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Quantitative comparison of plantar foot shapes under different weight-bearing conditions

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Abstract—Knowledge of the plantar foot shape alteration under weight bearing can offer implications for the design and construction of a comfortable and functional foot support. The purpose of this study was to quantify the change in three-dimensional foot shape under different weight-bearing conditions. The plantar foot shapes of 16 normal feet were collected by an impression casting method under three weight-bearing conditions: non-weight bearing, semi-weight bearing, and full-weight bearing. An optical digitizing system was used to capture the three-dimensional plantar surface shape of the foot cast. Measurements and comparisons from the digitized shapes were conducted for the whole foot and regions of the foot. The data showed that increased weight bearing significantly increased the contact area, foot length, foot width, and rearfoot width, while it decreased average height, arch height, and arch angle. Compared with the non-weight-bearing foot shape, the semi-weight-bearing condition would produce increases in the contact area of 35.1% ± 21.6 %, foot length of 2.7% ± 1.2%, foot width of 2.9% ± 2.4%, and rearfoot width of 5.9% ± 4.8%, and decreases in the arch height of 15.4% ± 7.8% and arch angle of 21.7% ± 17.2%. The full-weight-bearing condition would produce increases in the contact area of 60.4% ± 33.2%, foot length of 3.4% ± 1.3%, foot width of 6.0% ± 2.1%, and rearfoot width of 8.7% ± 4.9%, and decreases in the arch height of 20.0% ± 9.2% and arch angle of 41.2% ± 16.2%. The findings may be useful for considering the change of foot shape in the selection of shoe size and shoe or insole design.

Key words: foot arch, foot biomechanics, foot shape, insole, orthotics, shoe design.

INTRODUCTION

The human foot is a highly complex structure, with 26 major bones and more than 30 synovial joints [1]. It plays a role in both load support and shock absorption during walking. Shoes and insoles have been designed to protect the foot and facilitate proper foot functions for daily activities. An important determinant for a functional and comfortable foot support is how well it fits with the plantar foot shape [2]. The foot shapes corresponding to different weight-bearing conditions are believed to be unique and can provide a more comprehensive description of the foot-insole interaction. It is important to understand the foot shape and its change under weight bearing and to determine which foot shape would best be adopted as the deciding factor in designing the support shape.

Abbreviations: FWB = full-weight bearing, ICC = intraclass correlation coefficient, MTH = metatarsal head, NWB = non-weight bearing, SWB = semi-weight bearing.

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Previous studies on the anthropometrics of foot shape used varied protocols and measurement devices [3]. Most approaches directly measure the foot length, breadth, height, and girth dimensions using sliding caliper, cloth tape, flat ruler, etc. [3–6]. These measurements may vary because of inconsistencies in positioning and the orientation of scales.

Benninghoff [7] stated that the navicular bone was depressed, on average, 6.5 mm when bearing weight; the foot arch prolonged up to 19 mm within the second ray and 8 mm within the fifth ray upon weight bearing [8]. Carlsöö and Wetzenstein [9] mentioned a quite different finding: that weight bearing caused no significant change in foot length and foot height. The different results found by these researchers may be due to an inconsistency in measuring positions, so that the actual foot joint orientation and amount of load undertaken were different.

Kayano [10] used a surface-mounted electronic arch gauge to monitor the medial arch of the foot during normal walking. It was found that the medial arch length changed at different phases of gait. The degree of change in the length of the arch ranged from 3.7 to 9.5 mm. A similar method was used by Umeki [11], who investigated the factors that influenced the length of the medial arch of the foot in normal adults under various passive motions and loads on the foot. It was found that the medial arch was lengthened and the foot was abducted when a vertical load was added to it. Shortening was observed when the first metatarsophalangeal joint was manually dorsi-flexed. The results indicated that the medial arch length would change with weight bearing and foot positioning. The use of skin-mounted measurement techniques may limit the accuracy of measuring the kinematics estimates of motion [1,12,13]. This kind of error becomes considerable, as the foot shape alteration is relatively small.

Borchers et al. [14] used a commercial light-striping laser digitizer to scan a foot in a non-weight-bearing condition and a 95-percent body-weight-bearing condition. This kind of foot digitizing method avoided the error caused by skin displacement and tissue distortion. These shape variations gave the researchers ideas about the shape difference between a non-weight-bearing foot and a weight-bearing foot. Quantitative analyses and descriptions of these alterations are still limited. The purpose of this investigation is to quantify the three-dimensional (3D) foot shape and its alteration resulting from different weight-bearing conditions.

METHODS

Eight normal adults (three males and five females) participated in this study (**Table 1**). All had normal foot arch and were without foot deformity. The participants were assessed by an orthotist and each arch index was calculated from a footprint. The local research ethics committee reviewed the experimental protocol. Each subject signed a consent form before the experiment.

Impression Casting Protocols

Using an impression casting method, we captured the plantar foot shapes in three different weight-bearing conditions: full-weight bearing (FWB), semi-weight bearing (SWB), and non-weight bearing (NWB). During FWB casting, the casting board was placed horizontally on the electronic balance and filled with prepared liquid dental plaster. Each participant was instructed to stand upright with all weight placed on the casting foot. The noncasting foot was flexed up and bore no weight. The line of progression of the foot being cast was pointing forward. The casting foot alignment was examined by placing one arm of the goniometer parallel to the line of progression and the other arm parallel to the perpendicular line of the heel centers that were drawn on the ground. The electronic balance was continuously inspected in order to ensure that all weight was placed on the casting foot until the dental plaster was fully hardened.

Similar casting procedures and monitoring techniques were used for the SWB and NWB casts. For the SWB casting condition, half the body weight was placed on the casting foot, with the line of progression of both feet parallel to each other and pointing forward. The participant was instructed to stand upright, with the distance between two heel centers kept apart at the width of subject's shoulders. Under the NWB condition, the participant was instructed to sit without weight bearing on the casting foot. The knee and ankle were kept in 90° flexion, and the centers of both heels were separated by the width of the subject's shoulders. The line of progression of both feet was kept parallel and pointing forward.

The participant's posture and joint orientations were standardized and assessed by an orthotist. The level of each foot impression cast was taken to the level of the tip of the lateral malleolus of the foot. The negative cast was then filled with plaster of Paris to obtain the positive foot cast. The nonmodified positive foot cast was scanned for 3D shape measurements.

Table 1.
Subject information.

Characteristics	Subject 1 L	Subject 1 R	Subject 2 L	Subject 2 R	Subject 3 L	Subject 3 R	Subject 4 L	Subject 4 R	Subject 5 L	Subject 5 R	Subject 6 L	Subject 6 R	Subject 7 L	Subject 7 R	Subject 8 L	Subject 8 R	Mean	SD
Gender	M		F		F		F		M		M		M		M		—	—
Age	74		38		45		41		45		37		46		46		46.5	11.7
Height (m)	1.62		1.61		1.53		1.63		1.77		1.64		1.68		1.64		1.6	0.1
Weight (kg)	63		55		67		46		74.5		70		76		64		64.4	10.0
Foot Length (mm)	241	243	227	228	210	211	229	231	250	249	251	247	250	250	247	245	238	14
Foot Width (mm)	93	97	84	86	87	89	86	87	99	100	98	101	97	97	96	97	93	6
Heel Width (mm)	65	66	56	57	62	63	57	59	74	76	73	74	75	75	67	65	67	7
Ball Circumference (mm)	231	230	218	217	220	220	219	220	250	250	243	243	253	255	235	240	234	14
Instep Circumference (mm)	220	222	220	220	240	241	221	222	280	280	268	270	270	271	263	270	249	25
Span Circumference (mm)	300	301	295	295	300	299	296	297	330	331	325	326	338	339	320	321	313	17

SD = standard deviation
L = left foot
R = right foot
Note: Foot shape data were measured with sliding caliper and cloth type in non-weight-bearing sitting posture.

3D Shape Digitization, Registration, and Comparison

The 3D plantar shape of the foot cast was obtained with a commercial optical 3D digitizing system (COMET 100, Steinbichler, Germany), which measured the complex, free-form surface geometry of the cast using a white-light triangulation technique. Absolute 3D coordinates were calculated for each point in the resulting point cloud to describe the surface geometry with accuracy of 0.025 mm, as suggested by the manufacturer. Because of the limited scanning angle of the scanner, the surface geometry of the cast was digitized from the two sides and from the plantar views, in order to obtain a wider angular range of image. The files from the optical scanner were imported into PolyWork (InnovMetric, Canada), where the data sets were "merged" into the complete 3D surface geometry. In this process, eight landmarks (fiducial points) over the surface images were used to perform the primary registration process. Automatic translation and rotation of the corresponding points over the merging point clouds completed the global registration process. As there may be overlapping points from different surface images, a step was included that removed points with exactly the same coordinates.

In order to compare the foot models obtained from the three different weight-bearing conditions, we had to transform the foot models from different orientations into the reference orientation. We used Surfacer™, Version 10.0 (Imageware, EDS, USA), to transform the surface coordinates of the foot model point clouds. A line formed between the most posterior point of heel and tip of the second toe was used to define the longitudinal foot axis (x axis). Three bony landmarks, the first metatarsal head (MTH), the fifth MTH, and the center of heel, were selected to form the weight-bearing plane (x-y plane at $z = 0$). The first and fifth MTHs were defined as the most prominent points on the plantar foot surface over the first and fifth MTH regions, respectively. The center of heel was also selected as the mid-point center over the heel region on the plantar surface.

Procedures to Trim Foot Models

When the foot model was aligned to the reference frame, it was then trimmed with a reference boundary for standardizing the area of comparison. All points of the foot models beyond the boundary (or trimline) were removed automatically. The trimline design was similar to that of commercially available insoles, but in our design, the forefoot section was included. The foot models were trimmed 10 mm horizontally above the weight-bearing plane. On the medial aspect, the trimline for the foot model was curved up to fit the shape of the medial arch. A tangent line, connected between the widest part of the first metatarsal head and the heel in the same plane, was projected onto the foot model, which was temporally inverted up $30°$ about the longitudinal axis. When the foot model was rotated back to the referenced orientation, a curved up boundary line could then be formed over the medial arch region of the foot model. The shapes of the trimmed foot models were then standardized and used as final shapes for comparison.

To examine the shape variations in different weight-bearing conditions, we made quantitative comparisons in not only the whole foot, but also different foot portions. These comparisons involved removing the toe portion first and then dividing the foot model into three portions of equal length: forefoot, midfoot, and rearfoot. The dividing process was similar to that introduced by Cavanagh and Rogers [15] in calculating arch index.

Using custom-designed software, we analyzed each foot shape to provide seven morphological parameters, as defined in **Figure 1**: average height (average distance between the plantar surface and weight-bearing plane at every pixel); arch height (distance between the maximum points, apical arch, along the *z*-axis to the weight-bearing plane); arch angle (angle formed between the apical arch with the weight-bearing plan on the *z*-*y* plane); contact area (area formed by the points below the selected contact level $z \leq 1\,\text{mm}$); foot width and foot length (projected distance between the maximum and minimum

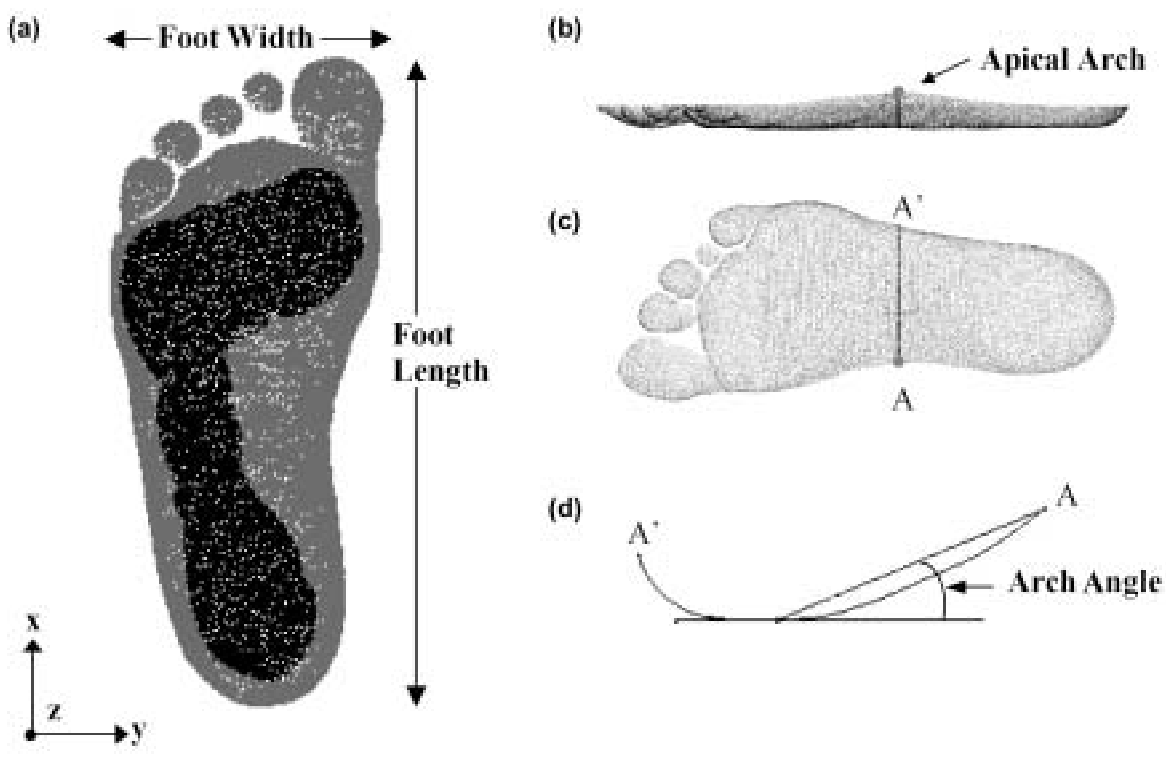

Figure 1.
Definitions of measured variables: **(a)** plantar view of right foot, foot width, foot length, and contact area (black region); **(b)** side view, arch height (distance between apical arch of foot from weight-bearing plane); **(c)** dorsal view, cross-section along *y*-axis from apical arch; and **(d)** frontal view, arch angle (angle formed between apical arch with weight-bearing plane).

points of the whole foot along the *y*- and *x*-axes, respectively); and rearfoot width (projected distance between the maximum and minimum points of the rearfoot along the *y*-axis).

Error Estimations

We used a $50 \times 50 \times 50$ mm^3 standard cube to determine errors in the experimental procedures, including shape digitization, image registration, and calculation of parameters using the custom-made software.

To determine the reliability of the entire experimental procedure, including casting, shape digitization, image registration, and calculation of parameters, the same tester repeated the same experimental procedures three times on three subjects. The intraclass correlation coefficients (ICC) (3,1)* were used to determine the intraobserver reliability of measuring the testing variables from the three casting conditions.

Data Analysis

To quantify the change in foot shape, we compared the parameters measured from the SWB and FWB conditions with those of the NWB condition. Data were obtained by averaging parameters for the 16 feet. SPSS (Version 10.0) statistical package was used for statistical analysis. Two-factor analysis (foot side and weight-bearing factors) of variance for repeated measures was used to determine whether the foot side and weight bearing factors could have significant interaction on the foot shape variables and whether the foot variables measured from the three different weight-bearing conditions were significantly different. The statistical significance level was set at 5 percent ($p < 0.05$). Correlation coefficients were calculated between variables within subjects to determine the relationships.

*Portney LG, Watkins MP. Foundations of clinical research: applications to practice, 2nd edition. Upper Saddle River, NJ: Prentice Hall; 2000. p. 509–13. According to Portney, there are three models of intraclass correlation coefficient (ICC). In model 3, each subject is assessed by each rater, but the raters represent the only raters of interest. Each of the three ICC models can be expressed in two forms, depending on whether the scores are single ratings or mean ratings. As we are testing the reliability of single rater and single rating of parameter, ICC (3,1) was used.

RESULTS

The calculated results of the accuracy test showed that the root mean square errors on measuring distance, area, and angle were less than 0.16 mm, 3.41 mm^2, and 0.21°, respectively (**Table 2**). The correlation coefficient for the intratester reliability of the entire experimental procedure is shown in **Table 3**.

A significant change in foot shape was found with different weight-bearing conditions (**Table 4** and **Figure 2**). Contact area was found to increase as the weight on the foot increased (**Figure 2(a)**). The contact area of the whole foot increased by a mean of 35.1 ± 21.6 percent for the SWB condition and 60.4 ± 33.2 percent for the FWB condition. In the forefoot region, the contact area increased by 20.3 ± 11.1 percent for the SWB condition and 33.4 ± 10.8 percent for the FWB condition. In the midfoot region, the contact area increased markedly by 52.5 ± 48.3 percent for the SWB condition and by 100.7 ± 75.3 percent for the FWB condition. In the rearfoot region,

Table 2.
Accuracy on measuring distances, angle, and area for cube measurement.

Foot Shape Parameters	Trial 1	Trial 2	Trial 3	Known Value	Root Mean Square Error	% Difference from Known Value
Length (mm)	50.23	50.13	49.94	50.00	0.09	0.18
Height (mm)	50.13	50.08	49.92	50.00	0.06	0.12
Average Height (mm)	49.96	50.18	50.45	50.00	0.16	0.33
Area (mm^2)	2500.42	2510.20	2499.61	2500.00	3.41	0.14
Angle (°)*	45.41	44.65	45.35	45.00	0.21	0.47

*This accuracy test was conducted as we measured the angle of a diagonally trimmed point cloud of the standard cube, which should have a 45º angle formed between highest point and supporting plane.

Table 3.
Intratester reliability on measuring testing parameters under three weight-bearing conditions.

Foot Shape Parameters	Intratester reliability, ICC (3,1)		
	NWB	SWB	FWB
Length	0.985	0.997	0.998
Width	0.925	0.999	0.991
Height	0.976	0.933	0.973
Average Height	0.718	0.852	0.793
Area	0.922	0.990	0.982
Angle	0.915	0.952	0.930

ICCs = intraclass correlation coefficients
NWB = non-weight bearing
SWB = semi-weight bearing
FWB = full-weight bearing

Table 4.
Pairwise comparison between foot shape parameters measured under three weight-bearing conditions ($n = 16$).

Foot Shape Parameters		*p*-Value		
		NWB vs. SWB	NWB vs. FWB	SWB vs. FWB
Contact Area	Wholefoot	0.002*	<0.001*	0.016*
	Forefoot	<0.001*	<0.001*	<0.001*
	Midfoot	<0.001*	<0.001*	<0.001*
	Rearfoot	<0.001*	<0.001*	0.189
Average Height	Wholefoot	<0.001*	<0.001*	0.247
	Forefoot	<0.001*	0.003*	0.625
	Midfoot	0.001*	0.001*	0.053
	Rearfoot	0.019*	0.043*	0.674
Arch Height	Wholefoot	<0.001*	<0.001*	0.003*
Arch Angle	Wholefoot	0.003*	<0.001*	0.002*
Length	Wholefoot	<0.001*	<0.001*	0.116
Width (L)†	Wholefoot	0.001*	<0.001*	0.046*
Width (R)†	Wholefoot	0.059	<0.001*	0.001*
Rearfoot Width	Rearfoot	0.042*	0.014*	0.018*

NWB = non-weight bearing
SWB = semi-weight bearing
FWB = full-weight bearing
*$p < 0.05$
L = left
R = right
†$n = 8$, one foot from each subject.

contact area increased by 31.7 ± 38.8 percent for the SWB condition and 37.2 ± 35.6 percent for FWB condition. The statistical analyses showed significant increases ($p < 0.05$) in contact area for all foot regions when the weight bearing on the foot increased. But the difference in the contact area in the rearfoot region between SWB and FWB conditions was not significant.

The average height of the foot from the weight-bearing plane decreased as the load increased (**Figure 2(b)**). Compared with the NWB condition, the average height decreased by 22.1 ± 10.8 percent under the SWB condition, and by 25.2 ± 8.6 percent under the FWB condition. The statistical analyses showed, for all foot regions, a significant decrease in average height between NWB and the weight-bearing conditions; however, no significant difference was found between the SWB and FWB conditions.

Figure 2(c) and **(d)** show the changes in arch height and arch angle, respectively. The arch height of the NWB foot measured for the 16 feet was 16.9 ± 1.6 mm. Arch height decreased significantly by 15.4 ± 7.8 percent and 20.0 ± 9.2 percent under the SWB and FWB conditions, respectively. The average arch angle of unloaded feet was 21.1 ± 4.6°, and this angle decreased by 21.7 ± 17.2 percent and 41.2 ± 16.5 percent under the SWB and FWB conditions, respectively.

The foot length and width were changed with weight bearing, as shown in **Figure 2(e)** and **(f)**. Compared with the NWB condition, the average foot length increased by 2.7 ± 1.2 percent and 3.4 ± 1.3 percent under the SWB and FWB conditions, respectively. For the foot width, the right foot was found to be larger than left foot by 1.9 mm ($p < 0.001$). The mean foot width of the left foot under the NWB condition was 93.5 ± 5.3 mm, and it became wider under the SWB and FWB conditions by 4.2 ± 2.1 percent and 6.4 ± 2.4 percent, respectively. The average foot width of NWB right foot was 96.4 ± 5.6 mm, and it was smaller than that measured under SWB and FWB conditions by 1.6 ± 2.1 percent and 5.6 ± 1.7 percent, respectively. No significant side difference was found in the rearfoot width: it mainly changed with different amounts of weight applied on it. Rearfoot width was found to increase by 5.9 ± 4.8 percent under the SWB condition and by 8.7 ± 4.9 percent under the FWB condition (**Figure 2(g)**).

In order to determine the correlation among the foot shape variables, we computed the correlation coefficients between any two variables (whole foot) under different weight-bearing conditions, as shown in **Table 5**. The

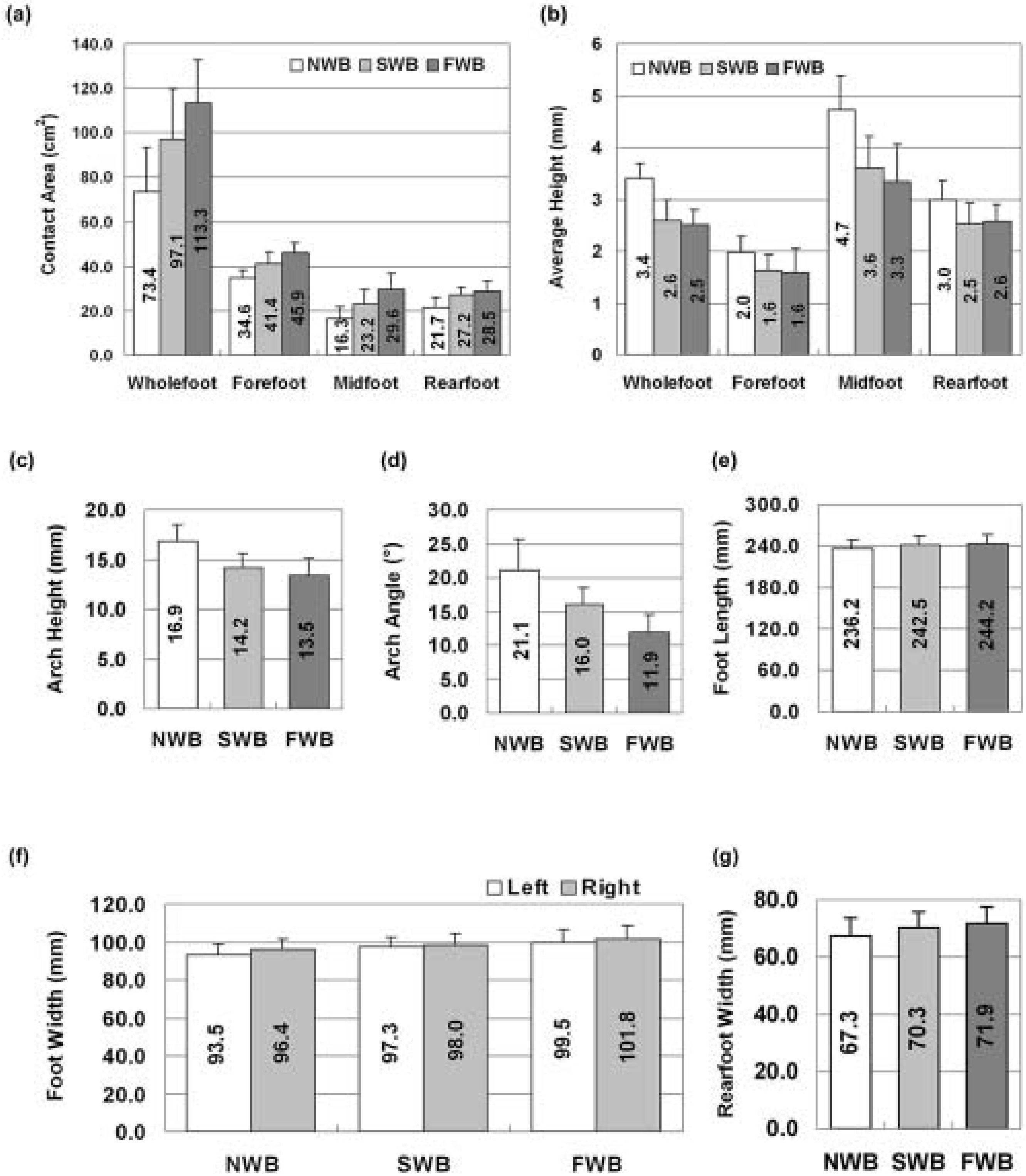

Figure 2.
Foot shape variables: **(a)** contact area, **(b)** average height, **(c)** arch height, **(d)** arch angle, **(e)** foot length, (f) foot width of both feet, and **(g)** rearfoot width, measured under different weight-bearing conditions. NWB = non-weight-bearing, SWB = semi-weight bearing, and FWB = full-weight bearing.

Table 5.
Average correlation between foot shape parameters with linear regression test.

Foot Shape Parameters	Average Height (Whole Foot)	Arch Angle	Contact Area (Whole Foot)	Foot Length	Foot Width
Arch Angle	0.73	—	—	—	—
Contact Area (Whole Foot)	0.79	0.75	—	—	—
Foot Length	0.83	0.71	0.72	—	—
Foot Width	0.73	0.66	0.77	0.73	—
Arch Height	0.76	0.76	0.72	0.87	0.60

change of foot length was highly correlated with the corresponding change in arch height and average height under the three tested weight-bearing conditions.

DISCUSSION

Impression casting is one of the most common techniques used in clinics for foot casting. Some previous authors used a negative impression technique with polystyrene foam for fabricating foot orthosis [16]. Different combinations of manipulation, such as adduction of the forefoot, external rotation of the tibia, and calcaneal inversion, were imposed on the casting foot. The aim was to test the biomechanics of longitudinal arch support mechanisms in foot orthoses and the effect on plantar aponeurosis strain. In this study, we applied no direct control over the subtalar joint on the casting foot in order to avoid any foot shape alteration due to the uncontrollable human factors rather than the weight-bearing effect being investigated.

Efforts were made to minimize errors caused by the inconsistent casting posture and amount of load acting on the casting foot. A digital balance (0.1 kg resolution) was placed under the casting board to inspect the load acting on the casting foot continuously. If the amount of load acting on the casting foot varied by more than 5 percent of the suggested load, the cast was discarded. The amount of shift of the participant's posture was then not only controlled by the assessment of the orthotist, but also reflected in the change of the digital balance's reading. The amount of subtalar joint rotation under different weight-bearing conditions was then indirectly controlled. The dental plaster (Alginoplast®, Heraeus Kulzer) was used as a means for impression casting, because its short hardening time (1.5 min after mixed) allows better control over the lower-limb joint alignment and posture during the initial period of casting. The hardened cast can provide an accurate representation of the foot and allows easy removal of the foot from the cast. A plastic box provided a flat, rigid supporting surface for the foot. The current foot shape changes were measured on the rigid support rather than on the foot-insole interface. Shape changes in foot tissue may be partially affected by the soft material, which is not easy to quantify.

Casting was arranged in the sequence of FWB, SWB, and NWB in order to minimize the demand on the participant to maintain the casting positions. Each participant stood in a relaxed, natural posture, and natural knee hyperextension was allowed for the SWB and FWB conditions to maximize stability. The sequence of casting the left or right side was randomly selected to minimize habitual variations.

In this study, the changes in the plantar foot shape under the three weight-bearing conditions were examined quantitatively. We found that increasing the weight bearing on the tested foot increased the contact area, foot length, and foot width, while it decreased average height, arch height, and arch angle. The results indicate that SWB condition on the foot can cause significant changes from the NWB condition in most of the parameters measured, and small changes from the SWB to the FWB condition. It is especially interesting to find that the contact area changes in the rearfoot region between the SWB and FWB conditions were not significant. The soft tissue over the rearfoot region is already deformed when standing on both limbs, and therefore significant change was not found when more weight was applied on it.

We found that both the foot length and foot width were increased significantly when the weight bearing was increased from NWB to SWB and FWB. The increase in foot length is highly associated with the decrease in arch height and average height simultaneously ($r > 0.75$). The foot arch is depressed, and the foot skeleton is forced to spread out and move forward like a depressed curve plate [17]. The flexible components of the foot can be regarded as a twisted plate with one edge (the MTHs) placed horizontally and in full contact with the supporting surface, while the other edge (calcaneus) is placed vertically. The resulting twist influences both the longitudinal and transverse arches. When the plate is loaded, it will be untwisted, and the arches will be slightly flattened. Restricted by the limited joint space and mobility of foot ligaments, the foot lengthening would be limited with further increasing load.

In this study, foot length increased by an average of 6.3 mm from NWB to SWB, and 1.7 mm from SWB to FWB. The amount of change is less than in the previous finding [8], in that the foot arch prolonged by 19 mm within the second ray and 8 mm within the fifth ray upon weight bearing. In our study, arch height decreased by an average of 2.7 mm from NWB to SWB and 3.4 mm from NWB to FWB. The amount of change was smaller than that found by Benninghoff [7], with the navicular bone being depressed by an average of 6.5 mm when bearing weight. The difference may be due to the use of different measuring methods and different definitions of measuring parameters. Arch height was defined as the distance between the highest point over the trimmed foot shape and the weight-bearing plane, for which the value of arch height was restricted by the trimline. This definition may be different from the arch height that is commonly defined as the distance between the tip of navicular bone and supporting ground.

The foot shapes obtained under different weight-bearing conditions were scanned in different angular ranges. A standard trimline was needed for standardizing the border of foot shape. Because no standard for trimline selection for the above purpose exists, we designed a new trimline definition in this study. Our trimline was similar to that of the commonly used semirigid insole, with a standard height on the side and an equal amount of medial curve up. The new trimline was designed with the purpose of minimizing the amount of subjective adjustment applied on it.

CONCLUSIONS

The primary criteria for a comfortable shoe should be how well it fits. Information on how the foot shape changes with load is then important for designing an appropriate space to house the foot. This study quantitatively reports a series of foot shape variables in three weight-bearing conditions that may be used to describe the essential 3D characteristics of the human foot under weight-bearing conditions. The study illustrates the necessity of considering the significant changes of foot shape under a full-body-weight-bearing condition. The foot length and foot width under full-body weight will increase by 3.4 percent (8.0 mm) and 6.0 percent (5.7 mm), respectively, compared with the NWB condition. These findings may be useful for both shoe design and the selection of shoe size. As the right foot was significantly wider than the left under the three weight-bearing conditions tested, we suggest that the shape of the left and right shoes might not need to be symmetrical. The width of the shoe could be 2 to 3 mm wider on the right foot for a better fit. This study suggests that one try the shoe on the right foot first and consider how well it fits. Because the subjects tested in this study were all right-hand dominant, the question of whether side dominance has significant effect on the tested results needs further study. The arch angle was found to reduce with load application. This reduction may be the combined effect of the reduced arch height and spreading soft tissues under loading. This change should be considered when creating functional insole supports [17]. We will continue our investigation to evaluate the insoles fabricated based on each of the three weight-bearing casts created in this study, to determine which foot shape is best used for insole design.

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