Foot Dimensions and Foot Shape: Differences Due to Growth, Generation and Ethnic Origin

Makiko Kouchi

Human-Environment System Department, National Institute of Bioscience and Human-Technology,
Higashi 1-1, Tsukuba 305-8566

(Accepted May 25, 1998)

Abstract Foot dimensions, indices, and variables relating to shape characteristics of foot outlines taken for Japanese, Australian aborigines, Indonesians and French were analyzed and compared with existing data to identify the differences due to growth, generation and ethnic background. The following findings were obtained: 1) There has been rapid increases in foot length for Japanese born after ca. 1950. 2) Japanese born after ca. 1960 had a smaller foot girth and foot breadth for their foot length compared to Japanese born before ca. 1950. 3) Secular change rather than aging is responsible for the generation differences in foot size and proportion. 4) Elderly female Japanese born before 1930 had very wide feet and a weaker valgus tendency of the first toe. Special attention should be paid to the needs of older men, and especially older women in the production planning and designing of the toe shapes of shoe lasts. 5) Differences due to growth and secular change in foot outflare, which is represented by posterior flexion angle of the medial axis of foot outline, were not significant. Ethnic differences in foot outflare was not significant for females. This does not appear to be easily influenced by environmental factors, such as nutritional status and shoe-wearing habits. 6) Mongoloid populations including Japanese have a wider foot for foot length compared to Caucasoid and Australoid populations. 7) East Asian populations including Japanese have a smaller foot length for height compared to Southeast Asians and Africans. The causes may be both genetic and environmental.

Keywords: medial axis, foot outline, elderly persons, secular change

Introduction

Studies of variation in foot morphology are based on measurements, such as foot dimensions and angles. Apart from research on the development of the plantar arch, there are few studies concerning variation in foot shape due to growth and aging. This is partly due to the lack of appropriate methods to represent the shape characteristics of the foot, and partly due to the difficulties of obtaining mass data. Several angle measurements

obtained from foot outlines have been used to represent shape characteristics of the foot (Kouchi, 1989), but these have only represented local characteristics of the foot such as the fanning out of the toes. The posterior flexion angle of the medial axis (skeleton) of a foot outline is useful in representing the shape characteristics of the foot (Kouchi, 1995), and is related to the three dimensional foot shape (Kouchi and Tsutsumi, 1996), and so to individual differences in shoe comfort. On the other hand, fanning out of the toes is influenced by the habit of wearing shoes (Lam Sim-Fook and Hodgson, 1958; Morioka and others, 1974), and is also related to shoe comfort. Therefore, it is important to identify the variation and distribution of shape characteristics; information about human foot morphology essential for the successful design of commercial products.

Ethnic differences in foot morphology has been studied from the viewpoint of the influence of footwear on the foot (Hoffmann, 1905; Lam Sim-Fook and Hodgson, 1958; Stewart, 1970), and shoe comfort for different ethnic populations (Hawes and others, 1994). These studies are also mainly based on foot dimensions and somatoscopy.

In this paper, changes due to age in the size and shape of the foot are analyzed based on cross-sectional data for more than 3000 Japanese, obtained from several somatometric researches, and the factors that influence differences in foot morphology due to age are examined. Also, the characteristics of the Japanese foot are investigated by comparing data for Indonesians, French, and also Australian aborigines, who are not in the habit of using footwear.

Subjects and Methods

Subjects

1. Japanese

The subjects are 1589 males and 1473 females aged 3 to 88 years measured in the following four somatometric studies.

1) JLIA series

A somatometric study of the foot was carried out in 1987-1988 by Japan Leather and Leather-Good Industries Association (JLIA) in order to obtain foot measurements to revise the Japanese Industrial Standard for shoes, and data for about 2500 males and females aged between 3 to 59 years was obtained (Japan Leather and Leather-Good Industries Association, 1987; 1988). Ten measurements for the right foot and three for the left foot, as well as the foot outline of both feet were taken by the hand. Height and weight were also measured, but the conditions under which these measurements were taken is not known. Measurements were taken by several technicians from the member companies of the research project and they were experienced in taking foot measurements.

2) IPRI series

Industrial Product Research Institute (IPRI) and National Institute of Bioscience and Human-Technology made an anthropometric study in 1991 (males) and 1992 (females) to obtain data necessary to develop a design-support system, and more than 200 measurements were taken for 217 young adult males and 206 females as well as 50 elderly

males and 50 elderly females aged 60 years and over (National Institute of Bioscience and Human-Technology, 1997). The measurements were taken with the subjects wearing only underwear. Height was measured with an anthropometer, and weight with digital scales. Measurements for male subjects were made by an experienced researcher, and two other experienced researchers took the measurements for female subjects.

3) Elderly citizens from Ibaraki Prefecture

The subjects were residents of Satomi village, Ibaraki Prefecture. Twenty five men and women aged 60 years and over were measured in November, 1994. Foot girth and outline were taken for both feet. Height was measured with a stadiometer, and weight with digital scales with the subjects clothed but barefoot. All the data were taken by the present author.

4) Veterans series

The subjects were veteran members of the baseball teams of Keio University, Meiji University and Tokyo University. The feet of 28 men aged 60 years and over were measured in December, 1994. Foot girth and foot outline was taken for the right and left feet. Height and weight were not measured, but obtained through self report. All the data were taken by the present author.

2. Indonesians

The subjects were employees of Indonesia Export Training Center in Jakarta, Indonesia, and were in the habit of wearing shoes. About 70% of the subjects came from Java, 20% from Sumatra, and 10% from other areas of Indonesia. Foot girth and foot outlines were taken for the right and left feet of 50 adult males and 33 adult females in July, 1991. Height was measured with an anthropometer and weight with scales with the subjects barefoot but wearing clothes. All the data were taken by the present author.

3. French

The subjects were researchers and students working in Cognitive Neuroscience Laboratory, Marseille, France. Foot girth and foot outline was taken for the right and left feet of 31 males and 31 females in November 1991. Height and weight were obtained through self report. All the data were taken by the present author.

4. Australian aborigines

The subjects were 33 males and 32 females judged to be adult, for in many cases the exact age of the subjects was unknown. In August, 1987, the foot outline of the right foot was taken using a scribe in Gamadi and several other outstations near Maningrida in Arnhemland, Northern Territory, Australia. All the subjects were born and lived in traditional living conditions, and were not in the habit of wearing shoes, except for a few of the men. Even these men wore shoes only on special occasions. They were usually barefoot or sometimes wore thongs. One male who was not in the habit of wearing shoes had a toe deformation that looks like hallux valgus on both feet, and was eliminated from the analysis. All the data were taken by the present author. Data on height, weight and

foot girth were not taken.

Measurement items

1. Dimensions and angular measurements

The measurements were taken according to the definitions by All Nippon Footwear Federation (Zen-Nihon Hakimono Dantai Kyogikai) that were used in the previous studies (Japan Leather and Leather-Good Industries Association, 1988). Foot measurements and foot outlines were taken for barefoot subjects standing with both feet apart 10-15 cm, and weight distributed equally on both feet. In the JLIA series, subjects stood with the medial aspects of both feet parallel, but in the other series subjects stood naturally.

Foot girth passes through metatarsale tibiale (mt, t) and metatarsale fibulare (mt, f), and it is identical to 70a by Knussmann (1988). Foot outline was taken using a scribe, and foot girth with a measuring tape. The following dimensions and angles were measured from the foot outlines: foot length, instep length, fibular instep length, foot breadth, heel breadth, ball flex angle, toe I angle, and toe V angle. Toe length was calculated as foot length minus instep length. The definitions of these measurement items are shown in Figure 1. All the length measurements are measured parallel to the foot axis defined as the line connecting pternion (pte) and the tip of the second toe. Sphyrion fibulare height was taken with a height gage. It was measured only for the JLIA series and IPRI series.

2. Indices

The following indices were calculated. 1) Relative foot girth: foot girth÷foot length×100, 2) foot index: foot breadth÷foot length×100, 3) relative toe length: toe length÷foot length×100, 4) ball flex index: fibular instep length÷instep length×100, 5) foot axis index: foot breadth, medial half÷foot breadth, lateral half×100, 6) foot breadth index: heel breadth÷foot breadth×100. Foot breadth, medial half and foot breadth, lateral half are the distance from mt, t or mt, f to the foot axis, respectively. Foot index, ball flex index, and foot axis index are known to have large variation in a principal component

Figure 1 Measurement items. ×1: foot length, ×2: instep length, ×3: fibular instep length, ×4: foot breadth, ×5: heel breadth, ×6: fibular sphyrion height, ×7: ball flex angle, ×8: toe I angle, ×9: toe V angle, ×10: toe length.

analysis of foot measurements (Kouchi, 1989).

3. Flexion angles of the medial axis

Foot outlines carry information about foot morphology that can not be represented by the above mentioned conventional variables. Kouchi (1995) proposed flexion angles of the medial axis (skeleton) of foot outline as a tool for analyzing variations in the foot outline form. The medial axis corresponds to the intuitive midline of an outline form, and is useful for the analysis of irregular form on which anatomical landmarks are not determined (Bookstein, 1991). The intuitive midline of the foot outline is not straight in many cases, and the results of previous studies suggest the importance of midline bends as a morphological feature of the foot (Freedman and others, 1946; Kouchi and Yamazaki, 1990).

Since the medial axis of foot outlines curves like an “S” between the heel triple point (HTP) and the toe triple point (TTP) as shown in Figure 2A, three regression lines (RL1-RL3) are fitted to the medial axis, and two angular measurements, posterior flexion angle (PFA) and anterior flexion angle (AFA) are calculated. Two factors influence the PFA, one is the medial bulge (Figure 2A, c) and the other is the lateral concavity (Figure 2A, d). To determine which is responsible in an individual case, the medial axis is calculated for the corrected foot outline with the medial bulge removed, and the corrected posterior flexion angle (CPFA) is calculated as shown in Figure 2B. The intensity of medial bulge (IMB) was defined as $PFA - CPFA$. It has been shown that IMB is correlated with the three dimensional foot shape (Kouchi and Tsutsumi, 1996). All the calculations were made using the method of Mochimaru and Kouchi (1997).

Figure 2 Flexion angles of the medial axis of the foot outline. A: original foot outline, B: corrected foot outline, a: 1/3 of foot length from pternion (pte), b: inflexion point determined by eye inspection, c: medial bulge, CPFA: corrected posterior flexion angle, d: lateral concavity, HTP: heel triple point, PFA: posterior flexion angle, RL1-RL3: regression lines, TTP: toe triple point.

Materials used for the analysis

1. Growth analysis

Data for children aged 3 to 18 years from the JLIA series for Japanese was used. Basic statistics were calculated for each age group, where age group n (n years old) consists of children aged over n years and 0 months and younger than $n+1$ years. Table 1a shows the number of subjects by age group.

2. Inter-generation differences

Data for Japanese subjects aged 18 years and over was used. The subjects were divided into the following groups according to age: 18-19 years, 20-24 years, 25-29 years, 30-39 years, 40-49 years, 50-59 years, and 60 years and over. The JLIA series and the IPRI series were treated separately because the studies were conducted with an interval of five years in between.

The data for the elderly persons from the IPRI series and that for the residents of Ibaraki Prefecture were pooled, because the subjects of both series lived in the same Prefecture and the differences in the dates of birth and body build were small. The pooled data will be referred to as the Ibaraki series in the following text. On the other hand, the subjects in the Veterans series were significantly taller and heavier and had larger foot dimensions than the subjects of the Ibaraki series. Therefore the Veterans series was treated separately. The number of subjects by age group is shown in Table 1b.

In order to identify differences in foot proportion between the age groups, the allometry of the foot should be taken into consideration (Kouchi and Yamazaki, 1992). The subjects

Table 1a Number of subjects for growth analysis

Age	Male	Female
3	31	40
4	48	36
5	45	44
6	56	55
7	56	56
8	59	56
9	61	57
10	60	66
11	67	60
12	62	66
13	52	44
14	36	42
15	20	25
16	39	40
17	47	42
18	46	45
total	785	774

Table 1b Number of subjects for aging analysis

Age	Male					Female			
	JLIA	IPRI	Ibaraki	Veterans	total	JLIA	IPRI	Ibaraki	total
18-19	67	50			117	82	85		167
20-24	89	114			203	118	80		198
25-29	93	53			146	57	34		91
30-39	156				156	125			125
40-49	82				82	56			56
50-59	58				58	54			54
60-			61	27	27			53	53
total					789				744

belonging to the following five age categories of 18-29 years, 30-39 years, 40-49 years, 50-59 years, and 60 years and over were divided into several groups according to their foot length. Groups with sample numbers of 20 or more were used for further analysis. Table 1c shows the number of subjects by foot length for each age category.

3. Ethnic differences

For ethnic comparison, data for the 20-59 years age group from the JLIA series of Japanese was used, so that the average age and age range would be similar between groups. The number of subjects by ethnic group is shown in Table 1d.

4. Statistical methods

Subjects with pathological deformations of the foot were eliminated before analysis. Basic statistics were calculated, and the equality of the means were tested by ANOVA. Sex differences were t-tested. All the calculations were made using the program package, Statview for Macintosh.

Results

Growth

Table 2 shows the basic statistics for the measurement items by age group and the results of the t-test for sex differences. In girls, foot dimensions did not increase after the age of 13 years, while height did not increase after 15 years. In boys, these foot measurements as well as height continued to increase until 18 years.

Changes in foot length and foot girth in the present subjects coincided well with those of Okada and others (1990) who measured 1086 children aged 7 to 15 years in 1986-87. Okada and others stated that the age at the cessation of growth in foot length was younger than that in the 1970s by one year.

Variables related to foot proportion and foot shape are divided into three categories: those without significant differences between age groups; those which increased according

Table 1c Number of subjects by age and foot length

Male				Female			
Series	Age	Foot length	N	Series	Age	Foot length	N
JLIA	18-29	-239	33	JLIA	18-29	-219	31
		240-244	34			220-224	45
		245-249	45			225-229	60
		250-254	49			230-234	55
		255-259	39			235-239	32
		260-264	28			240-244	23
		265-	21			245-	11
JLIA	30-39	-244	52	JLIA	30-39	-221	34
		245-254	56			222-230	58
		255-	47			231-	33
JLIA	40-49	-244	46	JLIA	40-49	-226	28
		245-	36			227-	28
JLIA	50-59	-244	26	JLIA	50-59	-225	30
		245-	32			226-	24
IPRI	18-29	-239	21	IPRI		-219	18
		240-244	20			220-224	20
		245-249	35			225-229	34
		250-254	40			230-234	41
		255-259	40			235-239	34
		260-264	27			240-244	30
		265-	34			245-	22
Ibaraki	60-	-239	24	Ibaraki		-227	27
		240-	37			228-	26
Veterans	60-	236-273	27				

Table 1d Number of subjects for ethnic comparison

Ethnic group	Male (age)	Female (age)
Japanese	478 (20-59)	410 (20-59)
Austrarian Aborigines	33	32
Indonesians	31 (22-57)	31 (19-52)
French	50 (23-54)	33 (23-55)

to age; and those in which the direction of change differs before and after the adolescent period.

Ball flex angle, ball flex index, and PFA belong to category 1. Toe I angle, toe V angle, and boys' AFA belong to category 2. Toe I angle increased from 7 years to 11-12 years in both sexes, and did not change after those ages. Toe V angle increased from 3 years to 11 years in girls and to 14 years in boys, and did not change after those ages. Relative foot girth, foot index, relative toe length belong to category 3. They decreased from 3 years to 11 years, and then increased again in both sexes.

Table 2 Basic statistics of measurement items by age and the results of t-test for sex differences

Group	Age (years)	Foot length (mm)				Instep length (mm)				Fibular instep length (mm)				Sex diff. t-test				
		Male		Female		Male		Female		Male		Female						
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.					
3	3.490	0.322	3.608	0.258	-1.715	ns	155.1	7.34	151.1	7.87	2.187	*	98.5	5.95	95.1	7.08	2.149	*
4	4.514	0.316	4.517	0.312	-0.043	ns	164.9	7.78	160.7	7.46	2.492	*	104.6	5.71	101.1	6.66	2.588	ns
5	5.452	0.293	5.354	0.253	1.687	ns	172.8	10.62	166.7	9.28	2.893	**	109.4	5.81	106.3	7.50	1.869	ns
6	6.506	0.278	6.494	0.260	0.236	ns	180.4	11.25	180.4	8.97	0.000	ns	114.4	8.22	113.9	6.99	0.346	ns
7	7.395	0.301	7.409	0.283	-0.254	ns	192.2	9.43	191.0	8.91	0.692	ns	126.6	6.81	122.7	6.99	-0.077	ns
8	8.425	0.292	8.422	0.282	0.056	ns	201.6	11.34	198.5	9.81	1.564	ns	129.4	5.70	126.2	6.79	2.394	*
9	9.421	0.299	9.453	0.269	-0.610	ns	208.3	12.08	204.2	8.96	2.082	*	134.7	8.27	131.2	5.92	2.627	**
10	10.432	0.259	10.418	0.254	0.306	ns	215.2	10.13	214.4	10.85	0.427	ns	139.3	7.54	137.4	7.29	1.437	ns
11	11.454	0.276	11.453	0.261	0.021	ns	222.0	10.58	224.0	10.08	-1.087	ns	142.9	7.25	142.1	7.39	0.615	ns
12	12.485	0.255	12.481	0.271	0.085	ns	232.5	12.83	226.8	9.24	2.889	**	149.2	7.18	145.1	7.71	3.094	**
13	13.437	0.263	13.396	0.254	0.773	ns	241.5	12.16	231.1	10.06	4.514	**	152.4	8.75	146.7	8.01	3.305	**
14	14.394	0.200	14.435	0.232	-0.829	ns	251.0	8.73	231.7	10.22	8.886	**	160.2	6.50	146.1	7.15	8.977	**
15	15.485	0.223	15.407	0.234	1.134	ns	248.5	9.56	229.0	10.05	6.608	**	158.1	5.89	145.3	7.20	6.413	**
16	16.472	0.262	16.321	0.212	2.819	**	251.7	9.66	232.2	8.65	9.457	**	158.6	6.39	146.0	6.14	8.938	**
17	17.355	0.219	17.582	0.296	-4.141	**	252.4	9.93	230.5	7.04	11.871	**	159.2	6.95	145.9	6.00	9.608	**
18	18.341	0.227	18.371	0.217	-0.644	ns	251.6	10.07	229.5	7.75	11.714	**	160.0	9.93	143.8	6.86	9.036	**

Group	Toe length (mm)	Foot girth (mm)				Foot breadth (mm)				Heel breadth (mm)				Sex diff. t-test				
		Male		Female		Male		Female		Male		Female						
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.					
3	42.9	3.67	42.4	4.59	0.496	ns	162.8	10.16	158.9	7.62	1.849	ns	42.8	2.60	40.6	3.20	3.112	**
4	44.9	4.48	45.3	4.46	-0.406	ns	169.1	9.35	164.9	9.45	2.028	*	43.8	2.91	42.2	2.74	2.556	*
5	47.5	4.43	45.8	4.07	1.884	ns	177.7	11.50	169.7	8.42	3.738	**	45.9	2.84	43.6	2.50	4.052	*
6	49.8	4.48	50.1	4.89	-0.339	ns	185.6	11.83	180.2	8.46	2.770	**	47.6	3.60	45.5	2.58	3.537	**
7	52.4	4.02	52.1	4.25	0.384	ns	192.7	11.62	186.6	9.50	3.041	**	50.2	3.50	47.3	4.75	3.678	**
8	53.1	4.78	53.3	4.24	-0.237	ns	202.4	13.90	194.4	10.64	3.452	**	52.3	3.58	50.3	3.87	2.879	**
9	54.2	4.18	54.4	3.58	-0.278	ns	206.1	14.49	199.1	11.26	2.916	**	53.3	3.26	51.6	2.91	2.981	**
10	56.4	4.02	56.5	4.72	-0.127	ns	210.8	10.84	208.6	12.09	1.071	ns	54.7	3.52	53.7	3.63	1.567	ns
11	58.7	4.58	61.0	4.69	-2.793	**	216.3	11.86	217.0	9.67	-0.362	ns	57.5	3.10	56.1	3.33	2.453	*
12	61.3	5.02	61.8	4.21	-0.610	ns	226.4	16.68	217.5	10.01	3.678	**	60.1	4.18	56.9	3.20	4.866	**
13	65.9	5.66	63.5	4.99	2.184	*	238.1	12.78	225.1	12.29	5.054	**	62.5	3.38	58.9	3.09	5.407	**
14	68.5	4.60	63.7	6.18	3.799	**	244.0	12.60	223.3	11.56	7.563	**	65.0	3.91	59.1	3.26	7.288	**
15	68.0	3.69	64.0	3.90	3.501	**	246.5	13.16	223.4	9.19	6.924	**	64.6	3.89	58.1	2.88	6.441	**
16	70.0	4.19	65.6	4.65	4.415	**	247.6	10.14	226.5	9.74	9.433	**	64.7	3.00	60.3	4.10	5.432	**
17	70.1	4.71	64.7	6.11	4.696	**	248.7	10.56	226.7	8.88	10.568	**	64.9	4.53	59.5	2.78	6.680	**
18	67.8	4.21	65.1	5.81	2.543	*	248.9	12.01	224.6	11.07	10.030	**	65.2	4.38	59.5	2.38	7.689	**

ns: not significant, *significant at the 5% level, **significant at the 1% level.

Table 2 (continued)

Group	Fibular sphyrion height (mm)					Ball angle (deg.)					Toe I angle (deg.)					Toe V angle (deg.)				
	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
3	29.9	2.97	28.8	2.78	1.605 ns	77.9	3.22	77.0	3.08	1.197 ns	5.1	3.95	5.2	4.79	-0.132 ns	4.7	4.52	7.0	4.00	-2.290 *
4	30.9	4.58	30.8	3.56	0.109 ns	76.8	2.16	77.5	2.50	-1.374 ns	4.8	3.78	3.8	3.97	1.350 ns	5.8	4.83	5.9	4.78	-0.019 ns
5	33.3	3.78	32.1	2.75	1.709 ns	77.1	2.46	77.4	2.92	-0.525 ns	4.9	4.51	3.7	4.54	1.230 ns	7.3	4.74	7.4	4.25	-0.136 ns
6	35.5	4.13	35.1	3.37	0.560 ns	77.6	3.40	76.8	2.68	1.380 ns	4.3	3.69	4.5	3.66	-0.187 ns	7.1	3.89	7.4	4.85	-0.362 ns
7	37.4	3.09	36.7	3.78	1.073 ns	77.4	2.84	77.5	3.53	-0.165 ns	5.3	3.96	7.0	3.80	-2.209 *	7.8	4.16	9.0	5.51	-1.268 ns
8	40.8	4.60	38.9	3.76	2.413 *	76.6	2.94	76.1	3.36	0.850 ns	4.8	3.52	7.4	4.33	-3.569 **	9.5	4.24	7.6	4.19	2.352 *
9	40.0	4.44	39.7	3.31	0.414 ns	76.8	3.01	76.8	2.75	0.000 ns	6.0	4.33	8.0	4.90	-2.377 *	8.6	4.30	9.3	5.11	-0.807 ns
10	42.1	3.17	42.2	3.43	-0.169 ns	76.7	3.27	75.9	2.56	1.536 ns	5.9	3.90	9.3	4.50	-4.491 **	9.2	4.58	10.0	4.99	-0.946 ns
11	43.6	4.34	43.3	3.16	0.441 ns	76.6	3.20	76.3	2.71	0.567 ns	6.8	3.69	10.5	5.28	-4.602 **	8.7	5.40	10.4	4.98	-1.913 ns
12	46.7	3.78	43.8	3.66	4.392 **	76.3	2.90	77.0	3.53	-1.067 ns	7.7	4.57	10.8	4.14	-4.037 **	11.1	4.73	10.2	4.32	0.956 ns
13	48.4	4.54	46.7	4.44	1.847 ns	77.3	2.09	76.2	2.90	1.893 ns	8.8	4.47	11.0	4.84	-2.229 *	12.0	3.96	10.5	4.55	1.632 ns
14	49.8	4.41	45.6	4.34	4.229 **	77.0	2.03	77.4	2.80	-0.536 ns	7.2	3.35	11.3	4.59	-4.515 **	11.0	4.91	10.8	4.98	0.155 ns
15	50.7	4.33	45.8	4.61	3.639 **	76.7	2.30	77.3	3.87	-0.935 ns	7.6	3.91	10.3	4.15	-2.216 *	13.9	4.19	9.4	3.70	4.996 **
16	51.5	3.81	45.7	3.64	6.919 **	76.9	2.71	77.7	3.79	-1.154 ns	7.4	4.35	11.0	3.97	-3.876 **	13.7	3.74	11.8	4.75	2.085 *
17	50.3	4.49	45.8	3.50	5.228 **	77.5	2.67	77.2	3.58	0.454 ns	7.9	3.94	9.8	3.84	-2.311 *	12.1	4.40	10.9	4.52	1.283 ns
18	51.5	5.43	45.0	3.63	6.698 **						8.6	4.47	9.7	4.30	-1.196 ns					

Group	Relative foot girth					Foot index					Relative toe length					Foot breadth index				
	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
3	105.0	4.82	105.3	5.45	-0.242 ns	42.0	1.92	41.70	2.27	0.590 ns	27.7	2.10	28.1	2.47	-0.722 ns	65.8	4.73	64.4	3.83	1.378 ns
4	102.6	3.90	102.6	3.76	0.000 ns	41.7	1.71	41.60	1.46	0.282 ns	27.2	2.20	28.2	2.58	-1.914 ns	63.7	3.43	63.2	2.65	0.727 ns
5	102.9	4.05	102.0	4.87	0.949 ns	41.7	1.95	41.50	2.18	0.454 ns	27.5	1.99	27.5	2.01	0.000 ns	63.7	3.24	63.0	3.58	0.952 ns
6	103.0	4.57	100.0	4.63	3.451 **	41.6	1.80	40.10	2.13	4.031 **	27.6	2.04	27.8	2.12	-0.509 ns	63.5	2.92	63.1	3.15	0.697 ns
7	100.2	3.68	97.8	3.47	3.551 **	40.7	1.75	39.80	1.86	2.637 **	27.3	1.78	27.3	1.85	0.000 ns	64.1	3.18	62.4	6.20	1.826 ns
8	100.4	3.79	97.9	3.61	3.618 **	40.7	1.66	39.90	1.54	2.675 **	26.3	1.77	26.9	1.55	-1.930 ns	63.8	2.70	63.6	3.28	0.358 ns
9	99.0	4.83	97.5	3.84	1.859 ns	40.3	1.97	39.70	1.56	1.826 ns	26.0	1.53	26.6	1.33	-2.267 *	63.5	3.33	63.8	3.34	-0.488 ns
10	98.0	4.08	97.3	3.97	0.976 ns	39.8	1.69	39.90	1.61	-0.340 ns	26.2	1.71	26.3	1.52	-0.348 ns	63.8	3.15	62.8	3.08	1.801 ns
11	97.4	3.59	96.9	3.71	0.771 ns	39.6	1.80	39.90	1.56	-0.712 ns	26.4	1.57	27.2	1.73	-2.732 **	65.4	3.55	63.1	3.36	3.738 **
12	97.3	4.38	95.9	3.52	1.992 *	39.9	1.79	39.30	1.66	1.960 ns	26.4	1.49	27.3	1.36	-3.559 **	65.0	3.28	64.0	2.97	1.803 ns
13	98.6	3.92	97.5	4.43	1.291 ns	40.6	1.51	40.30	2.01	0.834 ns	27.3	1.79	27.5	2.05	-0.510 ns	63.9	3.26	63.3	3.16	0.911 ns
14	97.2	3.82	96.4	3.54	0.959 ns	40.0	1.90	39.50	1.69	1.222 ns	27.3	1.60	27.5	2.23	-0.444 ns	64.7	1.95	64.7	3.14	0.000 ns
15	99.1	2.60	97.6	3.18	1.702 ns	40.3	1.37	39.60	1.29	1.760 ns	27.4	1.21	27.9	1.28	-1.334 ns	64.6	3.01	64.0	2.40	0.744 ns
16	98.4	4.04	97.5	2.83	1.149 ns	40.6	1.70	40.30	1.43	0.850 ns	27.8	1.24	28.2	1.47	-1.306 ns	63.5	3.06	64.6	3.44	-1.500 ns
17	98.6	3.38	98.4	4.60	0.235 ns	40.6	1.49	40.50	1.87	0.280 ns	27.8	1.56	28.1	2.41	-0.704 ns	63.5	4.14	64.0	3.14	-0.636 ns
18	99.0	4.19	97.9	4.05	1.273 ns	40.7	1.64	40.20	1.89	0.349 ns	27.0	1.59	28.4	2.40	-3.287 **	63.7	3.25	64.7	3.54	-1.404 ns

ns: not significant, *significant at the 5% level, ** significant at the 1% level.

Table 2 (continued)

Ball flex index					Posterior flexion angle (deg.)					Anterior flexion angle (deg.)					IMB (deg.)					
Group	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
3	87.9	3.43	87.5	4.29	0.424 ns	9.23	3.30	7.95	3.61	1.538 ns	7.40	2.91	8.14	3.69	-0.917 ns	7.49	2.50	6.56	2.42	1.583 ns
4	87.2	2.90	87.6	2.34	-0.678 ns	8.67	3.32	6.76	4.25	2.313 *	8.48	3.26	8.26	3.32	0.304 ns	6.60	2.41	5.33	2.89	2.274 *
5	87.3	2.51	87.9	2.89	-1.046 ns	8.30	3.91	7.61	3.75	0.849 ns	9.07	3.84	9.42	3.24	-0.464 ns	6.26	2.84	5.54	2.93	1.293 ns
6	87.7	3.30	87.4	2.61	0.532 ns	7.85	3.76	8.84	4.23	-1.310 ns	9.26	2.48	9.73	3.31	-0.852 ns	5.15	2.50	5.88	2.77	-1.465 ns
7	87.7	2.80	88.4	3.30	-1.210 ns	8.57	3.41	7.52	3.91	1.515 ns	9.08	2.75	9.40	3.53	-0.535 ns	5.90	2.65	4.86	2.41	2.173 *
8	87.2	2.67	87.0	3.09	0.372 ns	8.07	4.09	8.58	4.00	-0.676 ns	9.61	2.71	8.70	2.80	1.771 ns	5.49	2.58	5.89	2.30	-0.876 ns
9	87.4	2.88	87.6	2.64	-0.392 ns	8.33	3.69	7.50	4.30	1.127 ns	9.38	2.68	9.42	2.43	-0.085 ns	5.73	2.54	4.97	2.62	1.600 ns
10	87.8	2.99	87.0	2.13	1.742 ns	8.11	4.41	8.54	4.10	-0.567 ns	9.25	2.76	9.26	3.14	-0.019 ns	5.51	2.50	5.61	2.77	-0.212 ns
11	87.5	3.00	87.2	2.39	0.618 ns	8.58	4.03	7.60	4.37	1.315 ns	8.85	3.07	8.61	2.83	0.456 ns	6.16	2.95	4.75	2.32	2.970 **
12	87.2	2.45	88.0	2.88	-1.679 ns	9.06	4.31	8.14	4.56	1.166 ns	9.81	3.36	7.85	2.71	3.631 **	6.67	2.68	5.71	2.64	2.033 *
13	86.8	2.73	87.6	3.23	-1.315 ns	9.84	4.16	9.16	4.75	0.748 ns	10.38	3.05	9.31	2.47	1.866 ns	7.12	2.81	5.86	2.53	2.291 *
14	88.0	1.94	87.0	2.64	1.860 ns	8.64	4.24	10.22	3.96	-1.700 ns	10.26	3.44	9.25	2.73	1.445 ns	6.62	2.81	7.00	2.73	-0.605 ns
15	87.7	2.05	88.1	2.38	-0.595 ns	8.64	3.17	9.10	4.72	-0.373 ns	9.28	2.75	8.64	2.76	0.774 ns	6.01	2.43	5.38	2.58	0.835 ns
16	87.3	2.20	87.7	3.85	-0.565 ns	9.04	4.25	9.20	3.91	-0.174 ns	10.44	2.84	8.94	2.97	2.293 *	6.27	2.55	6.04	2.10	0.438 ns
17	87.4	2.55	88.0	3.48	-0.934 ns	8.30	3.53	8.64	3.43	-0.460 ns	10.67	2.29	10.04	3.09	1.100 ns	5.90	2.58	5.40	2.05	1.004 ns
18	87.2	4.71	87.5	3.41	-0.347 ns	8.06	4.19	9.07	3.55	-1.239 ns	8.90	2.8	9.89	3.33	-1.536 ns	5.75	2.64	5.62	2.25	0.253 ns

Height (cm)					Weight (kg)					
Group	Male		Female		Sex dif. t-test	Male		Female		Sex dif. t-test
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
3	96.6	4.062	94.4	4.33	2.181 *	15.3	1.93	14.7	1.69	1.394 ns
4	103.6	3.777	101.6	4.72	2.157 *	16.8	1.76	16.1	1.93	1.731 ns
5	108.9	5.276	107.2	4.86	1.580 ns	19.2	3.52	18.5	3.19	0.982 ns
6	115.2	5.639	115.0	4.12	0.214 ns	21.2	4.15	21.0	3.11	0.288 ns
7	121.2	5.212	121.3	4.95	-0.104 ns	23.5	4.10	23.1	3.38	0.563 ns
8	127.0	5.832	125.1	5.23	1.836 ns	27.2	6.53	25.9	5.53	1.149 ns
9	130.8	6.002	130.6	5.32	0.191 ns	29.9	6.72	28.0	4.41	1.802 ns
10	136.6	5.382	137.1	5.46	-0.517 ns	32.6	6.21	33.1	6.90	-0.426 ns
11	139.9	6.573	146.3	6.19	-5.630 **	34.9	6.96	39.0	7.76	-3.139 **
12	147.4	7.821	149.3	5.74	-1.569 ns	40.2	9.33	39.7	5.45	0.372 ns
13	155.1	7.263	154.7	5.19	0.305 ns	47.3	7.61	46.4	7.53	0.580 ns
14	165.4	5.499	166.7	6.10	6.569 **	53.5	7.84	47.4	6.76	3.691 **
15	164.9	5.142	158.4	5.67	3.981 **	53.7	7.00	47.6	6.12	3.117 **
16	169.6	4.541	157.1	3.81	13.267 **	59.4	7.82	50.0	4.45	6.587 **
17	170.4	5.364	158.7	4.51	11.065 **	61.3	7.19	51.1	5.33	7.528 **
18	171.1	4.959	157.2	4.53	13.952 **	62.4	8.38	50.5	5.27	8.088 **

ns: not significant, *:significant at the 5% level, **:significant at the 1% level.

ns: not significant, *significant at the 5% level, **significant at the 1% level.

In foot breadth index and IMB in both sexes and girls' AFA, the differences between age groups were significant, but did not show any age-related tendency.

Boys are significantly taller and heavier than girls for age groups 14 and over, and larger in most of the foot dimensions for age groups 12 and over. Sex differences were not significant in ball flex angle, foot breadth index, ball flex index, PFA, AFA, and IMB for most of the age groups. Toe I angle was larger in girls for age groups 7-17. Boys tend to have larger relative foot girth and foot index, but the difference was significant at the 1% level only in age groups 6-8. Girls tend to have larger relative toe lengths, but the difference was significant in only several age groups.

Inter-generation differences

Table 3 shows the basic statistics by sex and age group and the results of the t-test for sex difference together with the results of ANOVA for the means of the different age groups. Since the mean fibular sphyrion height is consistently smaller in the JLIA series than in the IPRI series, and female subjects from the JLIA series had consistently longer toe lengths than the female subjects from the IPRI series, the inter-observer measurement errors in locating sphyrion fibulare and metatarsale tibiale may not be negligible. Therefore, tests for the means were conducted using two sets of data; one consisting of six age groups from the JLIA series, and the other consisting of four age groups from the IPRI and Ibaraki series.

There are some contradictions between the results from the JLIA and IPRI series, probably due mainly to measurement errors, and the results of the t-test for sex difference may be different for age groups. However, the following findings are observed in many age groups of both data series: Males have larger mean foot dimensions than females. Sex difference was not significant in toe V angle, relative foot girth, foot breadth index, PFA, and IMB. Females have larger toe I angles than males.

Length measurements are larger for younger generations except toe length. Foot girth, foot breadth, and heel breadth are smaller in younger generation females, but such a tendency was not observed for the males. Younger generations tended to have a smaller relative foot girth and foot index. The generation difference was not significant in foot breadth index, relative toe length, PFA in both sexes, male toe I angle, and female toe V angle. The female toe I angle was smaller in the age groups 50-59 and 60+, while the male toe V angle was larger in the age groups of the Ibaraki and Veteran series. Anterior flexion angle was larger in the elderly groups of both sexes. The inter-generation difference in IMB was significant at the 5% level in the JLIA series females and the IPRI and Ibaraki series males, but the difference seems not to be related to aging.

Since longer feet tend to be relatively narrower (Kouchi and Yamazaki, 1992), the relatively narrower feet of the younger generations could be due to the larger foot length. Figures 3 to 5 show the relation between foot length and foot girth, foot breadth, and heel breadth by age group, respectively based on the subjects shown in Table 1c. These figures indicate that the younger generations have a smaller foot girth (Figure 3), foot breadth

Table 3 Basic statistics of measurement items for Japanese adults by age group

Age (years)								Foot length (mm)							
Age group	Male			Female			Sex dif. t-test	Male			Female			Sex dif. t-test	
	N	Mean	S.D.	N	Mean	S.D.		N	Mean	S.D.	N	Mean	S.D.		
18-19 (JLIA)	67	18.690	0.58	82	18.928	0.67	-2.290 *	67	253.0	10.46	82	229.5	8.00	15.534 **	
20-24 (JLIA)	89	22.183	1.44	118	22.236	1.61	-0.245 ns	89	250.8	10.15	118	230.0	9.38	15.245 **	
25-29 (JLIA)	93	27.704	1.60	57	27.115	1.65	2.163 *	93	249.2	10.33	57	227.3	7.88	13.736 **	
30-39 (JLIA)	156	33.240	2.48	125	33.918	2.61	-2.225 *	156	249.2	10.13	125	226.7	9.11	19.343 **	
40-49 (JLIA)	82	45.883	2.29	56	45.109	2.86	1.761 ns	82	244.0	9.83	56	225.7	7.97	11.570 **	
50-59 (JLIA)	58	54.595	2.44	54	53.442	1.98	2.734 **	58	243.7	9.77	54	225.3	9.15	10.268 **	
F-test								F=9.753 **			F=4.117 **				
18-19 (IPRI)	49	19.231	0.49	85	19.070	0.49	1.832 ns	49	256.2	11.34	85	232.5	10.62	12.136 **	
20-24 (IPRI)	115	21.935	1.45	80	21.514	1.28	2.091 *	115	254.9	10.97	80	234.3	8.18	14.259 **	
25-29 (IPRI)	53	27.530	1.58	34	27.484	1.56	0.193 ns	53	249.7	9.50	34	232.5	10.64	7.861 **	
60+ (Ibaraki)	61	73.569	6.05	53	70.088	5.66	3.157 **	61	241.1	9.99	53	227.2	9.67	7.521 **	
F-test								F=27.032 **			F=5.928 **				
60+ (Veterans)	27	66.34	3.40					27	251.9	10.35					

Instep length (mm)								Fibular instep length (mm)							
Age group	Male			Female			Sex dif. t-test	Male			Female			Sex dif. t-test	
	N	Mean	S.D.	N	Mean	S.D.		N	Mean	S.D.	N	Mean	S.D.		
18-19 (JLIA)	65	184.9	9.70	82	165.4	7.49	13.755 **	66	161.9	8.13	82	145.5	6.60	13.547 **	
20-24 (JLIA)	89	183.3	7.60	117	167.6	7.37	14.943 **	89	161.3	6.86	117	146.6	7.16	14.862 **	
25-29 (JLIA)	93	181.9	8.53	57	165.4	6.67	12.451 **	93	159.6	7.04	57	145.2	5.97	12.862 **	
30-39 (JLIA)	156	181.7	7.95	125	166.2	6.95	17.166 **	156	158.7	7.28	125	144.9	6.79	16.268 **	
40-49 (JLIA)	81	177.8	8.12	55	164.2	6.07	10.572 **	81	154.6	7.45	55	142.9	5.97	9.716 **	
50-59 (JLIA)	57	177.2	8.00	54	164.5	6.93	8.913 **	58	153.7	7.44	54	142.6	7.08	8.075 **	
F-test	F=9.350 **			F=2.547 *				F=15.574 **			F=3.875 **				
18-19 (IPRI)	49	187.0	8.30	85	171.5	8.26	10.443 **	49	165.2	6.97	85	148.8	7.79	12.187 **	
20-24 (IPRI)	115	186.4	8.67	80	172.8	6.37	11.960 **	115	164.0	7.83	80	149.2	5.52	14.569 **	
25-29 (IPRI)	53	182.6	7.01	34	171.5	7.69	6.938 **	53	159.3	6.71	34	148.0	7.81	7.185 **	
60+ (Ibaraki)	61	177.0	8.34	53	166.9	7.14	6.891 **	61	151.5	7.66	53	141.5	7.46	7.037 **	
F-test	F=20.547 **			F=7.189 **				F=45.114 **			F=14.989 **				
60+ (Veterans)	27	182.50	7.46					27	158.30	6.95					

Toe length (mm)								Foot girth (mm)							
Age group	Male			Female			Sex dif. t-test	Male			Female			Sex dif. t-test	
	N	Mean	S.D.	N	Mean	S.D.		N	Mean	S.D.	N	Mean	S.D.		
18-19 (JLIA)	65	68.1	5.30	82	64.1	5.17	4.607 **	67	249.9	12.57	82	224.1	10.90	13.900 **	
20-24 (JLIA)	89	67.5	6.63	117	62.5	4.58	6.396 **	89	247.5	10.36	118	225.3	10.12	15.467 **	
25-29 (JLIA)	93	67.3	4.39	57	62.0	4.24	7.270 **	93	248.2	11.34	57	224.4	9.01	13.450 **	
30-39 (JLIA)	156	67.5	4.81	125	60.5	4.57	12.394 **	156	250.8	10.60	125	227.5	9.91	18.846 **	
40-49 (JLIA)	81	66.1	4.00	55	61.6	4.31	6.240 **	82	249.8	10.22	56	228.0	9.13	12.840 **	
50-59 (JLIA)	57	66.4	5.61	54	60.8	4.37	5.845 **	58	248.6	10.48	54	228.2	8.34	11.345 **	
F-test	F=1.607 ns			F=7.307 **				F=1.439 ns			F=2.549 *				
18-19 (IPRI)	49	69.2	5.74	85	60.9	4.52	9.258 **	49	251.5	12.01	85	231.2	11.62	9.621 **	
20-24 (IPRI)	115	68.5	4.73	80	61.4	3.75	11.197 **	115	250.6	12.65	80	232.7	9.01	10.878 **	
25-29 (IPRI)	53	67.1	5.19	34	60.9	4.71	5.633 **	53	245.5	10.21	34	232.0	9.83	6.105 **	
60+ (Ibaraki)	61	64.2	5.57	53	60.2	4.26	4.256 **	61	248.4	12.24	53	236.0	12.47	5.348 **	
F-test	F=11.515 **			F=0.842 ns				F=2.828 *			F=2.215 ns				
60+ (Veterans)	27	69.40	3.84					27	250.7	10.50					

Foot breadth (mm)								Heel breadth (mm)							
Age group	Male			Female			Sex dif. t-test	Male			Female			Sex dif. t-test	
	N	Mean	S.D.	N	Mean	S.D.		N	Mean	S.D.	N	Mean	S.D.		
18-19 (JLIA)	67	102.7	4.94	82	92.1	4.74	13.324 **	67	65.7	4.30	82	58.9	3.06	11.254 **	
20-24 (JLIA)	89	101.6	3.97	118	93.0	4.41	14.493 **	89	65.9	3.74	118	59.6	3.47	12.505 **	
25-29 (JLIA)	93	101.2	5.15	57	91.6	4.22	11.842 **	93	65.1	4.09	57	59.2	3.36	9.157 **	
30-39 (JLIA)	156	102.4	4.59	125	92.7	4.62	17.553 **	156	65.3	3.77	125	58.8	3.73	14.431 **	
40-49 (JLIA)	82	102.2	4.73	56	94.1	4.03	10.476 **	82	65.7	3.93	56	60.6	3.59	7.750 **	
50-59 (JLIA)	58	102.1	4.58	54	94.7	3.61	9.450 **	58	65.4	3.20	54	60.5	3.02	8.320 **	
F-test	F=1.249 ns			F=4.328 **				F=0.583 ns			F=3.734 **				
18-19 (IPRI)	49	101.5	5.20	85	94.9	5.02	7.234 **	49	63.2	3.93	85	60.4	3.59	4.199 **	
20-24 (IPRI)	115	100.9	5.69	80	95.7	3.99	7.054 **	115	64.4	3.92	80	61.2	2.74	6.306 **	
25-29 (IPRI)	53	99.6	4.61	34	95.4	4.27	4.266 **	53	63.2	2.89	34	61.0	3.20	3.322 **	
60+ (Ibaraki)	61	101.3	5.45	53	98.6	5.67	2.589 **	61	63.6	3.39	53	62.5	3.78	1.638 ns	
F-test	F=1.260 ns			F=6.911 **				F=1.923 ns			F=4.383 **				
60+ (Veterans)	27	103.8	5.39					27	66.9	3.44					

Table 3 (continued)

Fibular sphyrion height (mm)								Ball angle (deg.)							
age group	Male			Female			Sex dif.	N	Male			Female			Sex dif.
	N	Mean	S.D.	N	Mean	S.D.	t-test		Mean	S.D.	N	Mean	S.D.	t-test	
18-19 (JLIA)	67	51.5	5.07	82	45.3	3.40	8.896 **	67	77.3	2.53	82	77.6	3.40	-0.599 ns	
20-24 (JLIA)	89	50.6	4.41	118	45.7	3.54	8.865 **	89	77.6	2.57	118	76.8	2.79	2.112 *	
25-29 (JLIA)	93	51.3	3.79	57	46.0	3.74	8.355 **	93	77.4	2.71	57	77.4	2.82	0.000 ns	
30-39 (JLIA)	156	50.9	4.37	125	46.4	4.28	8.657 **	156	77.1	2.88	125	76.7	2.81	1.170 ns	
40-49 (JLIA)	82	50.5	4.10	56	45.0	3.21	8.426 **	82	76.9	2.44	56	76.9	2.55	0.000 ns	
50-59 (JLIA)	58	49.8	4.94	54	45.0	3.77	5.749 **	58	77.1	3.24	54	76.5	2.04	1.163 ns	
F-test	F=1.316 ns			F=1.845 ns				F=0.616 ns			F=1.712 ns				
18-19 (IPRI)	48	55.6	4.41	84	51.8	3.95	5.095 **	49	77.6	2.79	85	76.2	2.60	2.923 **	
20-24 (IPRI)	114	54.7	4.51	80	51.0	4.21	5.780 **	115	77.4	2.56	80	75.9	2.38	4.141 **	
25-29 (IPRI)	53	53.9	4.65	34	50.5	3.30	3.704 **	53	76.6	2.53	34	75.8	2.44	1.459 ns	
60+ (Ibaraki)	47	52.2	4.43	42	50.2	3.74	2.286 *	61	75.6	3.04	53	75.3	2.21	0.595 ns	
F-test	F=5.245 **			F=1.799 ns				F=7.867 **			F=1.483 ns				
60+ (Veterans)	0							27	76.5	1.38					

Toe I angle (deg.)								Toe V angle (deg.)							
age group	Male			Female			Sex dif.	N	Male			Female			Sex dif.
	N	Mean	S.D.	N	Mean	S.D.	t-test		Mean	S.D.	N	Mean	S.D.	t-test	
18-19 (JLIA)	67	8.4	4.16	82	10.8	4.66	-3.280 **	67	12.7	4.50	82	11.7	4.48	1.353 ns	
20-24 (JLIA)	89	8.6	4.38	118	11.2	4.74	-4.035 **	89	13.4	3.68	118	12.3	4.48	1.885 ns	
25-29 (JLIA)	93	7.7	4.47	57	10.1	5.10	-3.024 **	93	13.5	5.20	57	11.1	4.44	2.960 **	
30-39 (JLIA)	156	7.9	4.24	125	10.9	4.81	-5.551 **	156	14.9	4.59	125	11.9	4.53	5.476 **	
40-49 (JLIA)	82	7.9	4.12	56	12.8	4.92	-6.336 **	82	13.9	4.60	56	12.4	4.85	1.840 ns	
50-59 (JLIA)	58	8.3	4.30	54	9.0	4.35	-0.856 ns	58	13.9	4.03	54	13.7	4.81	0.239 ns	
F-test	F=0.605 ns			F=3.872 **				F=2.859 *			F=2.203 ns				
18-19 (IPRI)	49	9.1	4.55	85	12.3	4.53	-3.932 **	49	12.7	4.44	85	11.7	4.31	1.279 ns	
20-24 (IPRI)	115	8.6	4.65	80	11.4	4.20	-4.301 **	115	12.4	4.43	80	11.7	4.56	1.072 ns	
25-29 (IPRI)	53	8.3	4.69	34	10.6	3.91	-2.377 *	53	12.3	3.89	34	12.0	4.52	0.329 ns	
60+ (Ibaraki)	61	7.9	6.45	53	8.3	5.27	-0.359 ns	61	14.8	5.13	53	14.0	4.89	0.849 ns	
F-test	F=0.526 ns			F=8.810 **				F=4.403 **			F=3.510 *				
60+ (Veterans)	27	9.6	5.25					27	16.0	4.36					

Relative foot girth								Foot index							
age group	Male			Female			Sex dif.	N	Male			Female			Sex dif.
	N	Mean	S.D.	N	Mean	S.D.	t-test		Mean	S.D.	N	Mean	S.D.	t-test	
18-19 (JLIA)	67	98.8	3.93	82	97.7	4.02	1.678 ns	67	40.6	1.55	82	40.1	1.84	1.769 ns	
20-24 (JLIA)	89	98.7	2.88	118	98.0	4.00	1.400 ns	89	40.5	1.27	118	40.4	1.61	0.483 ns	
25-29 (JLIA)	93	99.6	3.90	57	98.8	3.42	1.276 ns	93	40.6	1.87	57	40.3	1.59	1.008 ns	
30-39 (JLIA)	156	100.7	3.84	125	100.4	4.33	0.615 ns	156	41.1	1.65	125	40.9	1.90	0.944 ns	
40-49 (JLIA)	82	102.5	3.59	56	101.1	3.94	2.162 *	82	41.9	1.38	56	41.7	1.55	0.795 ns	
50-59 (JLIA)	58	102.1	3.75	54	101.4	4.13	0.940 ns	58	41.9	1.59	54	42.1	1.67	-0.649 ns	
F-test	F=14.906 **			F=12.245 **				F=12.411 **			F=13.573 **				
18-19 (IPRI)	49	98.2	3.88	85	99.5	3.86	-1.874 ns	49	39.6	1.66	85	40.9	1.80	-4.141 **	
20-24 (IPRI)	115	98.3	3.10	80	99.4	3.33	-2.364 *	115	39.6	1.49	80	40.9	1.47	-6.026 **	
25-29 (IPRI)	53	98.4	3.84	34	99.9	4.66	-1.634 ns	53	39.9	1.71	34	41.1	1.89	-3.065 **	
60+ (Ibaraki)	61	103.0	3.95	53	104.0	5.02	-1.189 ns	61	42.0	2.01	53	43.4	2.38	-3.405 **	
F-test	F=27.561 **			F=16.484 **				F=31.006 **			F=26.245 **				
60+ (Veterans)	27	99.6	4.19					27	41.3	2.09					

Relative toe length								Foot breadth index							
age group	Male			Female			Sex dif.	N	Male			Female			Sex dif.
	N	Mean	S.D.	N	Mean	S.D.	t-test		Mean	S.D.	N	Mean	S.D.	t-test	
18-19 (JLIA)	65	26.9	1.95	82	27.9	2.06	-2.993 **	67	64.0	3.63	82	64.0	3.70	0.000 ns	
20-24 (JLIA)	89	26.9	2.15	117	27.2	1.54	-1.167 ns	89	64.8	3.17	118	64.1	3.66	1.442 ns	
25-29 (JLIA)	93	27.0	1.43	57	27.3	1.57	-1.201 ns	93	64.4	3.47	57	64.7	3.43	-0.516 ns	
30-39 (JLIA)	156	27.1	1.49	125	26.7	1.55	2.197 *	156	63.8	2.88	125	63.4	3.46	1.057 ns	
40-49 (JLIA)	81	27.1	1.32	55	27.3	1.45	-0.833 ns	82	64.3	3.36	56	64.4	3.67	-0.165 ns	
50-59 (JLIA)	57	27.2	1.88	54	27.0	1.42	0.630 ns	58	64.1	3.24	54	63.9	2.83	0.347 ns	
F-test	F=0.415 ns			F=6.234 **				F=1.230 ns			F=1.278 ns				
18-19 (IPRI)	49	27.0	1.62	85	26.2	1.44	2.958 **	49	62.3	2.93	85	63.7	3.02	-2.613 *	
20-24 (IPRI)	115	26.9	1.41	80	26.2	1.20	3.620 **	115	63.8	3.06	80	64.0	2.59	-0.478 ns	
25-29 (IPRI)	53	26.9	1.54	34	26.2	1.35	2.168 *	53	63.5	2.70	34	64.0	2.87	-0.822 ns	
60+ (Ibaraki)	61	26.6	1.93	53	26.5	1.31	0.319 ns	61	62.8	3.07	53	63.5	3.05	-1.218 ns	
F-test	F=0.595 ns			F=0.666 ns				F=3.519 *			F=0.421 ns				
60+ (Veterans)	27	27.5	0.86					27	64.5	3.04					

Table 3 (continued)

Ball flex index								Foot axis index								
age group	Male			Female			Sex dif. t-test	N	Male			N	Female			Sex dif. t-test
	N	Mean	S.D.	N	Mean	S.D.			N	Mean	S.D.		N	Mean	S.D.	
18-19 (JLIA)	64	87.7	2.57	82	88.1	3.24	-0.809 ns									
20-24 (JLIA)	89	88.0	2.31	117	87.5	2.56	1.448 ns									
25-29 (JLIA)	93	87.8	2.49	57	87.8	2.91	0.000 ns									
30-39 (JLIA)	156	87.4	2.69	125	87.2	2.62	0.627 ns									
40-49 (JLIA)	81	87.0	2.41	55	87.0	2.63	0.000 ns									
50-59 (JLIA)	57	86.7	3.00	54	86.7	2.36	0.000 ns									
F-test	F=2.830 *			F=2.294 *												
18-19 (IPRI)	49	88.4	2.46	85	86.8	2.29	3.791 **		49	86.3	9.92		85	93.4	11.98	-3.511 **
20-24 (IPRI)	115	88.0	2.38	80	86.3	2.29	4.982 **		115	89.6	14.18		80	93.3	13.03	-1.852 ns
25-29 (IPRI)	53	87.3	2.34	34	86.3	2.26	1.971 ns		53	86.8	12.54		34	90.6	14.67	-1.290 ns
60+ (Ibaraki)	61	85.7	2.77	53	87.8	2.33	-4.343 **		61	81.6	14.85		53	83.8	11.39	-0.877 ns
F-test	F=15.297 **			F=8.673 **					F=4.788 **				F=7.722 **			
60+ (Veterans)	27	86.8	1.47						27	80.5	10.72					

Posterior flexion angle (deg.)								Anterior flexion angle (deg.)								
age group	Male			Female			Sex dif. t-test	N	Male			N	Female			Sex dif. t-test
	N	Mean	S.D.	N	Mean	S.D.			N	Mean	S.D.		N	Mean	S.D.	
18-19 (JLIA)	67	8.3	3.97	82	9.00	3.76	-1.102 ns		67	9.3	2.73		82	9.8	3.17	-1.019 ns
20-24 (JLIA)	89	8.1	4.69	118	8.50	3.83	-0.675 ns		89	9.7	2.62		118	9.4	2.69	0.803 ns
25-29 (JLIA)	93	8.5	4.10	57	7.10	4.10	2.030 *		93	10.4	2.89		57	8.7	2.81	3.534 **
30-39 (JLIA)	156	8.7	4.13	125	8.00	3.72	1.475 ns		156	10.9	2.85		125	9.3	2.86	4.669 **
40-49 (JLIA)	82	8.7	3.32	56	8.70	3.43	0.000 ns		82	10.4	3.03		56	10.0	3.00	0.765 ns
50-59 (JLIA)	58	7.8	3.62	54	8.30	2.94	-0.799 ns		58	10.1	2.81		54	10.6	2.65	-0.774 ns
6 groups ANOVA	F=0.599 ns			F=2.210 ns					F=4.031 **				F=2.975 *			
18-19 (IPRI)	49	7.4	3.44	85	8.80	3.52	-2.236 *		49	9.7	2.69		85	8.62	2.55	2.357 *
20-24 (IPRI)	115	7.7	3.95	80	8.12	3.39	-0.736 ns		115	9.6	2.44		80	8.72	2.75	2.404 *
25-29 (IPRI)	53	8.3	3.65	34	7.75	3.17	0.655 ns		53	10.2	2.63		34	9.35	2.99	1.312 ns
60+ (Ibaraki)	61	7.3	3.85	53	7.64	4.18	-0.398 ns		61	13.1	3.25		53	12.17	3.77	1.369 ns
F-test	F=0.746 ns			F=1.397 ns					F=24.926 **				F=18.674 **			
60+ (Veterans)	27	8.40	3.75						27	12.1	2.10					

IMB (deg.)								Height (cm)								
age group	Male			Female			Sex dif. t-test	N	Male			N	Female			Sex dif. t-test
	N	Mean	S.D.	N	Mean	S.D.			N	Mean	S.D.		N	Mean	S.D.	
18-19 (JLIA)	67	5.9	2.41	82	5.7	2.26	0.522 ns		67	171.7	4.89		82	157.4	4.32	18.940 **
20-24 (JLIA)	89	5.6	2.70	118	5.5	2.10	0.300 ns		88	171.9	5.02		117	157.9	4.53	20.905 **
25-29 (JLIA)	93	5.7	2.54	57	4.8	2.48	2.125 *		92	169.8	5.59		57	156.3	3.41	16.426 **
30-39 (JLIA)	156	5.8	2.47	125	4.9	2.49	3.024 **		156	169.9	5.61		125	156.1	4.74	21.934 **
40-49 (JLIA)	82	5.9	1.96	56	5.7	2.00	0.584 ns		82	164.8	5.07		56	153.9	4.66	12.810 **
50-59 (JLIA)	58	5.4	2.42	54	5.8	2.07	-0.937 ns		57	164.4	4.95		54	152.8	5.14	12.112 **
F-test	F=0.519 ns			F=2.743 *					F=29.053 **				F=13.267 **			
18-19 (IPRI)	49	5.30	2.11	85	5.93	1.88	-1.701 ns		49	172.6	5.83		84	158.3	5.68	13.870 **
20-24 (IPRI)	115	5.50	2.23	80	5.39	2.01	0.321 ns		115	172.0	6.39		80	160.1	4.73	14.170 **
25-29 (IPRI)	53	5.80	1.80	34	5.12	2.15	1.639 ns		53	169.0	5.81		34	158.5	5.12	8.607 **
60+ (Ibaraki)	61	4.60	2.38	53	5.25	2.30	-1.591 ns		57	158.4	4.84		51	146.3	5.32	12.377 **
F-test	F=3.282 *			F=1.968 ns					F=77.610 **				F=81.613 **			
60+ (Veterans)	27	5.60	2.04						27	169.5	5.82					

Weight (kg)							
age group	Male			Female			Sex dif. t-test
	N	Mean	S.D.	N	Mean	S.D.	
18-19 (JLIA)	67	62.8	8.28	75	49.6	5.18	11.515 **
20-24 (JLIA)	88	63.0	9.03	104	50.9	6.80	10.575 **
25-29 (JLIA)	92	63.7	9.62	55	50.4	4.56	9.618 **
30-39 (JLIA)	156	65.7	8.79	125	51.8	5.82	15.207 **
40-49 (JLIA)	82	63.2	7.31	56	52.6	5.96	8.997 **
50-59 (JLIA)	56	61.3	6.08	54	51.7	6.00	8.332 **
F-test	F=3.091 **			F=2.341 *			
18-19 (IPRI)	49	64.1	7.65	84	52.7	6.92	8.813 **
20-24 (IPRI)	114	63.5	9.00	80	52.6	5.75	9.547 **
25-29 (IPRI)	53	62.2	7.14	34	52.4	5.86	6.685 **
60+ (Ibaraki)	61	55.9	7.83	53	51.4	8.03	3.024 **
F-test	F=13.460 **			F=0.478 ns			
60+ (Veterans)	27	67.4	6.89				

ns: not significant
*: significant at the 5% level
**: significant at the 1% level

ns: not significant

*: significant at the 5% level

**: significant at the 1% level

(Figure 4), and heel breadth (Figure 5), when foot length is the same. For females, the age group 60+ have much larger means in these three measurements for the same foot length compared to the age groups 30-39, 40-49, and 50-59 of the JLIA series.

These figures also show that the IPRI series females aged 18-29 years have consistently larger mean values in the three measurements than the JLIA series females aged 18-29 years, and that the IPRI series males aged 18-29 years have consistently smaller breadths than the JLIA series males aged 18-29 years. It is not clear if the cause of these differences is a sampling bias or inter-observer measurement errors.

In the cross-sectional data, generation differences included not only changes due to aging, but also the effects of the secular change and sampling error, which can not be separated. Baba (1979) measured 826 males and 1018 females aged 18 to 40 years in 1972-73, and

Figure 3 Relation between foot length and foot girth. 1): Hawes and others (1994); 2): Kusumoto and others (1996); 3): Adachi and others (1993).

Figure 4 Relation between foot length and foot breadth.

Figure 5 Relation between foot length and heel breadth.

calculated the means of foot dimensions by group based on foot length. Figure 3 also shows the foot length and foot girth for Baba's data, in which the definitions of the two measurement items are the same as the present study. The relation between foot length and foot girth in Baba's data is practically the same as that of the age groups 40-49 and 50-59 in the present data. Since the subjects measured by Baba were about 35-60 years in 1987-92, this finding is consistent with the present results. It can be concluded that generation differences observed in the present data are due mainly to the secular change.

Secular change

Figure 6 shows the relation between foot length and the year of birth. The data included data from Japanese Standards Association (JSA) measured in 1978-80 (Japanese Standards Association, 1984), from Hoshi and others in 1977 and 1979 (Hoshi and Kouchi, 1978; Hoshi and others, 1980), from Industrial Arts Institute (IAI) in 1967 (Takeichi and others, 1969), and unpublished data by the present author. The subjects for the unpublished data were the policemen measured in 1976 (Kouchi-76 in Figure 6), and students of a fashion college measured in 1997 (Kouchi-97 in Figure 6). Mean foot length by age group were plotted against approximate year of birth. The methods for measuring foot length are different in the different studies, but when the measurements are taken with the subject standing, the difference in mean foot length obtained from different definitions of the foot axis is as small as 1 mm (National Institute of Bioscience and Human-Technology, 1997), the influence of the difference in measuring methods is expected to be small. The definition of foot length in JSA and Kouchi-97 was the same as the present study, though in JSA it was measured directly using large sliding calipers. Foot length in Hoshi and others (1978, 1980) and in Kouchi-76 was the distance between pternion and acropodion measured directly with spreading calipers. Takeichi and others (1969) measured foot length from pternion to acropodion using a foot measuring plate, and the definition of the foot axis is not described.

Japanese have become taller and to have relatively longer legs in the last 100 years, mainly due to changes in nutritional conditions (Kouchi, 1996). Figure 6 indicates that foot length rapidly increased for those born after ca. 1950. The secular change in height in Japan suddenly slowed down among the generation born after the mid-1960s (Kouchi, 1996), but it seems that the secular change in foot length has not slowed down for this generation.

The male age group 60+ of the Ibaraki series did follow the trend in the secular change, but the age group 60+ from the Veteran series did not, having a mean foot length close to that of the 25-29 age group (Figure 6). The mean height of the Veteran series obtained through self report was also close to that of the 25-29 age group. This fact suggests that the differences between the two series of elderly men were probably of socioeconomic origin.

Ethnic differences

Table 4 shows the results of the ethnic comparison. A statistical test was not made for

Figure 6 Relation between foot length and year of birth.

height and weight because of differences in measurement methods. Figures 3 to 5 also shows the relation between foot length and foot girth, foot breadth, and heel breadth in the ethnic groups other than Japanese.

Australian aborigines and French have larger length measurements and relatively narrower feet than Japanese and Indonesians (Figure 4). Japanese are taller than Indonesians, but the foot dimensions and proportion are similar between the two groups (Figures 3-5). Significant differences between Japanese and Indonesians were observed in toe length and toe V angle for both sexes, relative toe length for males, and relative foot girth and foot breadth index for females. Australian aborigines and French have similar mean values for foot dimensions and indices except male breadth measurements; French males have significantly larger breadths.

As for angles and indices, differences between the four populations were not significant for ball flex angle and ball flex index in both sexes. Toe I angle was significantly smaller in Australian aborigines than the other three groups, between which the difference was not significant. Differences in Toe V angle were not significant between Japanese and French, but Indonesians had smaller toe V angles than Japanese and French, and Australian aborigines had still smaller toe V angles than the Indonesians.

Significant ethnic differences were observed in male PFA and AFA; Australian

Table 4 Comparison of four ethnic groups

Males									
	Japanese (N=478)		Austrian Aborigines (N=33)		French (N=31)		Indonesians (N=50)		
Measurement item	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	F-test
Age (years)	34.9	10.66	-	-	36.4	8.62	33.7	7.76	
Height (cm)	168.7	5.97	-	-	177.1	6.88	162.4	5.76	
Weight (kg)	63.9	8.59	-	-	72.6	11.85	60.3	9.41	
Foot length (mm)	247.9	10.40	259.1	12.47	264.2	10.44	248.6	10.19	33.084 **
Foot girth	249.2	10.66	-	-	255.2	13.99	247.9	10.56	4.965 **
Instep length	180.8	8.32	188.6	9.94	191.3	8.25	179.1	8.09	24.431 **
Fibular instep length	158.2	7.96	164.3	10.86	167.7	8.25	155.9	7.01	20.955 **
Toe length	67.1	5.17	70.5	5.50	72.9	3.83	69.5	4.03	18.203 **
Foot breadth	101.9	4.62	102.8	4.32	105.8	5.92	103.3	5.46	7.194 **
Heel breadth	65.4	3.79	65.9	4.66	68.9	4.51	65.9	3.52	7.708 **
Ball flex angle (deg.)	77.2	2.77	76.1	3.44	77.1	2.11	77.3	2.54	1.586 ns
Toe I angle	8.1	4.29	4.6	11.10	9.6	13.12	6.9	13.12	5.216 **
Toe V angle	14.0	4.52	6.9	4.61	13.9	4.74	11.0	4.95	29.951 **
Relative foot girth	100.6	3.85	-	-	96.6	3.97	99.8	4.41	15.553 **
Foot index	41.1	1.66	39.7	1.84	40.0	1.69	41.6	1.96	12.433 **
Relative toe length	27.1	1.67	27.2	1.65	27.6	1.07	28.0	1.22	5.245 **
Foot breadth index	64.2	3.19	64.2	3.95	65.2	3.74	63.9	3.15	1.053 ns
Ball flex index	87.5	2.92	87.1	3.23	87.7	2.02	87.1	2.49	0.595 ns
Foot axis index	-	-	80.6	11.05	89.3	14.65	87.7	13.20	4.196 *
Posterior flexion angle	8.4	4.05	6.5	3.83	7.6	4.47	7.4	3.99	3.312 *
Anterior flexion angle	10.4	2.87	9.1	3.31	11.1	2.51	9.8	2.78	3.465 *
IMB	5.7	2.44	5.2	2.28	4.8	2.40	5.8	2.34	1.816 ns

Females									
	Japanese (N=410)		Austrian Aborigines (N=32)		French (N=31)		Indonesians (N=32)		
Measurement item	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	F-test
Age (years)	33.7	10.87	-	-	36.9	11.51	32.3	7.68	
Height (cm)	155.9	4.86	-	-	162.2	6.04	152.1	5.37	
Weight (kg)	51.5	5.99	-	-	58.8	4.95	51.9	8.83	
Foot length (mm)	227.4	9.02	238.6	9.77	237.4	10.60	230.0	8.54	24.694 **
Foot girth	226.6	9.61	-	-	219.2	10.53	223.3	10.16	9.521 **
Instep length	165.9	7.28	173.2	7.26	171.6	7.94	166.6	6.84	14.891 **
Fibular instep length	144.8	7.53	150.8	6.87	151.1	6.75	144.6	6.23	12.562 **
Toe length	61.5	4.79	65.5	4.79	65.7	4.54	63.4	2.93	14.375 **
Foot breadth	93.1	4.38	91.1	4.32	91.6	4.61	93.7	5.01	3.261 *
Heel breadth	59.5	3.55	59.4	3.67	60.3	3.44	60.5	3.44	1.150 ns
Ball flex angle (deg.)	76.8	2.68	75.7	3.31	77.0	2.50	76.8	2.68	1.782 ns
Toe I angle	10.9	4.88	2.7	4.78	10.3	4.50	10.1	5.35	27.686 **
Toe V angle	12.2	4.62	5.4	5.11	11.6	4.32	7.4	5.28	29.440 **
Relative foot girth	99.7	4.23	-	-	92.4	3.65	97.1	3.93	47.700 **
Foot index	41.0	1.80	38.2	1.56	38.6	1.48	40.8	1.77	38.629 **
Relative toe length	27.1	1.73	27.4	1.46	27.7	1.30	27.6	0.94	2.469 ns
Foot breadth index	64.0	3.48	65.2	3.16	65.9	3.27	64.6	3.32	3.986 **
Ball flex index	87.3	3.04	87.1	2.93	88.1	2.66	86.9	2.56	0.967 ns
Foot axis index	-	-	82.2	14.02	98.3	16.91	95.4	18.50	8.558 **
Posterior flexion angle	8.2	3.70	7.3	4.85	7.6	3.42	9.4	3.87	1.995 ns
Anterior flexion angle	9.5	2.84	8.8	3.38	10.2	2.36	8.7	3.06	1.876 ns
IMB	5.3	2.28	5.6	2.53	3.7	1.92	6.3	2.84	7.168 **

ns: not significant, *: significant at the 5% level, **: significant at the 1% level

aborigines had a smaller PFA and AFA than the other three groups. For the females, ethnic differences were significant for IMB; French females had a much smaller IMB compared with the other three groups. A much higher percentage of the present French female subjects had a weak development of the medial bulge of the foot outline compared to the other three ethnic groups.

Table 5 shows the results of the test for sex differences in angular measurements, indices and the variables of the medial axis for each ethnic group. Males seem to have larger relative foot girths. Sex difference was small or not significant for ball flex angle, relative toe length, foot breadth index, ball flex index, and PFA. Japanese are similar to Indonesians in having significant sex differences in toe I angle and toe V angle, and not having sex difference in foot index. Males have larger foot index in French and Australian aborigines. Japanese are similar to French in females having a smaller IMB.

Height and foot length

Japanese had a smaller foot length for height compared to Indonesians. Kusumoto and others (1996) studied the foot of Philippine women and reported that Japanese women had a smaller foot length for height. Figure 7 shows the relation between height and foot length for several ethnic groups. The Japanese data are the same with those used for Figure 6. Measurements for other ethnic groups were taken from the literature apart from those in the present data.

The differences in the relation between height and foot length among Japanese subgroups in the present data are negligible. However, the male subgroups for IAI with height shorter than 162 cm (workers in a factory, born before 1932) and female subgroups for IAI (nurses

Table 5 Significance of sex difference for four ethnic groups

Measurement item	Japanese t-test	Austrarian Aborigines t-test	French t-test	Indonesians t-test
Ball flex angle (deg.)	2.060*	0.517ns	0.275ns	0.852ns
Toe I angle	-9.238**	0.878ns	-0.298ns	-2.841**
Toe V angle	5.893**	1.220ns	1.961ns	3.129**
Relative foot girth	0.001**	-	4.333**	2.773**
Relative foot breadth	0.125ns	3.567**	3.533**	1.845ns
Relative toe length	0.166ns	-0.591ns	-0.288ns	1.562ns
Foot breadth index	1.084ns	-1.114ns	-0.722ns	-0.976ns
Ball flex index	0.874ns	0.068ns	-0.651ns	0.336ns
Foot axis index	-	-0.493ns	-2.254*	-1.951ns
Posterior flexion angle (deg.)	1.113ns	-0.668ns	-0.021ns	-2.236*
Anterior flexion angle	4.685**	0.355ns	1.756ns	1.623ns
IMB	2.621**	-0.761ns	2.042*	-0.952ns

ns: not significant, *: significant at the 5% level, **: significant at the 1% level

and workers, born before 1932) and for JSA (general citizens, born before 1935) with height shorter than 152 cm tend to have a larger foot length for their height. Even these subgroups have a smaller foot length for their height compared to the populations from Southeast Asia and Africa. Koreans and Sibos in Xinjiang Uighur Autonomous Region of China are similar to Japanese, or have a rather smaller foot length for their height. Some Caucasoid groups have similar foot length for height to Japanese (Germans, North American white, French), but others have a longer foot length for their height (American Air Force, English women, Czech and Turkish Army personnel). Since most of the American Air Force subjects are Caucasoid (99.3% males and 91.4% females), it is not clear why the two American data do not coincide with each other.

Figure 7 Relation between height and foot length. 1): Hoshi and Kouchi (1978), Hoshi and others (1980); 2): Japan Standards Association (1984); 3): Takeichi and others (1969); 4): Shao and others (1984), Fernandez and others (1989), Korea Research Institute of Standard and Science (1992), Kusumoto and others (1996); 5): Hertzberg and others (1954), Clauser and others (1972), Snow and others (1975), Prokopec (1977), DIN (1978), Redgrove (1979), Kayis and Ozok (1991), Hawes and others (1994); 6): Adachi and others (1993), Musiba and others (1997); 7) Abbie (1975), Prokopec (1977).

Japanese who belong to the subgroups with longer foot lengths for height shown in Figure 7 were born in 1918-35, whose growth was influenced by the second world war (Kouchi, 1996). It is interesting to note that the generations born after ca. 1950 have shorter foot length for their height in spite of the rapid secular change in foot length. It seems that leg bones are more sensitive to the environmental changes than foot bones.

The effects of shoe-wearing habits is another possible reason. However, Australian aborigines who are not in the habit of wearing shoes have a similar foot length for height to Japanese, and a much smaller one than African groups who also do not wear shoes. It seems that both environmental and genetic background influence the small foot length for height in East Asian populations including the Japanese.

Discussion

Outflare of the foot viewed from PFA

Foot flare means medial or lateral deviation of the forepart of the foot in relation to the heel (Freedman and others, 1946). When the forepart of the foot deviates medially, the foot is inflared, and when it deviated laterally, the foot is outflared. Posterior flexion angle represents the foot flare characteristics, which is related to shoe fitting (Rossi and Tennant, 1984).

The present results indicate that most feet are more or less outflared irrespective of age, sex, or ethnic group. Posterior flexion angle has large inter-individual variability, and the differences due to sex (Tables 2, 3, and 5) and generation (Table 3) were not significant. This fact suggests that foot outflare is not easily influenced by environmental factor such as nutritional status.

In the JLIA series, foot outlines were taken with the subject standing with the medial aspects of both feet parallel, while in a natural standing position, most people stand with toes out. Though the difference was small and not significant, JLIA seires young adult males aged 18-29 years have larger PFA than the IPRI series by 0.5 degrees. The difference between the two series was negligible in females. The differences in PFA due to ethnic origin (Table 4) were significant at the 5% level in males, but the difference would be insignificant when the differences in measuring conditions are taken into consideration. The effects of shoe-wearing habits on foot outflare is probably very small.

Pronation of the foot and IMB

IMB represents the amount of medial bulge of foot outline. IMB is related to the pronation of the foot, for it is correlated with the direction of the principal axis of the cross section of the foot at metatarsal and tarsal part and the medial inclination of the heel (Kouchi and Tsutsumi, 1996).

Age groups of 3 years have larger IMB in both sexes (Table 2). Differences between age groups in IMB were not necessarily consistent between males and females (Tables 2 and 3). The ethnic difference was not significant for males, but French females had a significantly smaller IMB (Table 4).

The foot can be intentionally pronated by changing weight distribution and by internal rotation of the lower leg, or by using special insoles, but the changes caused by these factors are temporary, and it is not clear whether changes induced by these factors can become permanent. Foot pronation is also related to the leg-heel alignment. It is not clear from the present materials if the smaller IMB in French females is a characteristics of European females, or is due to sampling bias or intentional training.

The effects of the measurement condition for children's foot outline is not clear, either. Further studies are necessary to clarify if the larger IMB is natural for 3-year-old infants.

Fanning out of the toes

Fanning out of the toes is represented by toe I angle and toe V angle. Toe I angle is related to the valgus deformation of the first toe, and toe V angle to the varus deformation of the fifth toe. They are related to the habit of wearing shoes (Morioka and others, 1974). Anterior flexion angle is highly correlated with toe V angle ($r=0.64$ for males, $r=0.66$ for females).

Toe I angle, toe V angle, and AFA increased during the growth period (Table 2), but changes after the cessation of growth seem to be minimal (Table 3). Ethnic difference was clear in toe I angle and toe V angle: Australian aborigines had the smallest means in both measurements (Table 4). The ethnic difference in AFA was not significant in females probably because the influence of the varus deformation of the fifth toe was canceled out by the valgus deformation of the first toe.

Japanese and Indonesians showed significant sex differences in these measurements (Table 5): toe I angle is larger and toe V angle is smaller in females than in males. Such differences may have resulted from differences in last shape and less toe room for women's shoes. This explanation, however, does not apply to the French, for which the sex difference was significant in neither toe I angle, nor toe V angle. Toe angles of lasts are larger in wider lasts (Kouchi and Yamazaki, 1992). The wider feet of Japanese and Indonesians compared to French (Table 4) may be responsible for the difference between French on one hand and Japanese and Indonesian on the other hand.

Feet of elderly persons

Feet of Japanese aged 40 years and over (born before ca, 1950) were wider compared to the young adults. Figure 3 suggests the possibility that the elderly persons born before the mid-1930s may have extremely wide feet. Also, the females of age groups 50-59 and 60+ had a significantly smaller toe I angle than those in the younger groups. These findings suggest that the foot morphology of the elderly females may be considerably different from that of the younger generation. If so, special attention should be paid to the toe shapes in designing lasts for the elderly women. Special care may be also necessary in planning the production of shoes for elderly persons.

The present female subjects of the Ibaraki series may be biased, for they have larger foot length than the JLIA series subjects of younger age groups. Also they may have larger

girth and breadths due to inter-observer measurement errors as suggested by the consistent differences between the IPRI series females aged 18-29 years and the JLIA series females aged 18-29 years (Figures 3-5). Further studies based on larger samples are necessary to confirm the present results.

The present results indicate that the secular change in foot length accelerated for those born after ca. 1950. When the people born after 1950 become 60 years old, the variation in the foot size and shape of elderly persons will be much larger than at present.

The Japanese foot

The Japanese foot is more similar to that of Indonesians than to Caucasoid or Australoid populations. Baba studied the foot dimensions of Japanese and French males, and stated that French males had a much smaller foot girth and foot breadth (Baba, 1975). According to Hawes and others who compared foot dimensions and shape of North American white male runners on the one hand and Japanese and Korean male runners on the other hand (Hawes and others, 1994), North American males have a smaller foot girth and foot breadth for foot length, but the differences between the two groups were smaller than those indicated by Baba.

Figure 3 also shows the relation between foot length and foot girth for the ethnic groups other than Japanese. It shows that differences between Japanese young adult males and North American white males are small for foot length smaller than 255 mm, while Japanese males with a foot length of 255 mm or longer have a larger foot girth. Since Hawes and others measured the foot in a full weight bearing position, differences in foot girth between their data and the present data may be underestimated in Figure 3.

The differences between the findings of Hawes and others and Baba is partly due to the secular change that occurred during the 20 years between 1972-1973 (Baba) and the early 1990s (Hawes and others). Hawes and others stated that foot girth for the French males in Baba's study was extremely small, and suggested the differences in the measurement conditions, that is, the subjects were sitting rather than standing.

The relation between foot length and foot girth in the female populations from southeast Asia and Africa is similar to that in the present young adult females from the JLIA series, but French females had a extremely small foot girth for the same foot length. It is not known whether this is a characteristics of European females or is rather caused by sampling bias, due to a lack of other comparative European materials.

Acknowledgments

The author express her sincere gratitude to all the participants. The author is indebted to emeritus Professor Shiro Kondo of Kyoto University and the project members of the Research and Development on Foot Studies by Japan Leather and Leather-Good Industries Association for their cooperation, Professor Shuzo Koyama of National Museum of Ethnology for his help in the research in Australia, Mr. Idris Jufri of Indonesia Export Training Center and Mr. Yoshimasa Sano of Industrial Product Research Institute for their

help in the research in Indonesia, and Professor John Seal of Cognitive Neuroscience Laboratory and Dr. Motoyuki Akamatsu of Industrial Product Research Institute for their help in the research in France. Research in Australia was supported by a Grant-in-aid from the Ministry of Education, Science, and Culture of Japan titled "Anthropological studies on Australian aboriginal society" headed by Professor Shuzo Koyama.

REFERENCES

- Abbie A.A. (1975) Studies in Physical Anthropology, volume II. Australian Institute of Aboriginal Studies.
- Adachi K., Kusumoto A., Kawada J., and Hosaka M. (1993) Anthropometric study of some West-African ethnic groups in relation to techniques of the body. *African Studies*, vol. 43, pp. 1-30.
- Baba K. (1975) Foot measurement for shoe construction with reference to the relationship between foot length, foot breadth, and ball girth, *Journal of Human Ergology*, vol. 3, pp. 149-156.
- Baba K. (1979) Statistical studies on the foot patterns of Japanese. *The Journal of the Kurume Medical Association*, vol. 42, pp. 505-558 (in Japanese with English abstract).
- Bookstein, F.R. (1991) *Morphometric Tools for Landmark Data*. Cambridge University Press, Cambridge.
- Clauser C.E., Tucker P.E., McConville J.T., Churchill E., Laubach L.L., and Reardon J.A. (1972) Anthropometry of Air Force Women, AMRL-TR-70-5, Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.
- Deutsches Institute für Normung (1978) *Deutsche Normen*, DIN 33402 Körpermasse de Menschen. vol. 2.
- Fernandez J.E., Malzahn D., Eyada O.K., and Kim D.H. (1989) Anthropometry of Korean female industrial workers. *Ergonomics*, vol. 32, pp. 491-495.
- Freedman, A., Huntington, E.C., Davis, G.C., Marge, R.B., Milstead, V.M. and Kirkpatrick, C.M. (1946) Foot dimensions of soldiers. Project No. T-13, Armoured Medical Research Laboratory, Fort Knox, Kentucky.
- Hawes M.R., Sovak D., Miyashita M., Kang S-J., Yoshihuku Y., and Tanaka S. (1994) Ethnic differences in forefoot shape and the determination of shoe comfort. *Ergonomics*, vol. 37, pp. 187-196.
- Hertsberg, H.T.E., Daniels G.S., and Churchill E. (1954) Anthropometry of flying personnel, 1950, WADC Technical report 52-321, Wright Air Development Center, Air Research and Development Command, United States Air Force, Wright-Patterson Air Force Base, Ohio.
- Hoffmann, P. (1905) Conclusions drawn from a comparative study of the feet of barefooted and shoe-wearing peoples. *The American Journal of Orthopedic Surgery*, vol. 3, pp. 105-136.
- Hoshi H. and Kouchi M. (1978) Anthropometry of adult male Japanese with remarks on

- correlation coefficients. *Acta Anatomica Nipponica*, vol. 53, pp. 238-247 (in Japanese with English summary).
- Hoshi H., Kouchi M., and Tsutsumi E. (1980) Anthropometry of adult female Japanese with remarks on correlation coefficients. *Acta Anatomica Nipponica*, vol. 55, pp. 525-534 (in Japanese with English summary).
- Japan Leather and Leather-Good Industries Association (1987) Report of the Research and Development on Foot Studies (Showa 61 nendo) (in Japanese).
- Japan Leather and Leather-Good Industries Association (1988) Report of the Research and Development on Foot Studies (Showa 62 nendo) (in Japanese).
- Japanese Standards Association (1984) Report of the Anthropometric Survey of Japanese —for Japanese Industrial Standard of Readymade Clothing (1978-81)—. Japanese Standards Association (in Japanese).
- Kayis B. and Ozok A.F. (1991) The anthropometry of Turkish army men. *Applied Ergonomics*, vol. 22, pp. 49-54.
- Knussmann R. (1988) *Anthropologie. Handbuch der vergleichenden Biologie des Menschen*. Bd. I. Gustav Fischer, Stuttgart.
- Korea Research Institute of Standards and Science (1992) National Anthropometric Survey of Korea 1992, Industrial Advancement Administration, Korea (in Korean).
- Kouchi M. (1989) An analysis of variation in Japanese foot shapes. *Journal of Anthropological Society of Nippon*, vol. 97, pp. 373-388 (in Japanese with English summary).
- Kouchi M. (1995) Analysis of foot shape variation based on the medial axis of foot outline. *Ergonomics*, vol. 38, pp. 1911-1920.
- Kouchi M. (1996) Secular change and socioeconomic difference in height in Japan. *Anthropological Science*, vol. 101, pp. 325-340.
- Kouchi M. and Tsutsumi E. (1996) Relation between the medial axis of the foot outline and 3D foot shape, *Ergonomics*, vol. 39, pp. 853-861.
- Kouchi M. and Yamazaki N. (1990) Analysis of variations in foot contours based on direction angles. *Journal of the Anthropological Society of Nippon*, vol. 98, pp. 91-105 (in Japanese with English summary).
- Kouchi M. and Yamazaki N. (1992) Allometry of the foot and shoe last. *Journal of Anthropological Society of Nippon*, vol. 100, pp. 101-118 (in Japanese with English summary).
- Kusumoto A., Suzuki T., Kumakura C., and Ashizawa K. (1996) A comparative study of foot morphology between Filipino and Japanese women, with reference to the significance of a deformity like hallux valgus as a normal variation. *Annals of Human Biology*, vol. 23, pp. 373-385.
- Lam Sim-Fook and Hodgson A.R. (1958) A comparison of foot forms among the non-shoe and shoe-wearing Chinese population. *Journal of Bone and Joint Surgery*, vol. 40A, pp. 1058-1062.
- Mochimaru M. and Kouchi M. (1997) Automatic calculation of the medial axis of foot

- outline and its flexion angles. *Ergonomics*, vol. 40, pp. 450-464.
- Morioka M., Miura T., and Kimura K. (1974) Morphological and functional changes of feet and toes of Japanese forestry workers. *Journal of Human Ergology*, vol. 3, pp. 87-94.
- Musiba C.M., Tuttle R.H., Hallgrímsson B., and Webb D.M. (1997) Swift and sure-footed on the savanna: a study of Hadzabe gaits and feet in Northern Tanzania. *American Journal of Human Biology*, vol. 9, pp. 303-321.
- National Institute of Bioscience and Human-Technology (1997) Human Body Dimensions Data for Ergonomic Design. Nihon Shuppan Service, Tokyo (in Japanese).
- Okada M., Kokubo H., Shindo M., and Morimoto M. (1990) Multi-item anthropometry of the foot in Japanese aged 7 to 15. *Journal of Anthropological Society of Nippon*, vol. 98, pp. 75-90.
- Prokopc M. (1977) An anthropometric study of the Rembaranga: comparison with other populations. *Journal of Human Evolution*, vol. 6, pp. 371-391.
- Redgrove J. (1979) Fitting the job to women. *Applied Ergonomics*, vol. 10, pp. 215-223.
- Rossi, W.A. and R. Tennant (1984) Professional Shoe Fitting. National Shoe Retailers Association.
- Shao X., Wang D., Cui J., Zhu X., Zhao W., Gu L. and Dong X. (1984) Anthropological survey on Sibo nationality in Xinjiang Uighur autonomous region. *Acta Anthropologica Sinica*, vol. 3, pp. 349-362 (in Chinese with English summary).
- Snow C.S., Reynolds H.M., and Allgood M.A. (1975) Anthropometry of Airline Stewardesses. FAA-AM-75-2. National Technical Information Service.
- Stewart S.F. (1970) Human gait and the human foot: an ethnological study of flatfoot. Part I. *Clinical Orthopedics and Related Research*, vol. 70, pp. 111-123.
- Takeichi K., Yamana Y., Uchimura Y. (1969) Anthropometric survey of human figure. *Bulletin of Industrial Arts Institute*, vol. 58, pp. 35-63 (in Japanese with English abstract).

Corresponding author: Makiko Kouchi (email: kouchi@nibh.go.jp)

Handling editor: Suzuki Takao