.2(6.53)	49.13(8.11)
	OT	16.2(3.21)	15.45(2.4)	16.55(2.78)	16.3(2)	18.35(3.4)	18.75(3.31)	16.65(1.89)	14.5(2.52)
	MM	22.8(2.3)	24.6(2.8)	20.25(0.8)	20.06(0.47)	30.8(2.12)	32.7(2.64)	34.5(2.76)	36.25(3.48)
	MidM	38.9(3.65)	38.05(4.45)	27.4(2.58)	27.3(2.3)	32.25(3.49)	30.25(2.01)	35.73(2.71)	34.35(1.97)
	LM	34.35(3.9)	33.85(4.7)	22.85(3.7)	24.2(2.82)	16.25(1.95)	16.9(2.22)	12.45(2.07)	12.75(2.15)
Mid foot	MA	8.45(1.04)	10.4(1.97)	8.36(1.65)	10.4(1.44)	7.55(0.78)	7.05(1.39)	6.3(0.81)	6.85(1.75)
	LA	14.15(2.32)	15.85(3.19)	11.15(2.76)	12.1(1.89)	10.05(0.28)	10.3(0.65)	7.2(0.89)	6.95(1.05)
Heel		35.9(1.17)	35.7(1.67)	24.7(2.69)	25.45(1.42)	23.4(3.67)	22.55(4.26)	18.2(3.7)	19.05(2.85)

Table 2 MV distributions in eight masks during walking (N/cm^2).

		Barefoot		Flat		Height 4.5 cm		Height 9 cm	
		L	R	L	R	L	R	L	R
Forefoot	GT	6.35(1.42)	6.29(2.28)	5.62(0.56)	5.24(1.17)	8.6(1.45)	8.17(1.69)	8.06(0.82)	8.11(1.26)
	OT	2.54(0.55)	2.77(0.3)	3.25(0.77)	3.31(0.7)	3.75(0.88)	3.99(0.9)	3.81(0.49)	4.22(0.6)
	MM	5.55(0.99)	5.82(0.53)	5.35(0.57)	5.05(0.62)	7.11(2.57)	7.15(1.77)	8.57(1.01)	9.85(1.4)
	MidM	7.62(1.05)	7.36(1.15)	7.18(0.7)	7.09(0.85)	6.77(1.06)	6.41(1.17)	9.19(0.87)	8.85(0.54)
	LM	6.98(2.38)	7.25(2.17)	6.34(1.57)	6.88(0.46)	3.55(0.54)	4.13(0.91)	2.58(0.1)	3.03(0.21)
Midfoot	MA	2.26(0.13)	2.12(0.16)	2.06(0.2)	2.16(0.29)	1.96(0.37)	2.01(0.79)	1.91(0.18)	2.02(0.13)
	LA	2.96(0.54)	3.98(1.25)	3.29(0.47)	4.26(0.68)	2.09(0.49)	2.05(0.45)	1.96(0.13)	2.00(0.05)
Heel		9.01(1.11)	9.14(0.99)	7.84(0.65)	8.01(0.97)	7.49(0.45)	7.28(1.12)	6.91(0.21)	6.67(0.17)

Changes in bearing area of insole: The bearing area of insole was by analyzed and computed the force signal of 99 capacitance sensors on Pedar insoles during walking. Changes in bearing area of the insole in barefoot and in shoes as a percentage of surface area of the insole are shown in Table 3. The MVP (Mean Value Picture) for the entire data collection period (Fig. 1) displays significant changes in bearing area of insole in barefoot vs. flat, and also noted increase heel height with decreased bearing area. The bearing area of flat is significantly greater than barefoot on the left and right foot. By increasing the heel height, the bearing area decreased obviously on forefoot, Midfoot and heel.

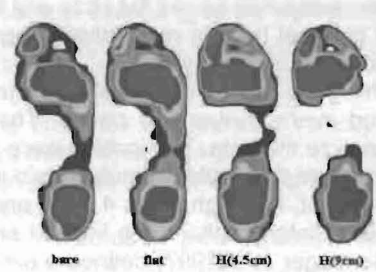

Figure 2 MVP for the entire date collection period.

Table 3 Changes in bearing area of the insole (%).

	Barefoot		Flat		Height 4.5 cm		Height 9 cm	
	L	R	L	R	L	R	L	R
Forefoot	96.3(1.86)	95.4(1.85)	98.1(2.9)	98.6(2.9)	94.9(3.51)	96.7(6.55)	82.3(5.12)	88.3(3.14)
Midfoot	58.8(10.23)	67.1(10.05)	72.9(14.91)	78.2(11.69)	55.9(8.45)	62.4(12.58)	32.9(15.88)	41.1(15.34)
Heel	97.3(3.35)	99(2.19)	99.3(1.79)	99.1(98.4)	96.4(2.19)	95.5(4.9)	90.9(7.16)	91.8(4.56)
Overall	84(3.82)	87.2(3.73)	90.3(5.95)	92(3.6)	82.4(3.32)	84.9(5.78)	68.7(5.51)	73.3(5.98)

Changes in temporal gait: Data analysis indicated that the stance phase of gait was prolonged in shoes comparing with barefoot. The duration of single limb support phase and double limb support phase was increased by increasing heel height (Table 4). The stance duration of flat was only slightly greater than barefoot. By increasing heel height, the swing duration was decreased obviously. Duration from first peak force to the second peak force was significantly greater in heel height 4.5 cm than in heel height 9 cm. Based on our data, we found that the stance phase of left and right foot was not identical, in the single limb support phase, the support duration of left foot was greater than that of right foot ($p < 0.05$). But in the double limb support phase, the double support duration was slightly greater than left foot ($p < 0.05$).

Table 4 Changes in temporal gait during walking (ms).

	Barefoot		Flat		Height 4.5 cm		Height 9 cm	
	L	R	L	R	L	R	L	R
Single limb support	836(60)	802(67)	811(79)	842(83)	931(41)	904(31)	984(66)	931(84)
Swing phase	401(50)	447(22)	413(10)	389(28)	376(26)	416(13)	387(85)	418(60)
1st peak to 2nd peak	315(24)	335(30)	330(12)	343(17)	383(31)	372(24)	345(37)	344(38)
Double limb support	201(18)		206(25)		262(19)		293(27)	

DISCUSSION: Compared with the prior studies, an important difference in this study is that we defined eight masks following eight areas of foot, and then studied the pressure distribution in each mask during walking in barefoot, flat and women's dress pump of different heel height. As people know, the size of bearing area is related to the pressure on that area, we analyzed and computed the force signal of capacitance sensors on Pedar insoles, and then discovered the changes in bearing area of the insole of Pedar during walking in barefoot and in shoes.Our study found the stance phase of left and right foot was not identical, which supported the finding of Schwartz et al. [2], showing that right and left foot gait patterns are not identical. Soames and Clark [1] found that increasing heel height decreased peak pressures under the third, fourth and fifth metatarsal heads while it increased peak pressure under the first and second metatarsals. Our results indicate a fairly coincidence in MM, MidM as heel height increased with MP increased while it decreased MP in LM.

CONCLUSION: Based on our data, we conclude that the characteristics of foot pressure distribution in rubber-soled flat shoe are similar to the barefoot, but the bearing area of flat is greater than barefoot, so the MMP and MV on each mask is lessened significantly. Increased heel heights with decreased bearing area of the insole, pressure at GT, MM and MidM increased significantly with the heel heights increasing while LM and Heel decreasing. The pressure distribution on both left and right foot was identical but not the temporal gait characteristics, in the single limb support phase, the support duration of left foot was slightly greater than right foot ($p < 0.05$). But in the double limb support phase, the double support duration was slightly greater than left foot ($p < 0.05$).

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