A Comparative Study of Foot Dimension between Adult Male and Female and Evaluation of Foot Hazards due to Using of Footwear

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Abstract Using footwear often becomes troublesome and creates many problems. Most of these problems are associated with the wearing of ill-fitting footwear, as it leads to biomechanical imbalance and ultimately give rise to different foot problems. In the present investigation different foot problems, viz., discomfort, pain and other hazards related to the use of footwear have been evaluated and attempts have been made to study different foot dimensions of men and women that are related to the design of footwear. For the present study different foot dimensions of both right and left feet of the subjects were measured on 300 Bengalee (Indian) subjects having the age range of 20–35 years. The subjects reported that they had got discomfort, pain, blister and corn due to using different footwear. It was noted that the occurrence of these problems in right foot was greater than that in left foot. There was no significant correlation between foot troubles and type of footwear. Results also showed that there was no significant difference in most of the foot dimensions between left foot and right foot. However, significant difference ($P < 0.001$) in all foot dimensions was observed between male and female subjects. Correlation coefficient among different foot dimensions has also been evaluated and it was noted that foot length was highly correlated with stature and foot volume, particularly in left foot. Footwear should be made according to the foot dimensions of the user population. The database collected from the Bengalee (Indian) population may be a helpful guide for manufacturing different footwear. *J Physiol Anthropol* 20 (4): 241-246, 2001 <http://www.jstage.jst.go.jp/en/>

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Introduction

Different kinds of footwear are used among the people

not only for protecting the foot but also used as a part of dress materials. Regular use of footwear often may become troublesome and create many problems. Most of these problems are associated with the wearing of ill-fitting footwear, as ill-fitting footwear leads to biomechanical imbalance and ultimately give rise to different foot problems such as blister, corn, ankle injury, acute or chronic pain in the foot (Killian et al., 1998). In addition to that deviation from normal pattern of working often due to trauma or disease affects the locomotor system (Lemmon et al., 1997; Frey, 1997; Menz and Lord, 1999; Patil et al., 1988; Takai and Mito, 1991, 1992) and cause imbalance of pressure on the foot, which may cause injury to the foot or other parts of the body. Proper designing of footwear is of great importance for proper fitting of foot within the shoe as well as for reducing many orthopedic and other problems. Moreover, length, breadth and other dimensions of both feet some times differ from one another so that one shoe fits within one foot but not in another foot because both shoes are made with the same size. However, it was observed that there was no significant difference in foot length, width and circumference between right and left foot, but foot volume measurement was significantly different (Rys and Kong, 1989). There was sexual dimorphism of foot dimension but had no relation between BMI and foot shape (Ashizawa et al., 1997). The design characteristics of the footwear may be important for safety during using footwear. It was observed that shoe ground contact area decreased with increased lateral stability and heel height (Soames and Evans, 1987). Different design criteria should be considered for making shoes for different user population. On studying the antislip properties and ranking of the grip of the industrial footwear it was observed that there was a significant correlation between roughness of the soling and coefficient of friction (Manning, 1991; Jung, 1991). To design a footwear shoe type, heel height, heel contour stiffness, longitudinal sole

rigidity have to be considered (Menz and Sherrington, 2000). In other studies for designing the sports footwear lateral stability, traction properties, foot classification and other biomechanical factors have also to be taken in consideration (Vigans, 1989; Less, 1988; Lake, 2000; Mc Poil, 2000). It was recommended that lighter, softer and more flexible footwear might give better fit, mobility and climatic comfort, to design the military footwear (Howard and Okley, 1984; Rosenblad-Wallin Else, 1998). Studies on gait pattern have shown that walking speed, step length and cadence were significantly greater in single walking than in group walking. Step length in heel shoes was found shorter than that in sneakers and flat shoes (Sato et al., 1991). Limb segments displacement tended to increase with decreasing heel height and increasing shoe ground area, being greatest when subjects were wearing pumps i. e., flexible-soled, no heeled shoes (Soames and Evans, 1987).

The present study was undertaken to evaluate different foot problems due to use of different kinds of footwear and attempts have been made to evaluate different foot dimensions of adult men and women of Bengalee (Indian) population.

Materials and Methods

For the present study 200 men and 100 women having the age range of 20–35 years were selected from different urban areas of Midnapore district, West Bengal (India). All the subjects volunteered for this study.

Evaluation of foot hazards

Different foot hazards of the subjects were evaluated by questionnaire technique. Some of the problems (viz., corn, blister, small injury etc.) were noted by direct observation. The problems of left and right foot due to use of different types of footwear were also evaluated separately.

Measurement of foot dimensions

The following foot dimensions were measured by standard anthropometric method (Ernakova et al., 1982; Wells and Luttgens, 1976). Foot volume was measured by applying a special technique.

1. Foot length: The distance from the maximum arch of the heel (pternion) to the tip of the most protruding toe (acropodion). This was measured by a standard anthropometer.

2. Foot breadth: The distance between metatarsale mediale and metatarsale laterale; measured with a sliding caliper.

3. Foot depth at base: The distance between the lower surface of the foot to the upper surface of the foot at point where leg meets the feet; measured with a sliding caliper.

4. Heel breadth: The distance between the lateral

Fig. 1. The device used for measuring the foot volume.

portion and anterior portion of heel region or arches of heel; measured with a sliding caliper.

5. Ankle height: The distance between maximum bulge of the ankle to the surface when subjects stands in erect posture; measured with a sliding caliper.

6. Foot volume: Foot volume of the subjects was measured by water displacement method. For this purpose a simple 30 cm × 15 cm × 14 cm rectangular box shaped device was developed (as shown in Fig. 1). It is made up of iron sheet. The top surface of the box was open. A small outlet of 10 cm long was fixed on upper side of the box above 10 cm from the base. The box was filled maximally with the water. Subjects were asked to dip his/her foot into the water up to maximum bulge of the ankle. The displaced water, which passed through to the outlet tube, was collected in a measuring cylinder. The volume of the displaced water was read which represented the foot volume of the person.

Statistical analysis

The collected data were analyzed statistically. To find out the significance of difference between the means of each foot dimensions of right and left foot a two-tail 't'-test was employed. Chi-square test was performed to evaluate the level of association between foot troubles and type of footwear. Product moment correlation coefficient was employed to compute the correlation coefficient between some selected pairs of foot dimensions. For the said purpose statistical software package (SPSS) was used.

Results and Discussion

The hazards of using different types of footwear have been presented in Table 1. From the results it appears that different percentage of subjects were affected due to wearing of different kinds of footwear. It was noted that feeling of discomfort or uneasiness during using of

Table 1 Results of subjective evaluation of foot troubles due to using different types of footwear in male (n=200) and female (n=100) subjects

Types of footwear	Sex	Number of subjects	Discomfort during use (%)		Pain sensation during use (%)		Problem of blister (%)		Problem of corn (%)	
			RF	LF	RF	LF	RF	LF	RF	LF
Shoe	M	45	24.44	17.78	15.56	8.89	48.89	33.33	37.78	20.00
	F	21	42.86	33.33	19.10	19.10	61.19	28.57	23.81	14.28
Sandal	M	87	28.73	21.84	24.14	15.85	37.93	19.54	19.54	12.64
	F	74	31.10	25.68	22.98	17.57	36.49	31.10	20.27	12.16
Slipper	M	68	25.00	16.18	19.11	10.29	22.10	13.26	7.35	4.41
	F	5	20.00	20.00	40.00	40.00	80.00	40.00	20.00	20.00

RF=Right foot, LF=Left foot.

Table 2 Percentage of foot deformation in relation to the use of different types of footwear in male (n=200) and female (n=100)

Types of footwear	Sex	Number of subjects	Footwear deformation (%)	
			RF	LF
Shoe	M	45	55.55	44.44
	F	21	38.10	23.81
Sandal	M	87	67.82	32.18
	F	74	58.10	29.19
Slipper	M	68	66.18	33.82
	F	5	20.00	20.00

RF=Right foot, LF=Left foot.

footwear was more or less the same in case of shoe, sandal and slipper. A greater number of sandal users felt pain sensation than that of shoe users or slipper users. The occurrence of blister and corn formation was found to be highest in shoe users and least in slipper users in case of both left and right foot among the users. It may be observed from Table 1 that women had got greater foot troubles than that of men. It may be due to the mal use of high-heeled shoes among the women. It was also noteworthy that the right foot was affected in greater percentage of subjects (male and female) in comparison to left foot, which may be due to the gait pattern of the subjects.

The occurrences of deformation of footwear have been shown in Table 2. In case of men highest percentage of deformation was found in sandals used in the right foot followed by the slipper in the same foot. A greater percentage of footwear deformation was noted in male users than that of female users. Right footwear was found to be more affected than that of left footwear. Regarding the preference of using footwear it was noted that a greater percentage of men (43.5%) and women (74%) used sandal than that of shoe. Such preference may be due to tropical climate in India.

The locations of the foot where different problems occurred were also studied. In case of shoe users pain sensation was found in heel region after long distance walking as reported by the users. Blister formation was

also in greater percentage in right foot than that of left foot and found usually in the lateral portion of the foot, just above the heel region. In case of sandal users problems were found in mid-tarsal region of the right foot mainly. Pain sensation was reported in the mid-tarsal region and also in the heel region in using some types of sandal. Blister formation was noted in between 1st and 2nd toe as well as in the mid-tarsal region. Corn formation was found in phalanges. In the slipper users blister formation was found in the anterior portion of the mid-tarsal region and in between 1st and 2nd toe. In the shoe users it was noted that the right footwear deformed first in most of the subjects and in the sandal and slipper users the strap of the footwear found to be deformed first.

Thus from the above observation it was revealed that foot problems as well as footwear deformation occurred in higher percentage in right foot of both male and female subjects than that of left foot. This may be due to unequal pressure imposed on the feet during the act of movement (walking). Probably most of the subjects exert greater pressure on right foot during locomotion than that of left foot as they were mainly right handed in nature. In addition to that, such occurrence may be related to the gait pattern of the subjects.

It may be noted that different type of foot troubles were not significantly associated with types of footwear used and two feet (right and left). Similarly, deformations of footwear were also not correlated with the kind of footwear used on left or right foot (Table 3). Similar types of finding were also noted by Takai and Mito (1991). They studied on foot and footwear in male undergraduate students and found that there was no correlation between the kind of footwear and the incidence of the foot troubles. The occurrence of deformation did not correlate with the kinds of shoe and incidence of the foot troubles. The problems of foot due to using footwear may be due to improper fitting of foot and footwear. Takai and Mito (1991) observed that the incidence of fatigue and pain closely correlated with the fitness in the wear of the footwear, higher in tight shoe and lower in proper fitting shoes.

Table 3 Chi-square values for evaluating level of significance of association of foot troubles between types of footwear and right/left foot

Type of foot trouble	Male		Female	
	Chi-square value	Level of significance	Chi-square value	Level of significance
Difficulty during use of footwear	0.108	NS	0.031	NS
Pain sensation during use of footwear	0.149	NS	0.153	NS
Blister formation	1.069	NS	1.350	NS
Corn formation	0.127	NS	0.140	NS
Deformation of footwear	2.060	NS	0.089	NS

NS=Not significant.

Table 4 Mean $\pm$ SD and t-value of different foot dimensions of male (n=200) and female (n=100) subjects

Foot dimensions	Male			Female		
	Left foot	Right foot	t-value	Left foot	Right foot	t-value
Foot length	24.38 $\pm$ 1.21	24.47 $\pm$ 1.25	0.73	22.14 $\pm$ 1.05	22.98 $\pm$ 1.44	4.71**
Foot breadth	9.47 $\pm$ 0.51	9.82 $\pm$ 0.96	4.35**	8.47 $\pm$ 0.37	8.55 $\pm$ 0.31	1.66
Foot depth at base	4.36 $\pm$ 0.27	4.19 $\pm$ 0.33	5.64**	3.78 $\pm$ 0.39	3.83 $\pm$ 0.52	0.77
Foot depth at joint	6.49 $\pm$ 0.55	6.43 $\pm$ 0.68	0.97	5.59 $\pm$ 0.39	5.75 $\pm$ 0.53	2.43*
Heel breadth	6.23 $\pm$ 0.47	6.19 $\pm$ 0.39	0.93	5.62 $\pm$ 0.34	5.66 $\pm$ 0.36	0.81
Ankle height	7.96 $\pm$ 0.84	8.0 $\pm$ 0.81	0.48	6.77 $\pm$ 0.56	6.87 $\pm$ 0.53	1.30
Foot volume	771.72 $\pm$ 99.62	778.19 $\pm$ 116.52	0.60	512.59 $\pm$ 71.42	525.05 $\pm$ 71.04	1.24

All dimensions are in cm except foot volume (cc). *P<0.02 **P<0.001.

Table 5 Percentage of difference and level of significance of difference in mean values of foot dimensions between male (n=200) and female (n=100)

Foot dimensions	Left foot		Right foot	
	% difference	t-value	% difference	t-value
Foot length	10.12	15.78*	6.48	9.24*
Foot breadth	11.81	11.44*	14.85	12.89*
Foot depth at base	15.34	13.35*	9.40	7.29*
Foot depth at joint	16.10	14.62*	11.83	8.76*
Heel breadth	10.85	11.55*	9.36	11.38*
Ankle height	17.58	12.81*	16.45	12.66*
Foot volume	50.55	23.19*	48.21	19.94*

*P<0.001.

From Table 4 it may be noted that there was no significant difference in foot dimensions between left and right foot of both male and female subjects except for foot breadth (P<0.001) and foot breadth at base (P<0.001) in men as well as foot length (P<0.001) and foot depth at joint (P<0.001) in women. Similar observations were also made by Rys and Kong (1989). They did not found any significant difference in foot length, width and circumference between right and left foot.

It was noted that there were highly significant (P<0.001) differences in the mean foot dimensions (both right and left feet) between male and female subjects (Table 5). All foot dimensions of female were lower than that of male. A marked difference was noted in case of foot volume which showed approximately 50% higher

value in case of male than that of female subjects. It may be pointed out that the left foot showed comparatively greater percentage of difference in all foot dimensions than that of right foot except for foot breadth. Significant difference of foot volume measurement among male and female subjects was also observed by other groups of investigators (Rys and Kong, 1989). The importance of measuring foot volume of the subjects lies with determination of the internal volume of the shoe. The internal volume of the shoe should be comparable with the volume of the foot along with the clearance for socks. This may be considered while designing the shoe and thus many of the troubles may be reduced.

The correlation coefficient of different pairs of foot dimensions was computed and some of the coefficient

Table 6 Correlation coefficient of foot dimensions between different parameters for both males (n=200) and females (n=100)

Foot dimensions	Male		Female	
	Left foot	Right foot	Left foot	Right foot
Foot length vs. Foot breadth	0.284***	0.111	0.373***	0.144
Foot breadth vs. Heel breadth	0.279***	0.002	0.053	0.422
Foot volume vs. Foot length	0.673***	0.141*	0.437***	0.106
Foot volume vs. Foot breadth	0.445***	0.048	0.284**	0.283*
Foot volume vs. Ankle height	0.138*	0.049	0.007	0.0424
Stature vs. Foot length	0.581***	0.119	0.445***	0.195
Stature vs. Foot breadth	0.246***	0.007	0.094	0.064
Foot depth at base vs. Foot depth at joint	0.069	0.199**	0.196*	0.032

*P<0.05, **P<0.01, ***P<0.001.

have been shown in Table 6. The highest degree of correlation was noticed between foot volume and foot length (P<0.001) in case of left foot of male subjects. A good correlation was also observed in between foot volume and foot breadth (P<0.001), and stature and foot length (P<0.001) in male and female subjects. It was noted that left foot had comparatively better correlation coefficient than that of right foot in both sexes. On the other hand male subjects showed better degree of correlation than that of female in case of left foot.

Footwear should be made according to the foot dimensions of the user population. The database collected from the Bengalee (Indian) population may be a helpful guide for manufacturing different footwear. However, there is a great variation in the dimension of foot among the adult males and females. So foot dimensions may be classified into some categories and this may be done by computing percentile values of each foot dimensions. Different categories of footwear may be manufactured taking some small range of foot dimensions. Such categories will be helpful for proper fitting of foot with the footwear and that will be comfortable for the users.

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