J. Human Ergol., **3**: 87–94, 1974

MORPHOLOGICAL AND FUNCTIONAL CHANGES OF FEET AND TOES OF JAPANESE FORESTRY WORKERS

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Comparison of foot forms and toe functions of 140 forestry workers and 40 members of the research institute staff revealed marked differences between them. The feet of forestry workers who habitually wore rubber-soled, snug fitting, glovelike footwear called *jikatabi* were flat and broad in comparison to the stature or foot length, their foot breadth at the heel, metatarsophalangeal, and toe levels being larger than those of the institute staff. The forestry workers also had relatively larger and broader toes, while deformation of toes in terms of outward inclination of the great toe and diminution of clefts between toes was less advanced among them than among the institute staff. The less deformed foot form of the field workers was suggested to have been derived from their wearing of the peculiar footwear with a separation between the great toe and the other toes. The pinch and flexion strength of toes of the forestry workers, however, was never stronger than the control group, and the maximally spread out position of the great or the fifth toe was almost equal for both groups. Passive activities of the toes in supporting the weight of body were thus postulated to be strengthened by the footwear and field work, producing less restricted configuration of the feet and toes.

Shoes often cause deformations of the feet, if they are made or chosen to measure. A typical example of such deformation may be the *hallux valgus*. In contrast to ordinary shoes worn by most urban inhabitants for their daily work, a special type of rubber-soled field footwears called *jikatabi* is often used by outdoor manual laborers. This kind of field footwear, which is a modern variation of the traditional sockslike *tabi*, is popular among elderly workers. Made of strong sailcloth and with rubber soles, *jikatabi*, like tabi, has a characteristic separation

Received for publication May 14, 1974

between the great toe and the other toes. The separation of toes, provides the wearer with the broad tiptoe part and comparatively wide room for toe movement (Fig. 1).

Fig. 1. Appearance of *jikatabi*, a special kind of rubber-soled field footwear.

It is interesting to know what kinds of effects field footwear such as *jikatabi* may have on the feet and toes, especially with respect to the separation of toes. In order to clarify the effects of *jikatabi*, we investigated the morphological and functional changes of the feet and toes of 140 forestry workers of age 20–59 in Gifu Prefecture. Measurements of 40 male laboratory members of a research institute in Tokyo, including some office clerks, of the same age range served as control data. These measurements were made in 1956 when almost all forestry workers used to wear *jikatabi* throughout the year except in the snowy season.

MEASUREMENT OF FOOT DIMENSIONS

Comparison of foot dimensions between the forestry workers and the institute staff were conducted by measuring the knee height, medial malleolus height, back of foot height, foot length, and foot breadth. Table 1 gives the relative differences between the means of the two groups, the positive or negative percent values indicating that the mean for the forestry workers was larger or smaller than that for the institute staff, respectively. The results of the statistical analyses between the means are also shown in the table.

The average stature plus or minus the standard deviation of the forestry workers was 1,594±47 mm. Their mean stature was about 3.6% smaller than that of the control group which was 1,654±46 mm. A similar difference was also seen for the body weight, which was 54.1±4.8 kg for the former and 56.1±6.0 kg for the latter. If the percent differences in foot dimensions between the two groups were compared with the relative difference in stature, the discrepancy seemed to be

Table 1. Comparison of foot dimensions between the forestry workers and the institute staff.

Measurement	Mean ± standard deviation for forestry workers (mm)		Percent difference from the mean for institute staff (%)	
	right	left	right	left
Stature	1,595±47		−3.6***	
Body weight	54.1±4.8 (kg)		−3.6*	
Knee height	409±19	409±19	−1.8*	−2.1**
Lower leg length	337±18	337±18	−0.7	−0.9
Lower leg girth (calf level)	331±17	330±17	−4.0***	−4.3***
Lower leg girth (ankle level)	201±11	200±10	−4.0***	−3.6***
Medial malleolus height	72±6	72±5	−6.2***	−6.0***
Foot length	240±10	240±11	−1.3	−1.4
Foot breadth (metatarsophalangeal joint level)	102±5	101±6	+2.2*	+0.7
Back of foot height	60±4	60±4	−5.5***	−5.5*
I-metatarsophalangeal joint height	32±3	32±2	−3.3*	−2.1
V-metatarsophalangeal joint height	22±2	22±2	−0.9	0.9
Plantar arch height	37±4	38±5	−5.9*	−4.3*

* the difference from the group B significant at the .05 level.
** significant at the .01 level.
*** significant at the .001 level.

more enhanced in the case of lateral malleolus height and back of foot height. But, for foot length, the difference between both groups was smaller than expected from the body height difference of 3.6%. More striking was the larger foot breadth of the forestry workers compared with that of the institute staff. Small differences in knee height and lower leg length might be partly attributed to the measurement errors possibly caused by the displacement of the patella during the measurements.

The relative foot dimensions calculated as permillages of the stature are shown in Table 2 for four major items. Statistically significant difference could be demonstrated for those stature-related values except for back of foot height. It is

Table 2. Comparison of permillage values to the stature between the forestry workers (A) and the institute staff (B).

Measurement	Distribution range	Means			
		right		left	
		A	B	A	B
Medial malleolus height	37–55	45.3*	46.6	45.1*	46.2
Foot length	135–170	151**	148	151**	147
Foot breadth	55–75	67.4***	61.8	67.1***	62.1
Back of foot height	30–45	37.6	38.3	37.6	38.2

* the difference from the group B significant at the .05 level.
** significant at the .01 level. *** significant at the .001 level.

shown that the forestry workers had relatively lower medial malleolus height, longer foot length, and broader foot breadth than the institute staff living in Tokyo. The medial malleolus height for the adult German population being about 5% of the stature (BASLER, 1938), the results may suggest that the Japanese have relatively lower feet than the German. The above-mentioned difference between the two investigated groups of the present study was as significant as such racial differences. It may be said that the feet of forestry workers were in general flatter and broader than those of the control group.

When toe dimensions are compared between the two groups, the forestry workers had obviously larger and broader toes than the institute staff, as shown in Table 3. Although the foot length of forestry workers was smaller than that of the

Table 3. Comparison of foot and toe dimensions between the forestry workers and the institute staff.

Measurement	Percent difference of means of both groups+	
	right	left
Foot length (heel to I toe)	−0.7	−1.8*
(heel to V toe)	−1.3	−1.3
Toe length of the great toe	+5.4***	+4.6***
Toe length of the fifth toe	+7.7***	+9.3***
Breadth of the great toe	+2.7*	+5.5**
Total breadth of five toes	+3.7***	+2.6**
Heel breadth	+4.8***	+4.0**

* the difference from the group B significant at the .05 level.
** significant at the .01 level.
*** significant at the .001 level.
\+ percent difference from the staff group.

control group, all of the toe dimensions were definitely larger for the workers than for the latter. The mean absolute difference was about 2 to 3 mm for each toe. This was even more remarkable than the above-mentioned difference in foot length or foot breadth. Thus the flat and broad feet of the forestry workers were apparently related to the large and broad toes.

DEFORMATIONS OF TOES

Outline of each sole was drawn on the floor surface and compared between the two subject groups. The institute staff usually had considerable deformation or disfigurement of toes typical amongst civilized urban people, *i.e.*, outward inclination of the great toe and disfigurement of the outer toes. As shown in Fig. 2, this contrasted with the widely spread toe positions of the forestry workers who usually had large and thick toes stretching inwards and outwards. The results of statistical analyses are given in Table 4 which summarizes the measurements

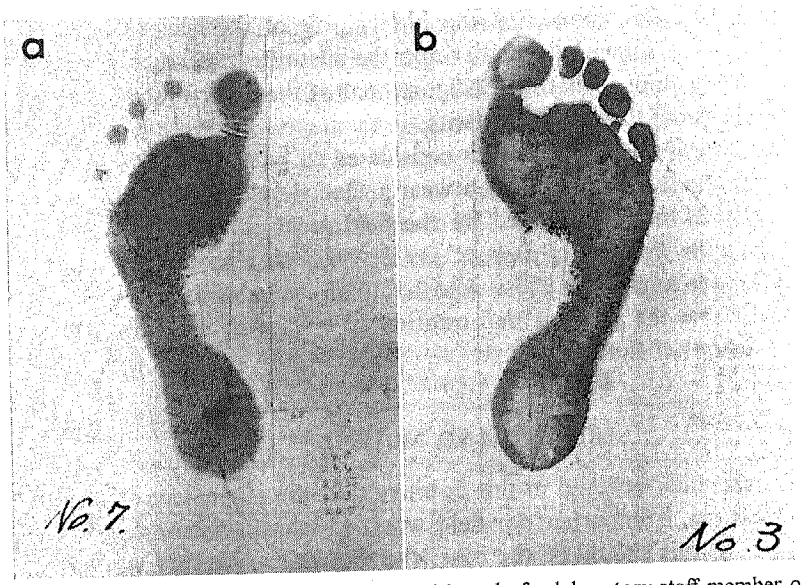

Fig. 2. Typical footprints of a forestry worker (a) and of a laboratory staff member of the research institute (b).

Table 4. Measurements related to the disfigurement of toes.

Measurement	Forestry workers			Institute staff		
	Min.	Mean	Max.	Min.	Mean	Max.
Separation between the great toe and the second toe (mm)	0	2.4***	12	0	0.9	5
Great-toe angle (°)	−5	6***	16	0	10	22
Outer-toe slope (°)	40	48**	60	40	46	52

** the difference from staff group significant at the .01 level.
*** significant at the .001 level.

related to toe deformations. While the cleft between the great and second toes was almost linear among the institute staff, the average width being only 0.9 mm for the right and left feet, that among the forestry workers was generally much wider, with the average width of 2.4 mm and with the maximum of 12 mm.

The degree of outward inclination of the great toe was measured as an angle between the line connecting the inner borders of the heel and the metatarsophalangeal joint and that connecting the inner borders of the great toe and the metatarsophalangeal joint. The angle may be called the great-toe angle according to BASLER (1938). As indicated in Table 4, the great-toe angle was smaller for the forestry workers than for the institute staff, the mean difference of about 4 degrees being statistically significant. The degree of outer toe slope, which is given as an angle between the line passing through the middle points of the second and

fourth toes and that connecting the hinder pole of the heel and the top of the second toe, was somewhat smaller for the institute staff than for the forestry workers. This implies that the disfigurement of the outer toes was more remarkable in the case of the city inhabitants.

The habit of wearing *jikatabi* is considered to be so favorable to feet that the toes are far less tortured by the footwear. One should also note that the natural development of toes was favored by the field work itself. Our results are consistent with the findings of BASLER (1938, 1941) that people going barefoot had larger great-toe angle than those who habitually went with boots on. It is also noteworthy that the great toe deformation of boot-wearing people in Japan was as much as that of Europeans.

STRENGTH AND MOVEMENT OF TOES

It is generally believed in this country that the movement of toes, especially of the great toe, is important for field work, to which *jikatabi* should be very appropriate. If this should be the case, the toes of the forestry workers would be very strong. In order to probe this assumption, pinch force of the great and second toes and the flexion strength of each toe were measured. The pinch force was indicated as a minimal force required to pull out a small piece of wood held between both toes. The flexion strength of each toe was measured by means of a strain meter as maximally exerted force on a horizontal small plate placed under the toe. Care was taken so that the flexion force was exerted on the plate without any help of the body weight.

The measurement results are shown in Table 5. Contrast to expectation, there were found no significant differences between the two groups with respect to

Table 5. Means of right and left toe strength measurements of the forestry workers and the institute staff.

Measurement		Forestry workers	Institute staff
Pinch force of the I and II toes (kg)		5.1	5.4
Flexion strength of each toe (kg/cm^2)	I toe	4.9*	5.7
	II toe	1.5**	2.0
	III toe	1.4**	1.7
	IV toe	1.4**	1.8
	V toe	1.5***	2.1

* the difference from the staff group significant at the .05 level.
** significant at the .01 level. *** significant at the .001 level.

the pinch force of toes. The flexion strength of five toes of the control group was even larger than that of the forestry workers. Although it should be taken into consideration that the manual workers are in general poorer in skillful fine movements, it does not seem likely that the toes of the forestry workers are actually

powerful. SOMBECK (1936) found that the outer four toes of those going on bare foot in summer were stronger in relation to the great toe than those of boot-wearing persons. Our findings did not confirm such effects.

Then the voluntary movement of toes was investigated also according to the method of BASLER (1942). The distance between the markings put on the middle of the nail of two neighboring toes was measured twice, that is, when the subject stood quite naturally on the floor and when he spread the toes as wide as possible. The difference between the two measurements gave the grade of toe spreading. The results are indicated in Table 6. The distance in natural standing

Table 6. Distance between neighboring toes in normal and maximally spread positions and the grade of spreading.

	Measurement	Distribution range	Means	
			Forestry workers	Institute staff
Between the I–II toes	Normal position	20 – 40	31***	28
	Maximally spread position	25 – 48	35	35
	Grade of spreading	−3 – 18	4.1***	6.5
Between the II–III toes	Normal position	15 – 26	20	20
	Grade of spreading	−2 – 10	2.6	2.7
Between the IV–V toes	Normal position	15 – 30	2.3	2.4
	Grade of spreading	−2 – 12	1.5*	2.5

* the difference from the staff group significant at the .05 level.
*** significant at the .001 level.

between the great and second toes was significantly larger by about 3 mm for the forestry workers than for the control group. This difference may correspond to the above-described results of the deformation of the great toe in the latter group. However, the maximal distance between the two toes when they were spread out as wide as possible was nearly the same for both groups, approximately as large as that by German subjects reported by BASLER (1942). As a result, the grade of toe spreading from the normal standing position was smaller for the forestry workers. It seemed that the subjects with larger outward inclination of the great toe could spread it more widely inwards. Similar results were obtained also in the case of the cleft between the fourth and fifth toes, the outward spreading from the normal positions being larger for the control group.

WORK AND FOOTWEAR

The results of the present study have demonstrated that the forestry workers habitually wearing field footwears with a separation between the great and outer toes have relatively flat and broad feet. It is suggested that their feet have not been tortured by shoes or boots universal among urban inhabitants and that their

way of working in the forestry may have helped the rather natural development of the toes. Because the pinch force or flexion strength of the toes of the forestry workers were not particularly strong as compared with the control group, it may be presumed that the major role of toes at work is rather a passive action in supporting the weight of the body, and not played by their own active motions. For such passive actions, the large and broad toes of the forestry workers and their footwear with a broad tiptoe end and a significant toe cleft seem very appropriate.

Our results also indicate that there may be a certain limit to the toe spreading which is determined by the foot structure. Thus the maximum possible spreading from the normal positions was less for the less tortured toes than for the disfigured ones. It should be noted that the individual variation of the toe spreading ability is very large as shown by Table 6, which has also been pointed out by BASLER (1942). If the active participation of toe motions is significant only for particular skillful working actions using feet, this was not the case for the forestry workers studied by us. Recent measurement made in 1972 on forestry workers have shown that western footwear has become popullar among children and young people of rural districts, and that deformations of toes are frequent among forestry workers of age under forty (MIURA, 1972).

An important requirement of working footwears may be that the toes are not tortured and an ample room is assured at the tiptoe. As a traditional type of field footwear, the *jikatabi* should be acknowledged to have remarkable merits in this respect. The problem of the toe separation by such field shoes seems to be open for discussion and needs further investigation, because it is associated with both the habits of wearers and the functional relation of the footwear with the working motions of feet.

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