COMPARISON OF FOOT MORPHOLOGY BETWEEN CHINESE AND MONGOLIAN CHILDREN

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ABSTRACT. Knowledge of foot morphology is fundamental to optimize children's footwear design. The aim of this study is to compare the foot morphology of Chinese and Mongolian children from 7 to 14 years old. Relative data of 339 Mongolian children and another matched 379 Chinese children were collected using 3D foot scanner. The findings of this study are as follows: i) the absolute foot length of Chinese children is significantly greater than that of Mongolian children of the same age; ii) Mongolian children show significantly greater heel width, toe thickness, lateral malleolus height, instep height and ball girth compared to Chinese children of the same age. The foot width of Chinese children is significantly greater than that of Mongolian children of the same age; iii) Chinese children have a higher risk of *hallux valgus* than Mongolian children of both sexes. Small variations in foot morphology discussed in this paper could be useful when considering the shoes design for Mongolian and Chinese children.
KEY WORDS: foot morphology, Mongolian children, Chinese children, footwear design

COMPARAREA MORFOLOGIEI PICIORULUI LA COPIII CHINEZI ŞI MONGOLI

REZUMAT. Cunoaşterea morfologiei piciorului este fundamentală pentru a optimiza proiectarea încălţămintei pentru copii. Scopul acestui studiu este de a compara morfologia piciorului la copiii chinezi şi mongoli cu vârste între 7 şi 14 ani. S-au colectat date de la 339 de copii mongoli şi 379 de copii chinezi folosind un scaner 3D pentru picioare. Rezultatele acestui studiu sunt următoarele: i) lungimea absolută a piciorului la copiii chinezi este semnificativ mai mare decât în cazul copiilor mongoli de aceeaşi vârstă; ii) copiii mongoli prezintă lăţimea călcâiului, grosimea degetelor, înălţimea maleolei exterioare, înălţimea căputei şi circumferinţa zonei metatarsofalangiene semnificativ mai mari în comparaţie cu copiii chinezi de aceeaşi vârstă. Lăţimea piciorului la copii chinezi este semnificativ mai mare decât în cazul copiilor mongoli de aceeaşi vârstă; iii) copiii chinezi au un risc mai mare de a dezvolta *hallux valgus* decât copiii mongoli de ambele sexe. Micile variaţii ale morfologiei picioarelor discutate în această lucrare ar putea fi utile la proiectarea încălţămintei pentru copiii mongoli şi chinezi.
CUVINTE CHEIE: morfologia piciorului, copii mongoli, copii chinezi, proiectarea încălţămintei

COMPARAISON DE LA MORPHOLOGIE DU PIED ENTRE LES ENFANTS CHINOIS ET MONGOLIENS

RÉSUMÉ. La connaissance de la morphologie du pied est fondamentale pour optimiser la conception des chaussures pour enfants. Le but de cette étude est de comparer la morphologie du pied des enfants chinois et mongols de 7 à 14 ans. Les données relatives de 339 enfants mongols et de 379 enfants chinois ont été collectées à l'aide d'un scanner 3D pour le pied. Les résultats de cette étude sont les suivants : i) la longueur absolue du pied des enfants chinois est nettement supérieure à celle des enfants mongols du même âge ; ii) les enfants mongols présentent une largeur de talon, une épaisseur des orteils, une hauteur de malléole latérale, une hauteur de cou-de-pied et une circonférence de la région des métatarses sensiblement plus grandes que les enfants chinois du même âge. La largeur du pied des enfants chinois est nettement supérieure à celle des enfants mongols du même âge ; iii) les enfants chinois ont un risque d'*hallux valgus* plus élevé que les enfants mongols des deux sexes. Les petites variations dans la morphologie du pied discutées dans cet article pourraient être utiles lors de la conception de chaussures pour les enfants mongols et chinois.
MOTS CLÉS : morphologie du pied, enfants mongols, enfants chinois, conception de chaussures

INTRODUCTION

Knowledge of foot morphology is the most essential requirement to optimize children's footwear design [1]. The foot morphology and motor development of children are changeable with increasing age [2-4]. Studies indicated that there was high variability of foot morphology of children due to difference in region, lifestyle, ethnicity, etc. [5]. Isabel C.N. Sacco *et al*. [6] found that German children had a wider forefoot (5 to 9 years old) and narrower rear foot (4 years old) compared to Brazilian children. Kusumoto, A. [7] showed that the protuberance of the first metatarsal phalanx joint was found in 4.5% of Filipino children, but in none of Japanese children. Mauch, M. *et al*. [8] found that German children displayed a significantly longer and flatter foot compared to Australian children. Previous literature also reported the significant differences in foot morphology of adults living in different countries [9, 10]. Therefore, the footwear industry should vary the last dimensions

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on the basis of foot morphology when exporting products to different countries [11].

Most children's footwear purchased in Mongolia are designed and manufactured overseas, mainly from China [12]. As previously mentioned, differences in foot morphology may exist among different countries. It is not sure if using Chinese lasts in Mongolian footwear industries can ensure a good fit for Mongolian children shoes [13]. Ill-fitting footwear has been reported to be the major cause for discomfort, pain, and even foot problems [14]. Therefore, the purpose of this study is to investigate the foot morphology between Chinese and Mongolian children from 7 to 14 years through comparative analysis of foot dimensions. The hypothesis put forward is that there are obvious differences in foot morphology between Chinese and Mongolian children.

MATERIALS AND METHODS

Participants

Two anthropometric databases were involved. The Mongolian database consists of 339 children aged 7 to 14 years old, who were recruited from Ulan Bator, Mongolia [12]. To match the Mongolian database in terms of age, body height and body mass, 379 healthy Chinese children aged 7 to 14 years in the Chinese database were selected. These Chinese children were recruited from randomly selected primary schools and middle schools in Yantai city, Shandong Province, China. Children who demonstrated a history of neuromuscular disease, orthopedic, lower-limb injury or discomfort during walking were excluded from the study.

The participants were separated into eight age groups at an interval of one year, and every age group was classified by gender. The basic information of all participants is shown in Table 1. The descriptive values are presented as mean (standard deviation). Parents or guardians were informed of children's participation in the study in advance and signed a written informed consent. The study was approved by the Ethics Committee of the Sichuan University.

Table 1: Basic information of participants (mean (standard deviation))

Age (yrs)	China					Mongolia				
	Height (cm)	Body mass (kg)	BMI (kg/m^2)	Boys (n)	Girls (n)	Height (cm)	Body mass (kg)	BMI (kg/m^2)	Boys (n)	Girls (n)
7-	126.4 (4.8)	25.1(1.8)	16.2(0.6)	19	30	124.5(2.9)	24.4(2.7)	15.2(1.1)	24	15
8-	131.7 (4.2)	30.2(2.0)	17.4(0.2)	49	63	129.7(4.6)	26.1(3.4)	15.5(1.3)	14	15
9-	137.6(4.8)	34.0(2.1)	18.0(0.5)	24	30	135.5(4.9)	29.7(3.9)	16.2(1.5)	16	15
10-	144.3(6.3)	39.4(3.8)	18.9(0.7)	15	28	143.9(6.0)	35.3(5.5)	17.0(1.9)	17	16
11-	151.3(8.1)	45.2(6.0)	19.7(1.1)	15	25	150.5(7.6)	40.6(7.3)	17.8(2.1)	34	27
12-	157.4(8.4)	48.8(5.8)	19.6(0.7)	19	24	156.4(7.4)	44.9(6.7)	18.3(2.1)	28	21
13-	163.8(5.8)	53.8(4.7)	20.0(1.0)	9	14	161.5(5.6)	49.5(6.4)	18.9(1.5)	31	14
14-	164.7(10.6)	55.6(8.1)	20.4(0.6)	5	10	160.8(9.4)	49.3(9.0)	18.9(1.6)	22	30

Procedure

Foot measurements were obtained with the Infoot foot scanner (IFU-S-01), which was developed by I-Ware Lab, Japan. Eight digital cameras were used to synchronously record the foot measurements. The foot scanner was mounted on a level and smooth ground. After familiarization, each participant was required to stand still with bipedal support and with the body weight evenly distributed on both feet.

Statistical Analysis

Thirteen foot parameters of foot morphology are shown in Table 2.

All analyses were performed for the right foot [15-18]. Statistical analyses were conducted with SPSS 17.0 (IBM). One-sample Kolmogorov-Smirnov test was tested for all data. Independent t-test was used to compare the significant differences of all normally distributed data between group 1 (Chinese children) and

group 2 (Mongolian children). Effect size (ES) was calculated as a tool of consistent measure using Cohen's d value. The interpretation of ES was set at trivial (0-0.2), small (0.2-0.6), moderate (0.6-1.2) and large (> 1.2) [19]. Linear regression equation and correlation coefficient '*r*' were calculated. Chi-square test was used to determine the difference of the hallux valgus rate between genders and countries. The level of $p < 0.05$ was perceived as significance for statistical analyses.

Table 2: Foot dimension definitions

Foot dimension	Definition	Figure
Foot length (FL)	Distance between the back most point of the hell and the furthest toe point, parallel to the x axis.	
Heel to first metatarsal head (H-1st MTH)	Distance between the back most point of the hell and the most prominent point on the first metatarsal head, parallel to the x axis.	
Heel to fifth metatarsal head (H-5th MTH)	Distance between the back most point of the hell and the most prominent point on the fifth metatarsal head, parallel to the x axis.	
Foot width (FW)	Distance between the medial and lateral points that define the ball of foot measured parallel to the y axis.	
Heel width (HW)	Distance between the two widest points of the heel at 15% of the foot length from the heel to the toe.	
Instep height (IH)	Distance between the protrusion of the instep and the ground plane.	
Navicular height (NH)	Maximum height of the intersection of a vertical cross-section of the foot along the z axis with dorsal foot surface.	
Lateral malleolus height (LMH)	Vertical (z axis) distance from the ground plane to the most prominent point on the lateral malleolus.	
Toe #1 thickness (GT)	Height of the vertical cross-section at top of #1 toe tendon.	
Ball girth (BG)	Total perimeter of the ball section joining the most medial and most lateral metatarsal points.	
Instep girth (IG)	Smallest girth over middle cuneiform prominence.	
Heel girth (HG)	Shortest perimeter that contains the back most point of the heel and the maximum height of the intersection of a vertical cross-section of the foot along the z axis with dorsal foot surface.	
Hallux valgus angle (HVA)	The angle between these two straight lines: A straight line (I) was drawn through the protuberance of the first metatarsal-phalangeal joint and the heel (inside edge). A second straight line (II) was drawn through the protuberance of the first metatarsal-phalangeal joint and the great toe (proximal phalanx)	

RESULTS

Foot Dimension

The trend of foot length with age is shown in Figure 1. The foot length of children increased with age in both countries. Measures of absolute foot length of Chinese children were significantly greater than that of Mongolian children at the same age ($p < 0.05$).
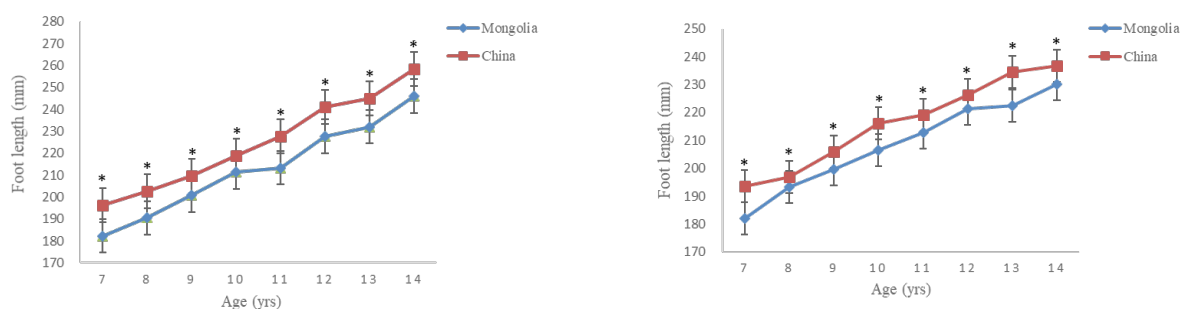

Figure 1. (a): Relationship between foot length and age of boys aged 7-14 years; (b): Relationship between foot length and age of girls aged 7-14 years

Descriptive values of H-1st MTH and H-5th MTH are shown in Table 3. Significant differences for H-1st MTH and H-5th MTH were not found between the two groups. Table 4 shows that the FW of Mongolian children was significantly smaller than that of Chinese children (8 to 10 years old). The HW of Mongolian children was significantly greater than that of Chinese children (9 to 10 years old). However, if we analyze the normalized HW, significant differences were found. It showed that the normalized HW of Mongolian children was significantly greater than that of Chinese children (7 to 10 years old).

Descriptive values of GT, IH, NH and LMH are shown in Table 5. Mongolian children showed significantly greater GT and LMH compared to Chinese children for all ages. Chinese children's feet were significantly smaller in IH than Mongolian children at the age of 7, 8, 9, 11, 12. Descriptive values of GT, IH, NH and LMH are shown in Table 6. When BG was normalized to the foot length, significant differences can be found. It showed that the normalized BG of Mongolian children was significantly greater than that of Chinese children at the age of 7, 14.

Table 3: Mean (SD) values of absolute and normalized foot length dimensions with *p* values and effect sizes for significant results for the two groups

Variables	Age (yrs)	Absolute (mm)		*p* value, ES*	Normalized (to foot length)		*p* value, ES*
		Group 1	Group 2		Group 1	Group 2	
H-1st MTH	7-	143.68(6.37)	132.63(9.12)	0.44	0.73 (0.02)	0.72 (0.01)	0.42
	8-	148.75(6.41)	139.07(11.75)	0.21	0.73 (0.02)	0.73 (0.01)	0.42
	9-	153.89(9.49)	147.38(7.01)	0.17	0.74 (0.02)	0.74 (0.02)	0.09
	10-	162.68(9.71)	153.82(11.74)	0.10	0.75 (0.02)	0.74 (0.02)	0.11
	11-	170.6(7.81)	154.62(8.52)	0.14	0.75 (0.02)	0.74 (0.01)	0.13
	12-	178.63(9.24)	167.39(10.63)	0.31	0.75 (0.01)	0.74 (0.01)	0.42
	13-	178.93(6.43)	170.03(9.79)	0.12	0.76 (0.02)	0.74 (0.01)	0.14
	14-	188.89(20.67)	177.41(9.83)	0.07	0.73 (0.02)	0.72 (0.01)	0.09
H-5th MTH	7-	126.44(6.18)	115.42(7.64)	0.45	0.64 (0.01)	0.63 (0.02)	0.42
	8-	130.41(6.45)	120.14(9.21)	0.39	0.64 (0.02)	0.63 (0.01)	0.43
	9-	136.91(6.12)	126.06(6.98)	0.12	0.65 (0.02)	0.63 (0.01)	0.09
	10-	142.65(8.5)	133.71(9.21)	0.09	0.65 (0.02)	0.63 (0.02)	0.11
	11-	148.01(8.32)	135.82(9.18)	0.07	0.65 (0.01)	0.64 (0.02)	0.09
	12-	155.69(8.42)	143.36(9.53)	0.23	0.65 (0.01)	0.64 (0.02)	0.13
	13-	156.91(7.23)	145.68(8.70)	0.47	0.65 (0.02)	0.64 (0.01)	0.42
	14-	164.16(20.6)	153.32(8.05)	0.09	0.65 (0.02)	0.64 (0.01)	0.10

Group 1: Chinese children, Group 2: Mongolian children.

Table 4: Mean (SD) values of absolute and normalized foot width dimensions with *p* values and effect sizes for significant results for the two groups

Variables	Age (yrs)	Absolute (mm)		*p* value, ES*	Normalized (to foot length)		*p* value, ES*
		Group 1	Group 2		Group 1	Group 2	
FW	7-	75.99(3.82)	67.54(5.54)	0.07	0.39 (0.02)	0.37 (0.01)	0.09
	8-	77.94(4.17)	68.64(5.96)	< 0.05, 1.80*	0.39 (0.03)	0.36 (0.02)	< 0.05, 1.17*
	9-	80.93(4.93)	72.75(4.14)	< 0.05, 1.79*	0.39 (0.02)	0.36 (0.01)	< 0.05, 1.89*
	10-	82.92(5.84)	77.29(5.08)	< 0.05, 1.03*	0.40 (0.03)	0.36 (0.01)	< 0.05, 1.78*
	11-	86.11(6.01)	76.56(3.87)	0.09	0.38 (0.02)	0.36 (0.02)	0.10
	12-	90.83(5.9)	81.04(5.83)	0.43	0.38 (0.06)	0.36 (0.03)	0.63
	13-	96.26(5.67)	83.03(5.68)	0.11	0.38 (0.03)	0.36 (0.02)	0.09
	14-	96.80(2.26)	87.55(7.23)	0.08	0.38 (0.02)	0.36 (0.02)	0.10
HW	7-	47.88(4.09)	48.77(3.55)	0.09	0.25 (0.02)	0.27 (0.02)	< 0.05, 1.00*
	8-	49.14(3.9)	50.54(3.19)	0.08	0.25 (0.02)	0.27 (0.02)	< 0.05, 1.00*
	9-	51.05(4.11)	53.07(3.52)	< 0.05, 0.53*	0.25 (0.01)	0.27 (0.02)	< 0.05, 1.26*
	10-	53.00(5.03)	55.70(3.82)	< 0.05, 0.61*	0.25 (0.01)	0.27 (0.02)	< 0.05, 1.26*
	11-	55.88(3.62)	57.68(3.50)	0.27	0.25 (0.02)	0.26 (0.01)	0.42
	12-	59.86(5.10)	61.42(4.43)	0.18	0.25 (0.01)	0.26 (0.02)	0.42
	13-	60.74(7.16)	62.00(4.60)	0.12	0.25 (0.01)	0.26 (0.01)	0.28
	14-	63.50(6.05)	65.06(4.33)	0.09	0.25 (0.01)	0.26 (0.02)	0.24

Group 1: Chinese children, Group 2: Mongolian children.
*p represents significant difference between Group 1 and Group 2

Table 5: Mean (SD) values of absolute and normalized foot height dimensions with *p* values and effect sizes for significant results for the two groups

Variables	Age (yrs)	Absolute (mm)		*p* value, ES*	Normalized (to foot length)		*p* value, ES*
		Group 1	Group 2		Group 1	Group 2	
GT	7-	14.64(1.46)	25.71(3.34)	< 0.01, 4.29*	0.07 (0.01)	0.14 (0.02)	< 0.01, 4.42*
	8-	15.89(1.70)	26.57(3.28)	< 0.01, 4.08*	0.08 (0.02)	0.14 (0.01)	< 0.01, 3.78*
	9-	15.9(1.52)	28.13(2.16)	< 0.01, 6.54*	0.08 (0.02)	0.14 (0.01)	< 0.01, 3.00*
	10-	16.78(1.35)	29.35(2.76)	< 0.01, 5.78*	0.08 (0.01)	0.14 (0.02)	< 0.01, 3.79*
	11-	17.28(1.24)	29.38(2.23)	< 0.01, 6.70*	0.08 (0.02)	0.14 (0.01)	< 0.01, 3.79*
	12-	17.69(1.44)	30.64(2.70)	< 0.01, 5.98*	0.07 (0.01)	0.14 (0.02)	< 0.01, 4.42*
	13-	19.14(2.34)	31.87(1.69)	< 0.01, 6.23*	0.08 (0.02)	0.14 (0.03)	< 0.01, 2.35*
	14-	19.44(2.85)	32.77(2.16)	< 0.01, 5.27*	0.08 (0.01)	0.14 (0.02)	< 0.01, 3.79*
IH	7-	43.09(5.60)	51.42(3.35)	< 0.05, 1.80*	0.22 (0.02)	0.27 (0.02)	< 0.05, 2.50*
	8-	45.13(4.85)	53.21(4.02)	< 0.05, 1.81*	0.22 (0.02)	0.27 (0.02)	< 0.05, 2.50*
	9-	47.90(4.95)	53.81(2.79)	< 0.05, 1.47*	0.23 (0.02)	0.27 (0.02)	< 0.05, 2.00*
	10-	53.18(5.16)	56.41(3.64)	0.11	0.24 (0.02)	0.27 (0.02)	0.09
	11-	53.49(6.94)	58.53(3.99)	< 0.05, 0.89*	0.24 (0.02)	0.28 (0.02)	< 0.05, 2.00*
	12-	55.10(6.38)	59.79(3.69)	< 0.05, 0.90*	0.25 (0.02)	0.28 (0.02)	< 0.05, 1.50*
	13-	64.22(4.77)	60.32(3.89)	0.15	0.26 (0.02)	0.28 (0.01)	0.10
	14-	67.45(4.74)	62.00(5.23)	0.06	0.26 (0.02)	0.28 (0.02)	0.09
NH	7-	60.37(3.90)	65.96(4.92)	0.09	0.31 (0.02)	0.33 (0.02)	0.06
	8-	61.53(3.91)	67.21(4.95)	0.07	0.31 (0.02)	0.33 (0.03)	0.11
	9-	64.41(3.72)	69.81(5.59)	0.09	0.31 (0.02)	0.33 (0.02)	0.09
	10-	68.86(5.73)	71.88(3.43)	0.13	0.32 (0.02)	0.34 (0.02)	0.31
	11-	71.79(4.09)	74.97(5.15)	0.09	0.32 (0.02)	0.34 (0.03)	0.15
	12-	76.49(5.06)	77.68(4.36)	0.17	0.32 (0.01)	0.34 (0.02)	0.09
	13-	79.06(4.58)	78.61(4.58)	0.21	0.32 (0.01)	0.34 (0.01)	0.10
	14-	81.18(5.27)	80.41(8.29)	0.37	0.32 (0.02)	0.34 (0.02)	0.30
LMH	7-	35.76(5.09)	50.46(5.12)	< 0.01, 2.88*	0.18 (0.01)	0.28 (0.02)	< 0.01, 6.32*
	8-	38.49(3.44)	51.79(6.33)	< 0.01, 2.61*	0.19 (0.02)	0.27 (0.01)	< 0.01, 5.06*
	9-	40.88 (5.21)	52.94(4.20)	< 0.01, 2.54*	0.19 (0.02)	0.27 (0.02)	< 0.01, 4.00*
	10-	45.52(5.95)	58.88(3.30)	< 0.01, 2.62*	0.22 (0.02)	0.28 (0.02)	< 0.01, 3.00*
	11-	45.71(4.82)	59.53(5.67)	< 0.01, 2.75*	0.21 (0.02)	0.28 (0.03)	< 0.01, 2.75*
	12-	50.36(5.50)	60.75(4.32)	< 0.01, 2.06*	0.21 (0.02)	0.27 (0.01)	< 0.01, 3.79*
	13-	54.40(3.75)	62.45(5.48)	< 0.01, 1.71*	0.22 (0.01)	0.27 (0.02)	< 0.01, 3.16*
	14-	56.53(4.46)	66.05(6.97)	< 0.01, 1.63*	0.22 (0.01)	0.27 (0.03)	< 0.01, 2.23*

Group 1: Chinese children, Group 2: Mongolian children.
p represents significant difference between Group 1 and Group 2

Table 6: Mean (SD) values of absolute and normalized foot breadth dimensions with *p* values and effect sizes for significant results for the two groups

Variables	Age (yrs)	Absolute (mm)		*p* value, ES*	Normalized (to foot length)		*p* value, ES*
		Group 1	Group 2		Group 1	Group 2	
BG	7-	190.19(11.63)	184.58(13.28)	0.06	0.97 (0.01)	0.99 (0.02)	< 0.05, 1.26*
	8-	197.25(10.32)	190.43(14.85)	0.09	0.97 (0.02)	0.99 (0.02)	0.15
	9-	205.65(10.83)	195.69(9.53)	0.43	0.97 (0.03)	0.99 (0.02)	0.33
	10-	208.54(5.84)	208.18(12.57)	0.83	0.96 (0.06)	0.99 (0.04)	0.59
	11-	216.85(14.82)	205.32(11.01)	0.47	0.94 (0.02)	0.96 (0.03)	0.31
	12-	227.03(13.09)	217.5(14.29)	0.09	0.95 (0.02)	0.96 (0.02)	0.29
	13-	238.65(12.15)	222.74(13.07)	0.07	0.96 (0.01)	0.97 (0.02)	0.42
	14-	242.15(4.94)	235.41(16.06)	0.10	0.94 (0.02)	0.96 (0.03)	< 0.05, 0.78*
IG	7-	199.53(12.00)	185.42(11.56)	0.37	1.02 (0.03)	1.01 (0.03)	0.59
	8-	202.54(19.7)	192.00(13.39)	0.51	1.00 (0.02)	0.99 (0.04)	0.83
	9-	206.86(11.85)	197.00(9.08)	0.43	0.99 (0.03)	0.98 (0.02)	0.09
	10-	203.01(12.31)	207.18(11.07)	0.81	0.96 (0.05)	0.96 (0.04)	0.91
	11-	224.31(18.67)	206.71(9.54)	0.23	0.97 (0.05)	0.96 (0.03)	0.76
	12-	219.8(22.39)	216.68(15.48)	0.75	0.93 (0.04)	0.95 (0.02)	0.42
	13-	241.55(15.15)	222.97(14.48)	0.11	0.98 (0.02)	0.96 (0.01)	0.33
	14-	252.41(5.05)	235.55(14.76)	0.21	0.96 (0.04)	0.96 (0.02)	0.83
HG	7-	263.46(17.25)	243.92(12.8)	0.23	1.32 (0.05)	1.34 (0.03)	0.42
	8-	269.45(34.51)	254.5(15.82)	0.51	1.34 (0.03)	1.33 (0.02)	0.55
	9-	272.72(14.18)	264.00(12.21)	0.43	1.30 (0.03)	1.33 (0.03)	0.10
	10-	277.71(30.56)	280.82(15.08)	0.79	1.32 (0.07)	1.31 (0.05)	0.81
	11-	300.33(38.96)	280.53(11.53)	0.11	1.28 (0.07)	1.31 (0.03)	0.61
	12-	304.95(28.28)	296.57(18.50)	0.83	1.28 (0.03)	1.30 (0.03)	0.18
	13-	311.22(16.28)	301.65(16.07)	0.41	1.27 (0.01)	1.31 (0.03)	0.30
	14-	328.13(17.18)	317.95(19.19)	0.37	1.25 (0.04)	1.29 (0.02)	0.18

Group 1: Chinese children, Group 2: Mongolian children.
p represents significant difference between Group 1 and Group 2

Correlation of Foot Parameters

The foot length and ball girth are considered to be the main functional foot parameters for shoe fitting [20]. Linear regression analysis was used to identify the relationship between foot length and ball girth for both genders. The regression results are shown in Figure 3 as follows:

(1) For Chinese boys: Ball girth = (0.847 x foot length) + 39.85, r^2 = 0.717;

(2) For Chinese girls: Ball girth = (0.859 x foot length) + 26.91, r^2 = 0.738;

(3) For Mongolian boys: Ball girth = (0.791 x foot length) + 39.11, r^2 = 0.802;

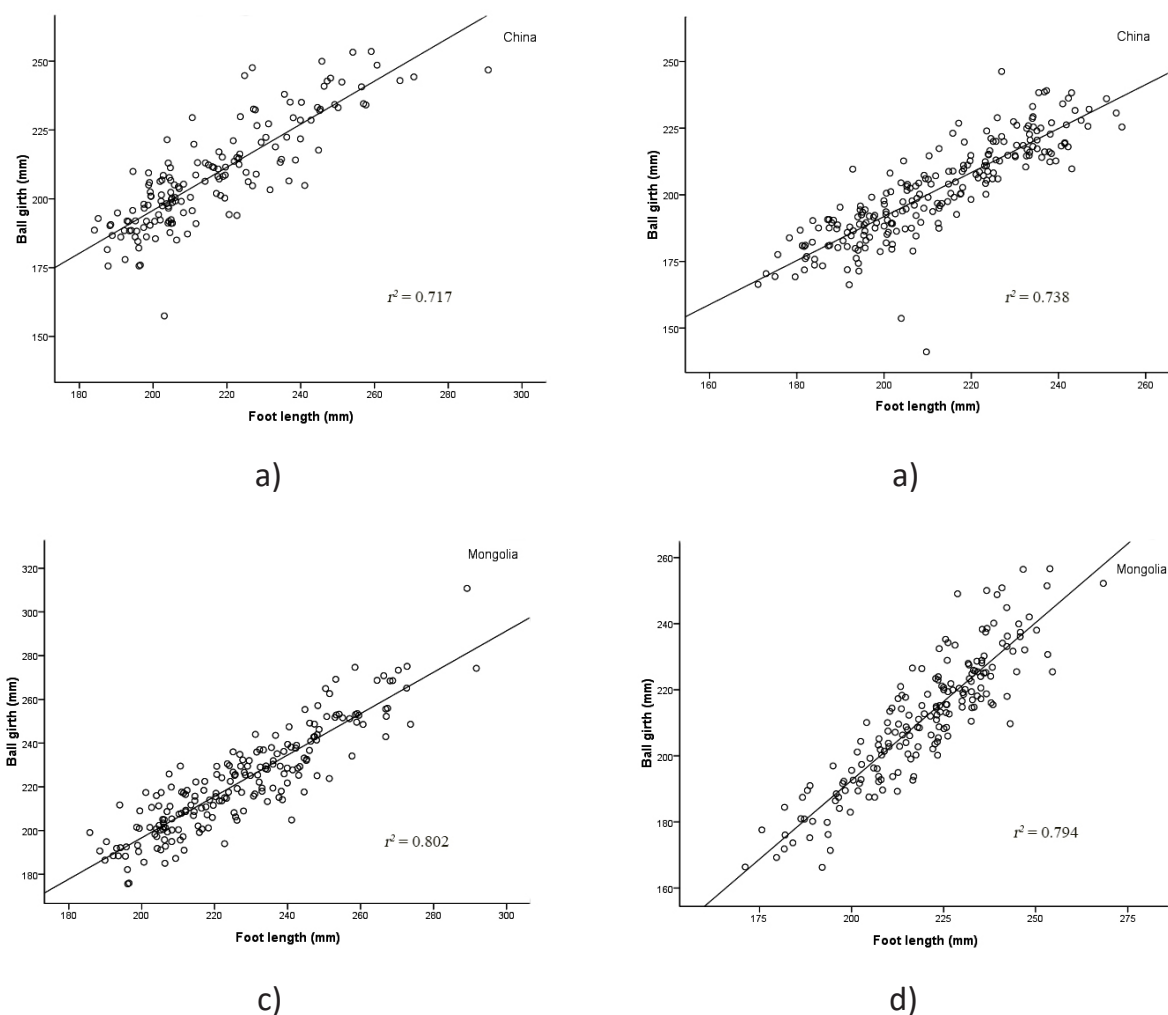(4) For Mongolian girls: Ball girth = (0.768 x foot length) + 31.26, r^2 = 0.794.

Figure 3. Correlation between foot length and ball girth for both genders, by countries.
(a): Chinese boys; (b): Chinese girls; (c): Mongolian boys; (d): Mongolian girls

Hallux Valgus

Measures of absolute *hallux valgus* angles are shown in Table 7. It was observed that *hallux valgus* angles of Chinese children were significantly greater than those of Mongolian children ($p < 0.05$). The degrees of *hallux valgus* were divided into three grades in Table 8: "Straight or mild", "Moderate" and "Severe" [12]. Chi-square test was used to determine the difference of the *hallux valgus* rate between genders and countries. The results showed that Chinese children appeared to demonstrate higher incidences of *hallux valgus* compared to Mongolian children of both sexes (for boys: $x^2 = 10.97$, $p = 0.004$; for girls: $x^2 = 14.48$, $p = 0.001$, respectively). Results revealed that girls appeared to demonstrate higher incidences of *hallux valgus* compared with boys in both countries for all ages (for China: $x^2 = 12.90$, $p = 0.002$; for Mongolia: $x^2 = 10.68$, $p = 0.005$, respectively).

Table 7: Comparison of means (standard deviations) of *hallux valgus* of the Chinese and Mongolian populations

Foot dimension	Boys		Girls	
	China	Mongolia	China	Mongolia
Hallux valgus angles (°)	8.16 (4.49)	6.05 (3.21)	10.04 (4.53)	7.31 (3.05)

Table 8: The number and proportion of participants with *hallux valgus*

Classification of hallux valgus	Girls, n (%)		Boys, n (%)	
	China	Mongolia	China	Mongolia
Straight or mild (> - 10° and < + 10°)	128(57.15%)	112(73.20%)	114(73.55%)	162(87.10%)
Moderate (> + 11° and < + 15°)	67(29.91%)	36(23.53%)	34(21.93%)	22(11.82%)
Severe (> + 16°)	29(12.95%)	5(3.27%)	7(4.52%)	2(1.08%)
Total	224	153	155	186

DISCUSSION

The results of this study showed that the foot length of Chinese children was significantly greater than that of Mongolian children of the same age. Studies have already shown the significant association between body height, body mass and foot length [21-23]. To match the Mongolian database, the Chinese database was controlled for age, body height and body mass as variable factors. But the tendency of higher height and body mass of Chinese children could be a reason for the difference in foot length. Previous study assumed that the differences in daily diet (especially protein intake) may be related to the differences in children' growth [6].

In comparison to the Chinese children, Mongolian children showed significantly greater toe thickness, instep height and lateral malleolus height. It implies that the vamp designed for Mongolian children should be of sufficient depth. Results showed that the foot width of Chinese children is significantly greater than that of Mongolian children. It indicates that the vamp designed for Chinese children should allow sufficient space around the metatarsal joint area, in order not to damage the soft cartilaginous toes or toe nails [18]. In this study, the absolute foot width of the Chinese children was similar to that of the Filipino children in Kusumoto's study [7], while Chinese children had a larger foot length compared to Filipino children. It is postulated that not only differences in dietary habit, but also differences in ethnicities and region may be responsible for modifying the shape of foot. The normalized foot dimensions provide the necessary information for describing the foot characteristics [24]. Interestingly, when the foot measures were normalized to the length of the foot, significantly greater ball girth and heel width were found in Mongolian children.

The most common foot deformity known and irregularity treated is *hallux valgus*, which affects more than 35% of individuals [25]. The results obtained in our study showed that girls appeared to demonstrate higher rates of moderate *hallux valgus* compared to boys of the same age in both countries, which have been proved in early literature [26]. However, Chinese children could be at a higher risk for *hallux valgus* compared to Mongolian children. Results showed that 30.11% of Chinese girls and 22.3% of Chinese boys aged from 7 to 14 years had *hallux valgus* deformity (greater than 8°). But the exact prevalence rate of *hallux valgus* is difficult to determine because of the paucity of large-scale epidemiological studies and varying definitions used in the literature. There is no unified explanation of what angle represents a healthy or deformed foot in the big toe area. Some authors indicated 8°, others used 10°, or 15° [25-29]. Specifically, hallux valgus found in different populations proved to be related to poorly-fitting footwear [25, 28, 29]. The prevalence of hallux valgus is higher in Chinese children, mainly due to the habit of wearing shoes with a narrow toe box. Because shoe styles for children tend to follow the fashion trends for adults, more so in regards to shape rather than the comfort [4]. Therefore, the footwear industry should vary the last dimensions on the basis of foot morphology when exporting products to specific countries.

CONCLUSION

In comparison to the Mongolian children, Chinese children had significantly greater foot length and foot width. However, Mongolian children showed significantly greater toe thickness, instep height, lateral malleolus height, heel width and ball girth than those of Chinese children. The hypothesis is proved that there is obvious difference in foot morphology between Chinese children and Mongolian children. This study thus suggests that small variations in foot

morphology should be considered in the shoe design for specific children. It is hoped that prospective studies could measure more foot parameters, like Chippaux-Smirak and Staheli indices of the longitudinal arch, which are also important variables for the footwear industry.

Conflict of Interest

Acknowledgments

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