

# Hand anthropometry and its relation to grip/pinch strength in children aged 5 to 13 years

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Juan Wen<sup>1,2,\*</sup>, Jing Wang<sup>1,\*</sup>, Qu Xu<sup>1,\*</sup>,  
Yan Wei<sup>3,\*</sup>, Lei Zhang<sup>1</sup>, Jiabin Ou<sup>1</sup>, Qin Hong<sup>1</sup>,  
Chenbo Ji<sup>1,2</sup>, Xia Chi<sup>1,4</sup>  and Meiling Tong<sup>1,4</sup>

## Abstract

**Objective:** To evaluate the development level of children's physiological hand shape indicators and their relationship with grip/pinch strength.

**Methods:** Hand shape and grip/pinch strength in 1255 Chinese children aged 5 to 13 years were prospectively measured. Development curves of physiological hand shape indicators and grip/pinch strength were constructed.

**Results:** The physiological hand shape indicators (full length, middle finger length, width, and wrist thickness) and grip/pinch strength of boys and girls increased with age and showed statistically significant differences at different ages. In most age groups, hand shape indicators and grip/pinch strength were larger in boys than in girls of the same age. After puberty, the physiological hand shape indicators and grip/pinch strength increased more rapidly in girls than in boys of the same age, and the differences gradually decreased thereafter. Moreover, a significant difference in pinch strength between the right and left hands was observed in most age groups. Pearson correlation analysis showed that the physiological hand shape indicators were significantly positively correlated with grip/pinch strength, height, weight, and body mass index.

**Conclusions:** This study revealed the relationship between physiological hand shape indicators and grip/pinch strength and provided reference ranges of physiological hand shape indicators and grip/pinch strength for children.

<sup>1</sup>Department of Children Health Care, Women's Hospital of Nanjing Medical University, Nanjing Maternity and Child Health Care Hospital, Nanjing, China

<sup>2</sup>Nanjing Maternity and Child Health Care Institute, Women's Hospital of Nanjing Medical University, Nanjing Maternity and Child Health Care Hospital, Nanjing, China

<sup>3</sup>Department of Child Health Care, The Affiliated Wuxi Children's Hospital of Nanjing Medical University, Wuxi, China

<sup>4</sup>Institute of Pediatrics, Nanjing Medical University, Nanjing, China

\*These authors contributed equally to this work.

## Corresponding author:

Xia Chi, Department of Children Health Care, Women's Hospital of Nanjing Medical University, Nanjing Maternity and Child Health Care Hospital, No. 123 Tianfeixiang, Mochou Road, Nanjing 210004, China.

Email: [chixia2001@njmu.edu.cn](mailto:chixia2001@njmu.edu.cn)



**Keywords**

Hand shape, grip strength, pinch strength, children, physiological indicators, height, weight, body mass index, reference values

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**Introduction**

Physiological hand shape indicators can indirectly or directly reflect the development of the hand. The main indicators are the full length of the hand, middle finger length, width of the hand, and wrist thickness.<sup>1</sup> Physiological hand shape indicators can be simply and easily measured, and they are important indices with which to evaluate children's growth and development, especially their fine motor ability. Several studies have shown that physical hand shape is associated with height, weight, nutritional status, and fine motor ability in different populations.<sup>2-4</sup> However, physiological hand shape indicators are often ignored in clinical practice.

Grip strength and pinch strength mainly represent the muscle strength of the hand, forearm, and upper limbs and are the basis of upper limb function. Therefore, they are regarded as important references in the evaluation of hand function, especially fine motor ability.<sup>5</sup> A research group from Sweden measured the height, weight, hand length, and grip strength of 530 children aged 4 to 16 years.<sup>6</sup> Sex-related differences were observed in hand length and grip strength, and strong correlations were found between grip strength and the anthropometric measures of weight, height, and particularly hand length. Another study from Saudi Arabia showed similar results, suggesting a positive correlation between hand length and grip strength.<sup>7</sup> Moreover, several countries have established normative data for hand grip strength, including Sweden, Brazil, The Netherlands, the United States, and

others; however, no such normative data have been established in China.<sup>6,8-11</sup> Relatively few studies have focused on pinch strength. In 1986, a study in a seven-county area of Milwaukee established normative data for children aged 6 to 19 years in four tests of hand strength. The authors found that increases in pinch strength coincided with increases in chronological age, that males were stronger than females in all age groups, and that hand dominance did not significantly affect hand strength scores.<sup>12</sup> In 2002, a study of preschoolers from New York City was performed to investigate whether relationships existed among grip strength, pinch strength, hand size, age, and sex.<sup>13</sup> The authors found that hand strength and hand size increased with each age level. However, there was no statistically significant difference in hand strength between the boys and the girls or between the preferred and non-preferred hands. Moreover, in 2003, Korean researchers established the normative data of pinch strength for children aged 7 to 12 years and found differences among the various types of pinch strength: lateral pinch strength was greater than palmar pinch strength, and tip pinch strength was weakest.<sup>14</sup>

Chinese studies on physiological hand shape indicators are limited, and most such studies have focused on the prediction of height and weight.<sup>2</sup> Even fewer studies on physiological hand shape indicators and grip/pinch strength have been performed in China. Therefore, further studies on children's physiological hand shape indicators and grip/pinch strength are necessary

to provide a working basis for clinical practice. In this study, we measured the hand shape and grip/pinch strength of 1255 Chinese children aged 5 to 13 years to objectively and normatively evaluate the development levels of children's physiological hand shape indicators and their relationships with grip/pinch strength.

## Materials and methods

### Study design

This study was conducted according to the guidelines in the Declaration of Helsinki, and all procedures involving children were approved by the Institutional Review Board of Nanjing Maternity and Child Health Care Hospital. Either a legal guardian or parent provided informed consent for each child's participation.

This prospective study involved a multi-stage stratified random sampling method to randomly select three urban areas (Gulou, Qinhuai, and Qixia) in Nanjing city. Two kindergartens and two primary schools were randomly selected in each urban area. We obtained a list of all children aged 5 to 13 years and numbered them respectively. Next, using random number tables, we randomly selected children in each school according to specific sex and age proportions. Children with a history of hand trauma, plastic surgery, abnormal hand development, endocrine disease, and genetic metabolic disease, were excluded from this study.

### Anthropometric measurements

Age and sex were recorded for each child. Body weight and height were measured using a standard digital weighing scale and a standard height scale with accuracy of 0.05 kg and 0.1 cm, respectively. Body mass index (BMI) was calculated using the formula  $BMI = \text{weight (kg)}/\text{height (m)}^2$

After they had been informed about the procedure for measurement of, physiological hand shape indicators, the children were asked to sit comfortably, spread and stretch out their hands, and place them on a table. Four anthropometric variables of the hand were measured: the full length of the hand, middle finger length, width of the hand, and wrist thickness.<sup>15</sup> The full length of the hand was measured as the distance from the tip of the middle finger to the midline of the distal wrist crease. The middle finger length was measured as the distance from the tip of the middle finger to the crease of the metacarpophalangeal joint. The width of the hand was measured as the distance from the radial side of the second metacarpal joint to the ulnar side of the fifth metacarpal joint. The wrist thickness was measured as the sagittal diameter of the wrist at the crease of the proximal wrist. The full length of the hand and middle finger length were measured using a flexible measuring tape, and the width of hand and wrist thickness were measured using a vernier caliper. All variables were measured in centimeters.

### Hand grip/pinch strength recording

The children were seated at a desk facing the evaluator with their shoulder adducted and neutrally rotated and their elbow flexed at 90°. The wrist was positioned between 0° and 30° of dorsiflexion and between 0° and 15° of ulnar deviation, but it was not positioned in flexion. The forearm was positioned in neutral for evaluation of grip strength and lateral pinch strength and in pronation for evaluation of palmar pinch strength and tip pinch strength.<sup>14</sup> Grip strength was tested first, followed by palmar pinch, lateral pinch, and tip pinch.

The Jamar Hydraulic Hand Dynamometer and Jamar Hydraulic Pinch Gauge (Sammons Preston; Performance Health, Chicago, IL, USA) were used to

measure grip strength and pinch strength, respectively, in pounds. Three consecutive measurements were performed while alternating the left and right hands. The mean of the three measurements was used as the outcome of this study. For measurement of palmar pinch, the pinch meter was grasped between the pads of the thumb, index finger, and long finger. For measurement of lateral pinch, the pinch gauge was positioned between the pad of the thumb and the radial side of the middle phalanx of the index finger. For measurement of

**Table 1.** Children's basic characteristics.

Sex	Age (years)	n	Height (cm)	Weight (kg)
Boys	5.0-5.4	65	115.39 ± 4.62	20.92 ± 4.25
	5.5-5.9	63	118.78 ± 5.23	22.93 ± 4.41
	6.0-6.4	60	121.68 ± 4.60	22.99 ± 3.88
	6.5-6.9	54	125.92 ± 5.10	25.99 ± 4.33
	7.0-7.4	33	131.02 ± 4.28	29.81 ± 5.72
	7.5-7.9	25	132.61 ± 6.60	30.27 ± 7.38
	8.0-8.4	30	135.34 ± 7.30	33.05 ± 7.60
	8.5-8.9	29	140.22 ± 6.67	36.51 ± 9.86
	9.0-9.4	32	143.49 ± 6.46	39.52 ± 10.33
	9.5-9.9	26	142.48 ± 7.22	37.13 ± 8.27
	10.0-10.4	34	147.63 ± 5.99	42.10 ± 8.52
	10.5-10.9	32	149.89 ± 7.86	42.88 ± 9.92
	11.0-11.4	35	154.05 ± 7.66	46.31 ± 12.15
	11.5-11.9	34	157.50 ± 7.14	50.34 ± 12.11
12.0-12.4	60	158.76 ± 10.02	53.20 ± 13.61	
12.5-13.0	13	166.28 ± 9.15	57.05 ± 13.36	
Girls	5.0-5.4	65	113.26 ± 4.34	19.08 ± 2.85
	5.5-5.9	62	117.47 ± 5.12	22.22 ± 12.42
	6.0-6.4	63	120.41 ± 4.53	22.88 ± 4.25
	6.5-6.9	54	123.71 ± 8.49	24.26 ± 5.01
	7.0-7.4	30	128.46 ± 4.18	25.02 ± 2.44
	7.5-7.9	27	131.85 ± 5.13	28.50 ± 5.43
	8.0-8.4	32	135.92 ± 6.28	29.85 ± 5.43
	8.5-8.9	28	137.07 ± 6.80	31.16 ± 7.48
	9.0-9.4	37	138.89 ± 6.57	33.84 ± 6.46
	9.5-9.9	25	143.83 ± 8.63	35.64 ± 8.30
	10.0-10.4	30	147.03 ± 6.77	38.95 ± 8.71
	10.5-10.9	31	150.65 ± 6.08	42.22 ± 8.20
	11.0-11.4	36	153.49 ± 6.87	42.77 ± 6.78
	11.5-11.9	39	158.15 ± 6.18	48.93 ± 11.90
12.0-12.4	61	160.94 ± 6.43	50.95 ± 8.71	
12.5-13.0	10	158.53 ± 2.03	45.01 ± 6.19	

**Table 2.** Physiological hand shape indicators (in centimeters).

Sex	Age (years)	Left hand				Right hand			
		Full length	Middle finger length	Width	Wrist thickness	Full length	Middle finger length	Width	Wrist thickness
Boys	5.0-5.4	13.08 ± 0.72	5.54 ± 0.33	6.10 ± 0.35	2.69 ± 0.38	13.08 ± 0.72	5.54 ± 0.33	6.10 ± 0.35	2.69 ± 0.38
	5.5-5.9	13.42 ± 0.79	5.67 ± 0.38	6.30 ± 0.37	2.76 ± 0.43	13.42 ± 0.79	5.67 ± 0.38	6.32 ± 0.36	2.76 ± 0.43
	6.0-6.4	13.79 ± 0.71	5.86 ± 0.34	6.37 ± 0.29	2.70 ± 0.42	13.79 ± 0.71	5.86 ± 0.34	6.38 ± 0.29	2.70 ± 0.42
	6.5-6.9	14.16 ± 0.81	5.88 ± 0.44	6.59 ± 0.48	2.74 ± 0.38	14.16 ± 0.81	5.88 ± 0.44	6.60 ± 0.48	2.74 ± 0.38
	7.0-7.4	14.19 ± 0.76	6.05 ± 0.52	6.70 ± 0.57	3.04 ± 0.53	14.19 ± 0.76	6.05 ± 0.52	6.70 ± 0.57	3.04 ± 0.53
	7.5-7.9	14.22 ± 0.95	6.05 ± 0.62	6.56 ± 0.63	2.96 ± 0.37	14.22 ± 0.95	6.05 ± 0.62	6.56 ± 0.63	2.96 ± 0.37
	8.0-8.4	15.02 ± 0.88	6.34 ± 0.51	6.94 ± 0.53	3.25 ± 0.42	15.02 ± 0.88	6.34 ± 0.51	6.94 ± 0.53	3.25 ± 0.42
	8.5-8.9	15.18 ± 0.96	6.50 ± 0.63	7.23 ± 0.80	3.33 ± 0.54	15.18 ± 0.96	6.50 ± 0.63	7.23 ± 0.80	3.33 ± 0.54
	9.0-9.4	15.94 ± 0.83	6.81 ± 0.75	7.53 ± 0.84	3.34 ± 0.38	15.94 ± 0.83	6.81 ± 0.75	7.53 ± 0.84	3.34 ± 0.38
	9.5-9.9	15.53 ± 0.80	6.44 ± 0.55	7.17 ± 0.57	3.24 ± 0.33	15.53 ± 0.80	6.44 ± 0.55	7.17 ± 0.57	3.24 ± 0.33

(continued)

Table 2. Continued.

Sex	Age (years)	Left hand				Right hand			
		Full length	Middle finger length	Width	Wrist thickness	Full length	Middle finger length	Width	Wrist thickness
Girls	10.0–10.4	16.18 ± 1.11	6.94 ± 0.71	7.49 ± 0.67	3.30 ± 0.38	16.18 ± 1.11	6.94 ± 0.71	7.49 ± 0.67	3.30 ± 0.38
	10.5–10.9	16.80 ± 1.24	7.07 ± 0.67	7.75 ± 0.84	3.36 ± 0.35	16.80 ± 1.24	7.07 ± 0.67	7.75 ± 0.84	3.36 ± 0.35
	11.0–11.4	17.11 ± 1.26	7.33 ± 0.70	7.91 ± 0.80	3.54 ± 0.47	17.11 ± 1.26	7.33 ± 0.70	7.91 ± 0.80	3.54 ± 0.47
	11.5–11.9	17.54 ± 1.21	7.54 ± 0.70	8.02 ± 0.73	3.58 ± 0.43	17.54 ± 1.21	7.54 ± 0.70	8.02 ± 0.73	3.58 ± 0.43
	12.0–12.4	17.65 ± 1.11	7.68 ± 0.77	8.12 ± 0.92	3.65 ± 0.44	17.65 ± 1.11	7.68 ± 0.77	8.12 ± 0.92	3.65 ± 0.44
	12.5–13.0	18.04 ± 1.30	7.81 ± 0.76	8.39 ± 0.67	3.60 ± 0.40	18.04 ± 1.30	7.81 ± 0.76	8.39 ± 0.67	3.60 ± 0.40
	5.0–5.4	12.72 ± 0.72	5.40 ± 0.34	5.85 ± 0.31	2.60 ± 0.34	12.72 ± 0.72	5.40 ± 0.34	5.85 ± 0.31	2.60 ± 0.34
	5.5–5.9	13.17 ± 0.78	5.65 ± 0.37	6.03 ± 0.35	2.61 ± 0.35	13.17 ± 0.78	5.65 ± 0.38	6.04 ± 0.35	2.61 ± 0.35
	6.0–6.4	13.61 ± 0.79	5.83 ± 0.43	6.19 ± 0.38	2.67 ± 0.35	13.61 ± 0.78	5.83 ± 0.43	6.20 ± 0.37	2.67 ± 0.35
	6.5–6.9	13.71 ± 0.87	5.79 ± 0.47	6.32 ± 0.51	2.70 ± 0.37	13.71 ± 0.87	5.79 ± 0.47	6.32 ± 0.51	2.70 ± 0.37
	7.0–7.4	13.95 ± 0.79	6.06 ± 0.58	6.45 ± 0.57	2.79 ± 0.39	13.95 ± 0.79	6.06 ± 0.58	6.45 ± 0.57	2.79 ± 0.39
	7.5–7.9	14.18 ± 1.09	6.07 ± 0.53	6.48 ± 0.73	2.94 ± 0.42	14.18 ± 1.09	6.07 ± 0.53	6.48 ± 0.73	2.94 ± 0.42
	8.0–8.4	14.84 ± 1.00	6.37 ± 0.59	6.65 ± 0.55	3.01 ± 0.31	14.84 ± 1.00	6.37 ± 0.59	6.65 ± 0.55	3.01 ± 0.31
	8.5–8.9	14.85 ± 0.92	6.56 ± 0.55	6.80 ± 0.49	3.13 ± 0.35	14.85 ± 0.92	6.56 ± 0.55	6.80 ± 0.49	3.13 ± 0.35
	9.0–9.4	15.43 ± 0.95	6.72 ± 0.70	7.04 ± 0.87	3.05 ± 0.32	15.43 ± 0.95	6.72 ± 0.70	7.04 ± 0.87	3.05 ± 0.32
9.5–9.9	15.98 ± 0.84	6.82 ± 0.47	7.13 ± 0.50	3.18 ± 0.42	15.98 ± 0.84	6.82 ± 0.47	7.13 ± 0.50	3.18 ± 0.42	
10.0–10.4	16.20 ± 0.95	7.08 ± 0.73	7.39 ± 0.83	3.11 ± 0.39	16.20 ± 0.95	7.08 ± 0.73	7.39 ± 0.83	3.11 ± 0.39	
10.5–10.9	16.72 ± 1.11	7.16 ± 0.73	7.43 ± 0.73	3.20 ± 0.31	16.72 ± 1.11	7.16 ± 0.73	7.43 ± 0.73	3.20 ± 0.31	
11.0–11.4	17.12 ± 1.13	7.51 ± 0.69	7.73 ± 0.80	3.34 ± 0.31	17.12 ± 1.13	7.51 ± 0.69	7.73 ± 0.80	3.34 ± 0.31	
11.5–11.9	17.35 ± 0.88	7.42 ± 0.50	7.74 ± 0.73	3.48 ± 0.41	17.35 ± 0.88	7.42 ± 0.50	7.74 ± 0.73	3.48 ± 0.41	
12.0–12.4	17.82 ± 1.16	7.82 ± 0.86	8.07 ± 0.95	3.51 ± 0.29	17.82 ± 1.16	7.82 ± 0.86	8.07 ± 0.95	3.51 ± 0.29	
12.5–13.0	17.54 ± 0.56	7.58 ± 0.40	7.85 ± 0.63	3.11 ± 0.33	17.54 ± 0.56	7.58 ± 0.40	7.85 ± 0.63	3.11 ± 0.33	

tip pinch, the pinch meter was grasped with the tips of the thumb and index finger.

### Statistical analysis

Continuous variables are presented as mean  $\pm$  standard deviation or percentile, and Student's *t*-test or one-way analysis of variance was used for comparison between groups. Categorical variables are presented as percentage, and the  $\chi^2$  test was used for comparison among groups. Correlation analysis was performed using Pearson's correlation coefficient. Partial correlation analysis was conducted to control for the influence of age on correlations. Multivariate regression analysis was also

performed, taking key potential confounders (age, sex, height, and weight) into account. Regression curve estimation was used to plot the development curve. All statistical analyses were performed with PASW Statistics for Windows, Version 18.0 (SPSS Inc., Chicago, IL, USA), and a *P* value of  $\leq 0.05$  in a two-sided test was considered statistically significant.

## Results

### Children's basic characteristics

In total, 1255 children (625 boys, 630 girls) were enrolled in this study. Their basic characteristics (sex, age, height, and

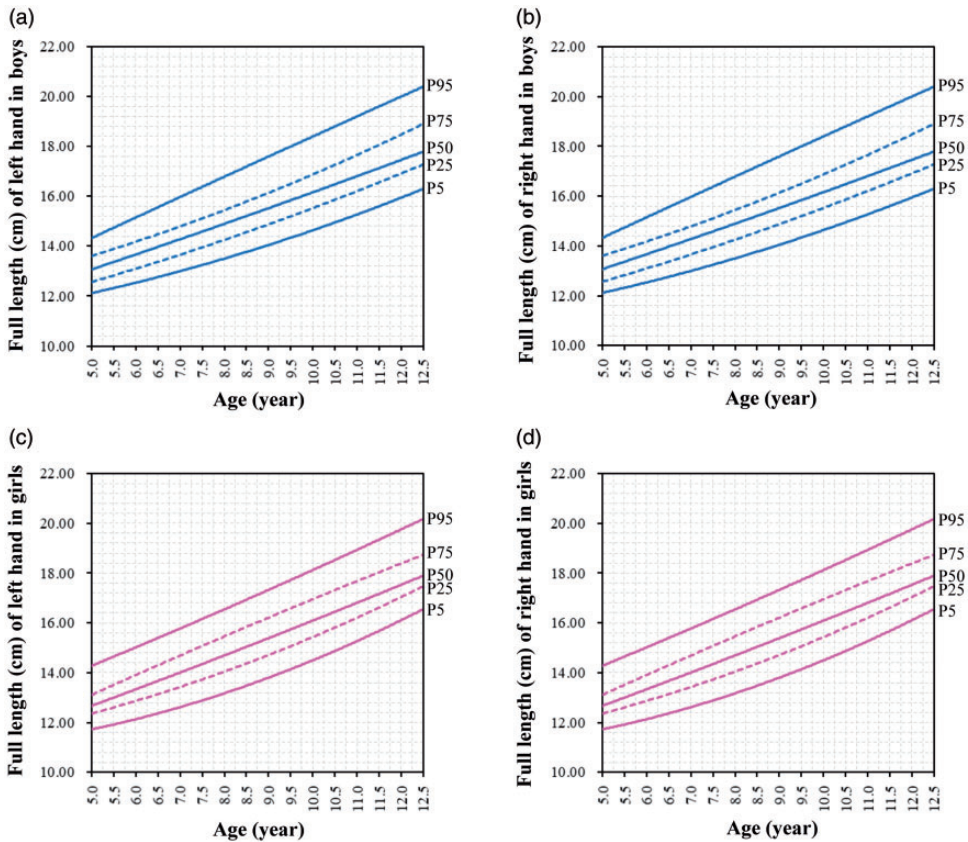


Figure I. Full length of left and right hand in boys and girls.



weight) are shown in Table 1. The children were divided into 16 age groups at 6-month age intervals (5.0–5.4, 5.5–5.9, 6.0–6.4, 6.5–6.9, 7.0–7.4, 7.5–7.9, 8.0–8.4, 8.5–8.9, 9.0–9.4, 9.5–9.9, 10.0–10.4, 10.5–10.9, 11.0–11.4, 11.5–11.9, 12.0–12.4, and 12.5–13.0 years).

### Analysis of physiological hand shape indicators

The full length of the hand, middle finger length, width of the hand, and wrist thickness of boys and girls increased with age, and there were statistically significant differences in these hand shape indicators at different ages (all  $P < 0.001$ ) in line with the basic trend of physical growth

and development of children (Table 2). A regression curve was estimated based on the percentile of each physiological hand shape indicator, and a development curve of physiological hand shape indicators was constructed to provide normative data for each physiological hand shape indicator in children aged 5 to 13 years (Figures 1–4). Only slight differences were present between the left and right hands of children of the same sex and age; no statistical significance was found, suggesting symmetry in the physical development of normal children.

Sex-related differences were found in the development of the full length of the hand, middle finger length, width of the hand, and wrist thickness in children aged 5 to 13 years.

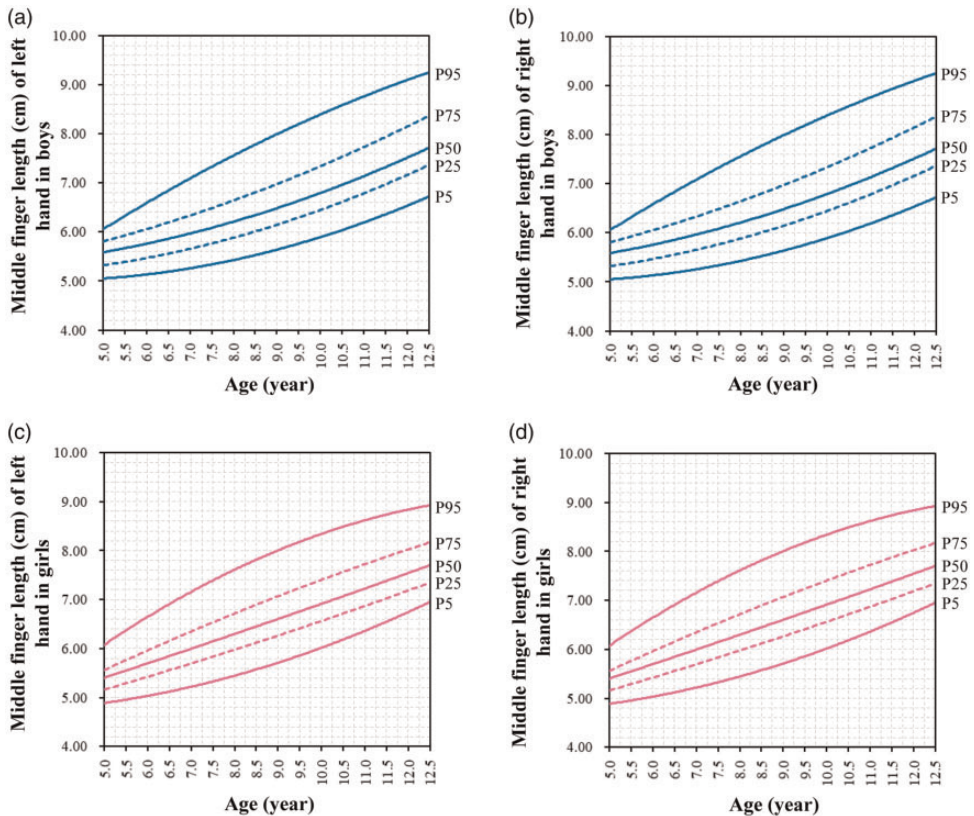


Figure 2. Middle finger length of left and right hand in boys and girls.

In most age groups, the shape of both the left and right hands was larger in boys than girls of the same age; this was especially true for wrist thickness. After puberty, compared with boys of the same age, girls' physiological hand shape indicators grew faster and the differences gradually decreased. In the age groups of 5.0–5.4, 6.5–6.9, and 9.0–9.4 years, the full length of both hands was significantly longer in boys than girls ( $P < 0.05$ ). In the age group of 5.0–5.4 years, the middle finger length of both hands was significantly longer in boys than girls ( $P < 0.05$ ). In the age groups of 5.0–5.4, 5.5–5.9, 6.0–6.4, 6.5–6.9, 8.0–8.4, 8.5–8.9, and 9.0–9.4 years, the width of both hands was significantly greater in boys than girls ( $P < 0.05$ ). In the age

groups of 5.5–5.9, 7.0–7.4, 8.0–8.4, 9.0–9.4, 11.0–11.4, 12.0–12.4, and 12.5–13.0 years, the wrist thickness of both hands was significantly greater in boys than girls ( $P < 0.05$ ). These results suggest that although sex-related differences exist in the development of physiological hand shape indicators in children aged 5 to 13 years, the differences gradually decrease after puberty.

### Analysis of grip/pinch strength

The grip, palmar pinch, lateral pinch, and tip pinch strength of boys and girls increased with age, and there were statistically significant differences in grip/pinch strength at different ages ( $P < 0.001$ ) (Table 3). A regression curve was estimated

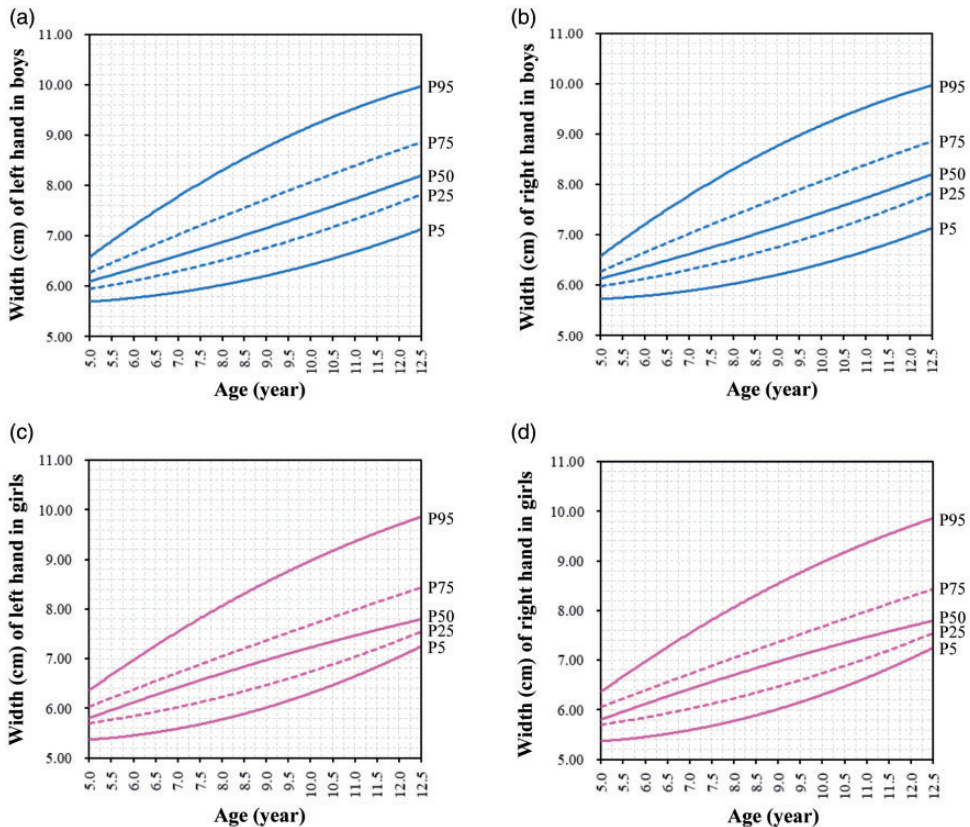


Figure 3. Width of left and right hand in boys and girls.



based on the percentile of grip/pinch strength, and a development curve of grip/pinch strength was constructed to provide normative data for grip/pinch strength in children aged 5 to 13 years (Figures 5–8). In the age groups of 5.5–5.9, 7.0–7.4, 8.0–8.4, and 9.0–9.4 years, grip strength of both hands was significantly greater in boys than girls ( $P < 0.05$ ). In the age groups of 5.0–5.4, 5.5–5.9, 6.0–6.4, 6.5–6.9, and 7.0–7.4 years, palmar and lateral pinch strength of both hands was significantly greater in boys than girls ( $P < 0.05$ ). After 7.5 years of age, palmar and lateral pinch strength of the right hand was greater in boys than girls in some age groups ( $P < 0.05$ ). In the age groups of

7.0–7.4, 9.0–9.4, and 10.0–10.4 years, tip pinch strength of both hands was significantly larger greater in boys than girls ( $P < 0.05$ ).

Grip strength was not significantly different between the right and left hands of children aged 5 to 13 years. For children aged 6.5 to 13.0 years, palmar pinch strength was significantly greater in the right than left hand ( $P < 0.05$ ). In the age groups of 6.0–6.4, 9.5–9.9, and 12.0–12.4 years, lateral pinch strength was significantly greater in the right than left hand ( $P < 0.05$ ). Tip pinch strength was also significantly greater in the right than left hand in children aged 7 to 13 years ( $P < 0.05$ ).

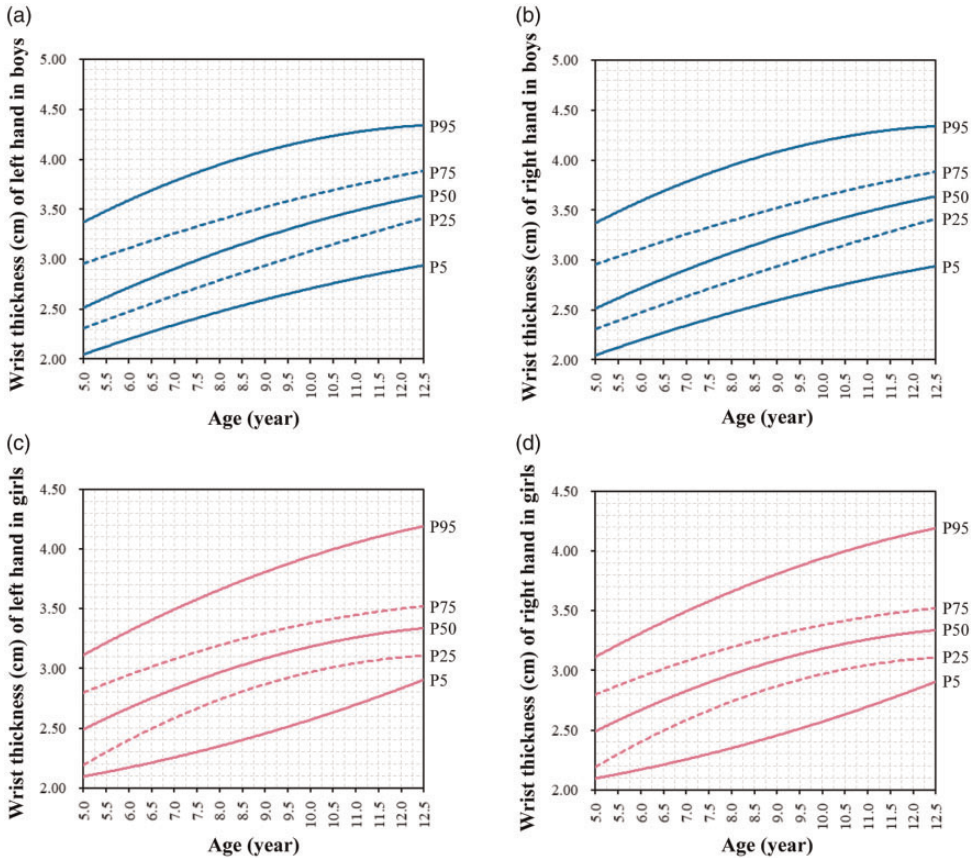


Figure 4. Wrist thickness of left and right hand in boys and girls.

**Table 3.** Grip and pinch strength (in pounds).

Sex	Age (years)	Left hand				Right hand			
		Grip strength	Palmar pinch strength	Lateral pinch strength	Tip pinch strength	Grip strength	Palmar pinch strength	Lateral pinch strength	Tip pinch strength
Boys	5.0-5.4	30.7 ± 7.9	5.5 ± 1.1	4.2 ± 1.1	-	31.0 ± 8.5	5.6 ± 1.1	4.4 ± 1.1	-
	5.5-5.9	35.0 ± 8.8	6.0 ± 1.3	4.7 ± 1.1	-	35.2 ± 7.7	6.3 ± 1.2	4.9 ± 1.2	-
	6.0-6.4	36.7 ± 8.9	6.3 ± 1.6	4.9 ± 1.3	-	36.2 ± 8.4	6.6 ± 1.5	5.3 ± 1.3	-
	6.5-6.9	37.6 ± 9.6	6.2 ± 1.7	5.0 ± 1.4	-	39.0 ± 10.7	6.6 ± 1.7	5.2 ± 1.5	-
	7.0-7.4	42.6 ± 10.4	5.4 ± 1.2	6.9 ± 1.3	5.2 ± 1.2	42.7 ± 9.1	7.2 ± 1.2	7.5 ± 1.7	7.2 ± 1.8
	7.5-7.9	43.5 ± 10.3	5.4 ± 1.3	7.3 ± 1.6	5.3 ± 1.2	43.9 ± 8.3	7.5 ± 1.5	7.4 ± 1.5	7.0 ± 1.5
	8.0-8.4	48.0 ± 11.9	5.8 ± 1.3	7.9 ± 1.9	5.8 ± 1.6	48.8 ± 11.9	8.5 ± 2.2	7.9 ± 1.9	7.8 ± 1.9
	8.5-8.9	49.1 ± 10.0	6.4 ± 1.7	8.0 ± 1.8	6.3 ± 1.9	48.7 ± 9.0	8.6 ± 1.9	8.6 ± 1.9	8.1 ± 1.8
	9.0-9.4	53.2 ± 12.0	7.2 ± 1.9	9.1 ± 1.4	7.1 ± 1.9	55.1 ± 11.4	9.5 ± 1.5	9.5 ± 2.1	8.6 ± 1.9
	9.5-9.9	50.6 ± 9.1	7.4 ± 1.8	8.8 ± 1.6	6.6 ± 1.4	52.8 ± 8.1	9.3 ± 1.9	9.9 ± 2.1	9.1 ± 2.0
	10.0-10.4	49.0 ± 13.1	7.6 ± 1.9	9.2 ± 1.8	7.0 ± 1.7	49.0 ± 14.1	9.5 ± 2.0	9.8 ± 2.1	9.4 ± 1.8
	10.5-10.9	47.7 ± 13.8	7.9 ± 2.7	9.7 ± 2.2	7.3 ± 1.8	49.7 ± 14.4	10.4 ± 2.8	10.3 ± 1.9	9.4 ± 1.9
	11.0-11.4	49.6 ± 14.7	8.4 ± 2.5	10.2 ± 2.7	7.8 ± 1.8	52.1 ± 15.4	10.5 ± 2.1	10.4 ± 2.1	9.8 ± 2.1
	11.5-11.9	52.8 ± 16.1	9.4 ± 2.7	11.3 ± 2.0	8.7 ± 2.3	55.4 ± 16.5	11.7 ± 2.2	12.3 ± 3.0	11.1 ± 3.0
	12.0-12.4	61.0 ± 17.2	9.4 ± 2.8	12.0 ± 3.0	8.8 ± 2.3	63.7 ± 16.8	12.5 ± 2.9	13.0 ± 2.8	12.3 ± 3.1
12.5-13.0	67.5 ± 23.5	9.0 ± 2.9	11.1 ± 2.8	8.6 ± 2.7	66.1 ± 23.8	11.5 ± 2.6	13.1 ± 3.1	11.7 ± 3.2	
Girls	5.0-5.4	28.4 ± 8.4	4.8 ± 0.9	3.6 ± 0.8	-	30.4 ± 8.8	5.0 ± 1.0	3.9 ± 0.9	-
	5.5-5.9	31.2 ± 7.3	5.3 ± 1.1	4.1 ± 1.0	-	32.4 ± 7.4	5.5 ± 1.2	4.3 ± 1.1	-
	6.0-6.4	34.5 ± 9.4	5.7 ± 1.4	4.4 ± 1.1	-	35.0 ± 8.9	5.8 ± 1.4	4.6 ± 1.2	-
	6.5-6.9	34.6 ± 9.7	5.2 ± 1.3	4.2 ± 1.1	-	35.9 ± 9.4	5.7 ± 1.4	4.5 ± 1.4	-
	7.0-7.4	38.0 ± 7.2	4.7 ± 1.1	6.1 ± 1.5	4.4 ± 1.0	38.8 ± 6.2	6.3 ± 1.3	6.1 ± 1.6	5.4 ± 1.1
	7.5-7.9	42.0 ± 13.7	5.1 ± 1.1	6.6 ± 1.3	4.8 ± 1.1	41.2 ± 10.5	6.5 ± 1.5	7.1 ± 1.6	6.9 ± 1.5
	8.0-8.4	42.6 ± 8.4	5.5 ± 1.8	7.4 ± 1.4	5.4 ± 1.4	42.9 ± 9.1	7.6 ± 1.6	7.4 ± 2.2	7.0 ± 1.7
	8.5-8.9	43.1 ± 13.5	5.9 ± 1.5	7.8 ± 2.2	5.7 ± 1.3	46.4 ± 12.4	8.2 ± 1.8	7.8 ± 1.9	7.0 ± 1.8
	9.0-9.4	46.0 ± 10.7	6.3 ± 2.0	7.8 ± 1.7	5.8 ± 1.7	47.7 ± 11.1	8.3 ± 1.6	8.1 ± 1.7	7.6 ± 1.7
	9.5-9.9	49.0 ± 10.4	7.0 ± 2.2	8.0 ± 1.6	6.6 ± 2.0	52.1 ± 10.4	8.2 ± 1.7	8.8 ± 2.3	8.2 ± 2.2
10.0-10.4	47.1 ± 10.6	6.8 ± 2.1	8.4 ± 2.1	6.1 ± 1.7	49.7 ± 10.9	8.8 ± 2.1	8.6 ± 2.2	7.7 ± 1.7	
10.5-10.9	46.5 ± 12.1	7.2 ± 1.6	8.9 ± 2.3	6.7 ± 1.4	47.0 ± 11.6	9.1 ± 1.8	9.4 ± 2.1	8.8 ± 2.3	

(continued)

Table 3. Continued.

Sex	Age (years)	Left hand				Right hand			
		Grip strength	Palmar pinch strength	Lateral pinch strength	Tip pinch strength	Grip strength	Palmar pinch strength	Lateral pinch strength	Tip pinch strength
	11.0–11.4	48.5 ± 13.2	8.2 ± 2.3	10.3 ± 2.1	7.5 ± 1.9	49.8 ± 11.7	10.9 ± 2.3	10.6 ± 2.2	9.5 ± 1.9
	11.5–11.9	54.3 ± 16.5	8.4 ± 2.4	11.1 ± 2.3	7.8 ± 2.2	56.4 ± 17.4	11.8 ± 2.2	10.8 ± 2.5	10.3 ± 2.5
	12.0–12.4	62.9 ± 18.6	8.7 ± 2.0	11.8 ± 2.3	8.4 ± 1.6	64.6 ± 17.8	11.8 ± 2.4	12.2 ± 2.4	11.2 ± 2.3
	12.5–13.0	52.6 ± 18.9	8.0 ± 3.5	10.3 ± 4.8	7.1 ± 3.1	58.1 ± 19.9	10.3 ± 4.2	10.1 ± 3.8	8.8 ± 3.5

### Correlation analysis between physiological hand shape indicators and grip/pinch strength

Pearson correlation analysis was used to analyze the relationship of the physiological hand shape indicators with grip strength, pinch strength, height, weight, and BMI (Tables 4 and 5). The results showed that the physiological hand shape indicators were significantly positively correlated with grip strength, pinch strength, height, weight, and BMI ( $P < 0.001$ ). A partial correlation analysis was then conducted to control for the influence of age on these correlations. After controlling for age, significant positive correlations remained between the physiological hand shape indicators and grip strength, pinch strength, height, weight, and BMI, but the correlation coefficients were lower than those before controlling for age (Tables 6 and 7). A further multivariate regression analysis also suggested that physiological hand shape indicators may play an important role in the assessment of grip strength and pinch strength (Table 8).

### Quality control

A random retest method was adopted during the study to remeasure 5% of the total sample of children. The results showed that the correlation coefficient of the two tests ranged from 0.865 to 0.900, proving that the test had high reliability.

### Discussion

Physiological hand shape indicators are predictors of the physical growth and development of children and are simple and easy to measure. These indicators are not only positively correlated with children’s grip strength, pinch strength, height, and weight, but they are also related to children’s psychological and behavioral

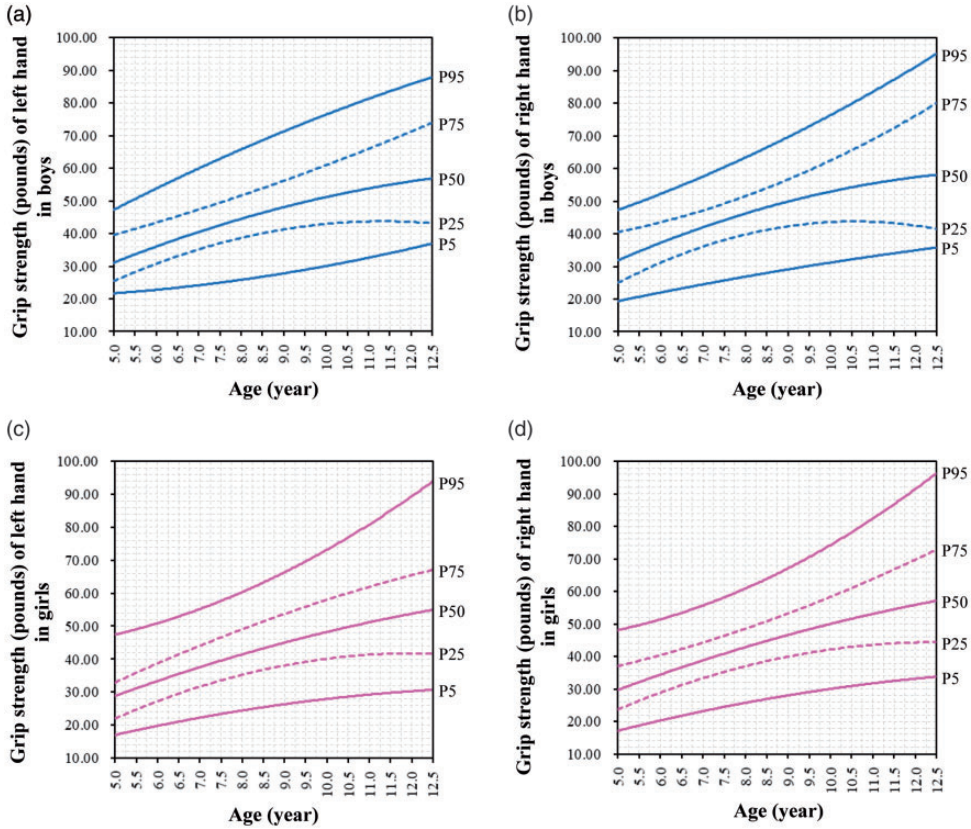


Figure 5. Grip strength of left and right hand in boys and girls.

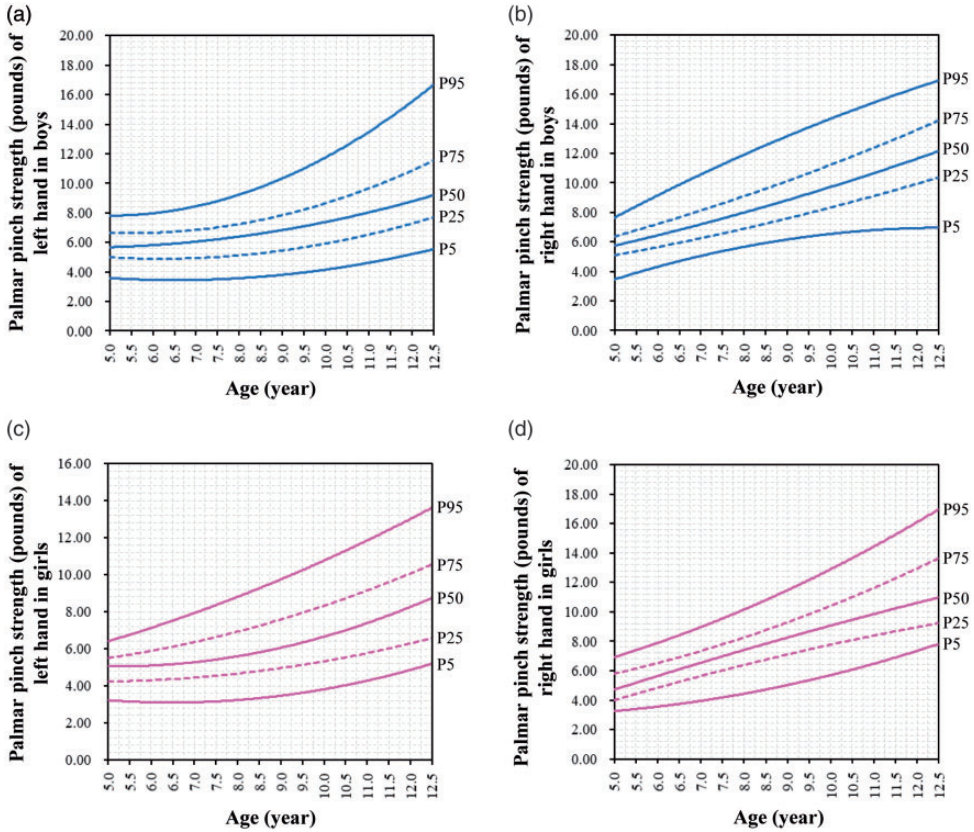
problems, fine movement, and writing ability.<sup>2,3</sup> In the present study, we obtained data regarding physiological hand shape indicators, grip strength, and pinch strength of children aged 5 to 13 years in Nanjing city and revealed a relationship between physiological hand shape indicators and grip/pinch strength. We constructed a growth curve of physiological hand shape indicators, grip strength, and pinch strength and provided reference ranges for each of these parameters in children aged 5 to 13 years.

As research has progressed, researchers have identified certain rules and characteristics of physiological hand shape indicators in terms of sex and age. Several studies have shown that physiological hand shape

indicators increase with age, and the physiological hand shape indicators of boys are larger than those of girls of the same age in most age groups.<sup>1,2,16</sup> The present study showed similar results in young children. After puberty, however, the physiological hand shape indicators grew faster in girls than boys of the same age. This finding is thought to be related to the earlier onset of puberty in girls than boys.

Previous studies and the present study have suggested the presence of a positive correlation between physical hand shape and grip/pinch strength in children.<sup>7,15</sup> Good grip and pinch strength is the basis for acquisition of basic grasping and finger-pinching abilities. The development of children's hand function starts from





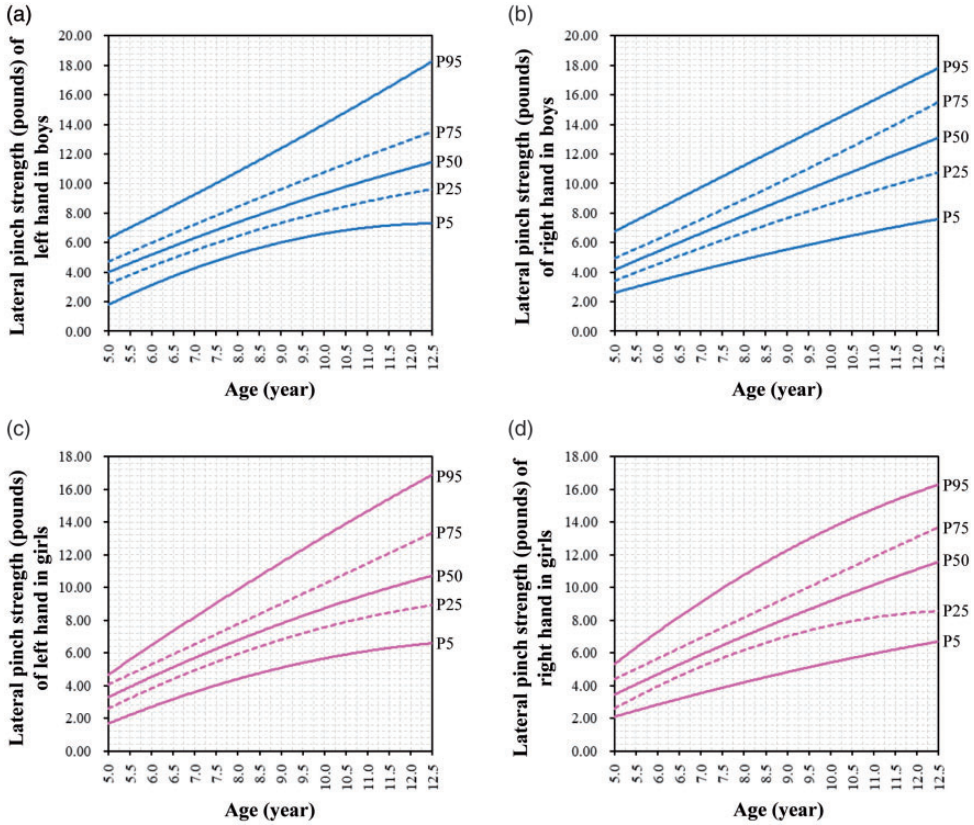
**Figure 6.** Palmar pinch strength of left and right hand in boys and girls.

grasping and pinching; thus, these actions are the basis for mastering more complex, accurate, and skillful movements. As a simple and economical method, measurement of grip and pinch strength can not only reflect the development of hand function but also serve as an auxiliary monitoring method for the development of various systems throughout the whole body; thus, measurement of grip and pinch strength has been receiving increasingly more attention.<sup>5,17</sup> Research on grip strength and pinch strength is performed not only to evaluate strength but also to comprehensively evaluate children’s health condition, allowing the physical examination findings to better serve the ultimate goal of promoting health. Therefore, research on the

development of grip and pinch strength is also very important to fully understand the development of children’s hand function.

Researchers have found that the development of grip strength and pinch strength has certain rules and characteristics in terms of sex, age, and handedness (i.e., left vs. right handedness).<sup>18–20</sup> Several studies have shown that grip and pinch strength increases with age and that grip and pinch strength is always greater in boys than girls of the same age.<sup>12,21</sup> However, the present study showed that boys had greater grip strength and pinch strength than girls of the same age only in some age groups, especially in the younger age groups. These inconsistent results may be related to differences in study populations, grouping



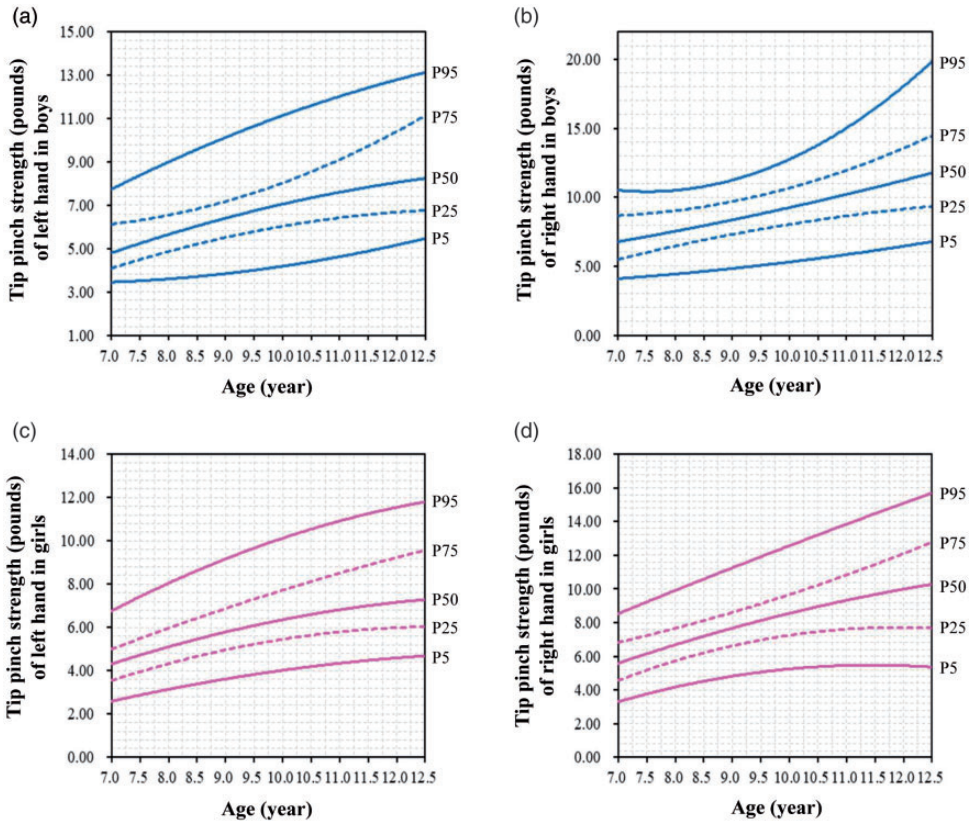


**Figure 7.** Lateral pinch strength of left and right hand in boys and girls.

criteria, sample sizes, measurement methods, or statistical methods. The children in the present study were 5 to 13 years of age; thus, the study population included children in adolescence. Growth and development changes are relatively rapid during adolescence, and the development rates differ between boys and girls. Moreover, the relatively higher number of subgroups in the present study may have also contributed to these inconsistent results. Therefore, these results should be interpreted with caution and further verified.

The difference in hand grip/pinch strength between the left and right hands may be related to handedness. Handedness refers to the hand that a person uses in daily life to perform skilled activities.

Hepping et al.<sup>22</sup> evaluated grip strength in children aged 4 to 17 years and de Souza et al.<sup>8</sup> evaluated grip strength in children aged 6 to 13 years, and both found that grip strength of the preferred hand was greater than that of the non-preferred hand. Newman et al.<sup>23</sup> presented norms for hand grip strength of healthy children and found that handedness influenced grip strength and was most noticeable in children aged >10 years. Another study of hand function among Korean children showed no significant difference in hand function according to hand dominance in boys. However, girls with left hand dominance showed weakness of bilateral grip, right tip pinch, and bilateral lateral pinch strength compared with girls with right



**Figure 8.** Tip pinch strength of left and right hand in boys and girls.

hand dominance.<sup>14</sup> Our results showed no significant difference in grip strength between the right and left hands. For children aged 6.5 to 13.0 years, the palmar pinch strength was significantly greater in the right than left hand. In the age groups of 6.0–6.4, 9.5–9.9, and 12.0–12.4 years, the lateral pinch strength was significantly greater in the right than left hand. Additionally, the tip pinch strength was significantly greater in the right than left hand in children aged 7 to 13 years. Therefore, the results tended to show that the grip/pinch strength was greater in the right than left hand, which may be related to handedness. After establishment of the habit of handedness, especially right handedness, the relatively higher frequency of

using this hand in daily life and games increases the muscle strength, resulting in a greater grip/pinch strength in the right than left hand.

In summary, we investigated physiological hand shape indicators, grip strength, and pinch strength of children aged 5 to 13 years in Nanjing. We preliminarily assessed their characteristics by age, sex, and hands and then analyzed the relationship between hand shape and grip/pinch strength, providing a basis for further clinical and scientific research. However, our study had some limitations. Because measurements of infants and young children are prone to errors, we did not obtain data of physiological hand shape indicators and grip/pinch strength in infants and young

**Table 4.** Correlation analysis between hand shape and grip/pinch strength.

Hand	Hand shape	Left hand						Right hand									
		Grip strength		Palmar pinch strength		Lateral pinch strength		Tip pinch strength		Grip strength		Palmar pinch strength		Lateral pinch strength		Tip pinch strength	
		r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P
Left hand	Full hand length	0.63	<0.001	0.75	<0.001	0.79	<0.001	0.56	<0.001	-	-	-	-	-	-	-	-
	Middle finger length	0.57	<0.001	0.68	<0.001	0.72	<0.001	0.44	<0.001	-	-	-	-	-	-	-	-
	Hand width	0.57	<0.001	0.66	<0.001	0.70	<0.001	0.46	<0.001	-	-	-	-	-	-	-	-
	Wrist thickness	0.54	<0.001	0.65	<0.001	0.67	<0.001	0.51	<0.001	-	-	-	-	-	-	-	-
Right hand	Full hand length	-	-	-	-	-	-	-	-	0.65	<0.001	0.75	<0.001	0.79	<0.001	0.62	<0.001
	Middle finger length	-	-	-	-	-	-	-	-	0.59	<0.001	0.68	<0.001	0.71	<0.001	0.50	<0.001
	Hand width	-	-	-	-	-	-	-	-	0.58	<0.001	0.66	<0.001	0.70	<0.001	0.52	<0.001
	Wrist thickness	-	-	-	-	-	-	-	-	0.56	<0.001	0.65	<0.001	0.68	<0.001	0.54	<0.001

**Table 5.** Correlation analysis between hand shape and body type.

Hand	Hand shape	Height (cm)			Weight (kg)			Body mass index (kg/m <sup>2</sup> )		
		r	P	r	r	P	r	r	P	
		Left hand	Full hand length	0.91	<0.001	0.82	<0.001	0.47	<0.001	0.47
	Middle finger length	0.82	<0.001	0.73	<0.001	0.40	<0.001	0.40	<0.001	
	Hand width	0.77	<0.001	0.75	<0.001	0.49	<0.001	0.49	<0.001	
Right hand	Wrist thickness	0.68	<0.001	0.74	<0.001	0.57	<0.001	0.57	<0.001	
	Full hand length	0.91	<0.001	0.82	<0.001	0.47	<0.001	0.47	<0.001	
	Middle finger length	0.82	<0.001	0.73	<0.001	0.40	<0.001	0.40	<0.001	
	Hand width	0.77	<0.001	0.75	<0.001	0.49	<0.001	0.49	<0.001	
	Wrist thickness	0.68	<0.001	0.74	<0.001	0.57	<0.001	0.57	<0.001	

**Table 6.** Partial correlation analysis between hand shape and grip/pinch strength.

Hand	Hand shape	Left hand						Right hand									
		Grip strength		Three-finger pinch strength		Two-finger pinch strength		Fingertip pinch strength		Grip strength		Three-finger pinch strength		Two-finger pinch strength		Fingertip pinch strength	
		r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P
Left hand	Full hand length	0.26	<0.001	0.23	<0.001	0.24	<0.001	0.28	<0.001	-	-	-	-	-	-	-	-
	Middle finger length	0.18	<0.001	0.11	<0.001	0.19	<0.001	0.17	<0.001	-	-	-	-	-	-	-	-
Right hand	Hand width	0.21	<0.001	0.17	<0.001	0.23	<0.001	0.26	<0.001	-	-	-	-	-	-	-	-
	Wrist thickness	0.25	<0.001	0.27	<0.001	0.32	<0.001	0.37	<0.001	-	-	-	-	-	-	-	-
	Full hand length	-	-	-	-	-	-	-	-	0.26	<0.001	0.26	<0.001	0.25	<0.001	0.23	<0.001
	Middle finger length	-	-	-	-	-	-	-	-	0.17	<0.001	0.17	<0.001	0.16	<0.001	0.10	0.004
	Hand width	-	-	-	-	-	-	-	-	0.21	<0.001	0.20	<0.001	0.24	<0.001	0.19	<0.001
	Wrist thickness	-	-	-	-	-	-	-	-	0.25	<0.001	0.33	<0.001	0.35	<0.001	0.34	<0.001

**Table 7.** Partial correlation analysis between hand shape and body type.

Hand	Hand shape	Height (cm)			Weight (kg)			Body mass index (kg/m <sup>2</sup> )		
		r	P		r	P		r	P	
		r	P		r	P		r	P	
Left hand	Full hand length	0.55	<0.001		0.43	<0.001		0.24	<0.001	
	Middle finger length	0.35	<0.001		0.25	<0.001		0.12	<0.001	
	Hand width	0.31	<0.001		0.38	<0.001		0.29	<0.001	
	Wrist thickness	0.32	<0.001		0.51	<0.001		0.43	<0.001	
Right hand	Full hand length	0.55	<0.001		0.43	<0.001		0.24	<0.001	
	Middle finger length	0.35	<0.001		0.25	<0.001		0.12	<0.001	
	Hand width	0.31	<0.001		0.37	<0.001		0.29	<0.001	
	Wrist thickness	0.32	<0.001		0.51	<0.001		0.43	<0.001	

**Table 8.** Multivariate regression analysis between hand shape and grip/pinch strength.

Hand	Hand shape	Left hand						Right hand									
		Grip strength		Three-finger pinch strength		Two-finger pinch strength		Fingertip pinch strength		Grip strength		Three-finger pinch strength		Two-finger pinch strength		Fingertip pinch strength	
		$\beta$	P	$\beta$	P	$\beta$	P	$\beta$	P	$\beta$	P	$\beta$	P	$\beta$	P	$\beta$	P
Left hand	Full hand length	0.15	0.045	0.35	<0.001	-0.00	0.972	0.21	0.004	-	-	-	-	-	-	-	-
	Middle finger length	-0.03	0.592	-0.13	0.043	0.05	0.214	-0.08	0.193	-	-	-	-	-	-	-	-
	Hand width	0.06	0.260	-0.02	0.777	0.02	0.562	0.05	0.314	-	-	-	-	-	-	-	-
	Wrist thickness	0.12	<0.001	0.16	<0.001	0.13	<0.001	0.18	<0.001	-	-	-	-	-	-	-	-
	Age	-0.02	0.722	0.13	0.029	0.39	<0.001	0.23	<0.001	-	-	-	-	-	-	-	-
	Sex	-0.03	0.121	-0.09	<0.001	-0.05	0.001	-0.11	<0.001	-	-	-	-	-	-	-	-
	Height	0.33	<0.001	-0.05	0.516	0.21	<0.001	0.06	0.339	-	-	-	-	-	-	-	-
	Weight	0.13	0.005	0.22	<0.001	0.12	<0.001	0.16	<0.001	-	-	-	-	-	-	-	-
	Full hand length	-	-	-	-	-	-	-	-	0.17	0.018	0.15	0.010	0.12	0.024	0.18	0.017
	Middle finger length	-	-	-	-	-	-	-	-	-0.06	0.297	0.03	0.606	-0.04	0.313	-0.12	0.078
Right hand	Hand width	-	-	-	-	-	-	-	-	0.06	0.202	-0.05	0.242	0.04	0.257	0.02	0.747
	Wrist thickness	-	-	-	-	-	-	-	-	0.11	<0.001	0.17	<0.001	0.16	<0.001	0.14	<0.001
	Age	-	-	-	-	-	-	-	-	0.05	0.348	0.32	<0.001	0.43	<0.001	0.21	<0.001
	Sex	-	-	-	-	-	-	-	-	-0.01	0.542	-0.08	<0.001	-0.07	<0.001	-0.07	0.010
	Height	-	-	-	-	-	-	-	-	0.26	<0.001	0.13	0.029	0.11	0.043	0.07	0.279
	Weight	-	-	-	-	-	-	-	-	0.16	<0.001	0.13	<0.001	0.12	<0.001	0.23	<0.001



children aged <5 years. Moreover, data of tip pinch strength of children aged 5 to 7 years were not obtained because of the poor command execution of children aged <7 years. Finally, the relatively small sample size used in this study may affect the statistical significance of our results, which require verification in further studies.

### Authors' contributions

Tong M and Chi X designed the study. Wen J, Wang J, Xu Q, Wei Y, and Ou J carried out the study and collected the data. Wen J, Hong Q, Ji C, and Zhang L conducted the statistical analysis and interpreted the data. Wen J wrote the report. Tong M and Chi X revised the report. All authors reviewed the report and approved the final version.

### Data availability

All datasets generated for this study are included in the manuscript and/or the supplementary files.


### Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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### ORCID iD

Xia Chi  <https://orcid.org/0000-0002-7439-0000>

### References

- Hohendorff B, Weidemann C, Burkhart KJ, et al. Lengths, girths, and diameters of children's fingers from 3 to 10 years of age. *Ann Anat* 2010; 192: 156–161. DOI: 10.1016/j.aanat.2010.03.002.
- Guerra RS, Fonseca I, Pichel F, et al. Hand length as an alternative measurement of height. *Eur J Clin Nutr* 2014; 68: 229–233. DOI: 10.1038/ejcn.2013.220.
- Loovis EM and Butterfield SA. Relationship of hand length to catching performance by children in kindergarten to grade 2. *Percept Mot Skills* 2003; 96: 1194–1196. DOI: 10.2466/pms.2003.96.3c.1194.
- Alahmari KA, Kakaraparthy VN, Reddy RS, et al. Percentage difference of hand dimensions and their correlation with hand grip and pinch strength among schoolchildren in Saudi Arabia. *Niger J Clin Pract* 2019; 22: 1356–1364. DOI: 10.4103/njcp.njcp\_121\_19.
- Wind AE, Takken T, Helders PJ, et al. Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults? *Eur J Pediatr* 2010; 169: 281–287. DOI: 10.1007/s00431-009-1010-4.
- Hager-Ross C and Rosblad B. Norms for grip strength in children aged 4-16 years. *Acta Paediatr* 2002; 91: 617–625. DOI: 10.1080/080352502760068990.
- Alahmari KA, Silvian SP, Reddy RS, et al. Hand grip strength determination for healthy males in Saudi Arabia: a study of the relationship with age, body mass index, hand length and forearm circumference using a hand-held dynamometer. *J Int Med Res* 2017; 45: 540–548. DOI: 10.1177/0300060516688976.
- de Souza MA, de Jesus Alves de Baptista CR, Baranauskas Benedicto MM, et al. Normative data for hand grip strength in healthy children measured with a bulb dynamometer: a cross-sectional study. *Physiotherapy* 2014; 100: 313–318. DOI: 10.1016/j.physio.2013.11.004.
- Bohannon RW, Wang YC, Bubela D, et al. Handgrip strength: a population-based study of norms and age trajectories for 3- to 17-year-olds. *Pediatr Phys Ther* 2017;

- 29: 118–123. DOI: 10.1097/PEP.00000000000000366.
10. Dodds RM, Syddall HE, Cooper R, et al. Global variation in grip strength: a systematic review and meta-analysis of normative data. *Age Ageing* 2016; 45: 209–216. DOI: 10.1093/ageing/afv192.
  11. Molenaar HM, Selles RW, Zuidam JM, et al. Growth diagrams for grip strength in children. *Clin Orthop Relat Res* 2010; 468: 217–223. DOI: 10.1007/s11999-009-0881-z.
  12. Mathiowetz V, Wiemer DM and Federman SM. Grip and pinch strength: norms for 6- to 19-year-olds. *Am J Occup Ther* 1986; 40: 705–711. DOI: 10.5014/ajot.40.10.705.
  13. Bear-Lehman J, Kafko M, Mah L, et al. An exploratory look at hand strength and hand size among preschoolers. *J Hand Ther* 2002; 15: 340–346. DOI: 10.1016/s0894-1130(02)80005-9.
  14. Yim SY, Cho JR and Lee IY. Normative data and developmental characteristics of hand function for elementary school children in Suwon area of Korea: grip, pinch and dexterity study. *J Korean Med Sci* 2003; 18: 552–558. DOI: 10.3346/jkms.2003.18.4.552.
  15. Fallahi AA and Jadidian AA. The effect of hand dimensions, hand shape and some anthropometric characteristics on handgrip strength in male grip athletes and non-athletes. *J Hum Kinet* 2011; 29: 151–159. DOI: 10.2478/v10078-011-0049-2.
  16. Barut C, Tan U and Dogan A. Association of height and weight with second to fourth digit ratio (2D:4D) and sex differences. *Percept Mot Skills* 2008; 106: 627–632. DOI: 10.2466/pms.106.2.627-632.
  17. Liptak GS, Fried R, Baltus-Hebert E, et al. Do grip and pinch strength predict neurologic complications in children with spina bifida and hydrocephalus? *Pediatr Neurosurg* 2006; 42: 208–213. DOI: 10.1159/000092356.
  18. Lam NW, Goh HT, Kamaruzzaman SB, et al. Normative data for hand grip strength and key pinch strength, stratified by age and gender for a multiethnic Asian population. *Singapore Med J* 2016; 57: 578–584. DOI: 10.11622/smedj.2015164.
  19. Maleki-Ghahfarokhi A, Dianat I, Feizi H, et al. Influences of gender, hand dominance, and anthropometric characteristics on different types of pinch strength: a partial least squares (PLS) approach. *Appl Ergon* 2019; 79: 9–16. DOI: 10.1016/j.apergo.2019.04.002.
  20. Shetty M, Balasundaran S and Mullerpatan R. Grip and pinch strength: reference values for children and adolescents from India. *J Pediatr Rehabil Med* 2019; 12: 255–262. DOI: 10.3233/PRM-180580.
  21. Ager CL, Olivett BL and Johnson CL. Grasp and pinch strength in children 5 to 12 years old. *Am J Occup Ther* 1984; 38: 107–113. DOI: 10.5014/ajot.38.2.107.
  22. Hepping AM, Ploegmakers JJ, Geertzen JH, et al. The influence of hand preference on grip strength in children and adolescents; a cross-sectional study of 2284 children and adolescents. *PLoS One* 2015; 10: e0143476. DOI: 10.1371/journal.pone.0143476.
  23. Newman DG, Pearn J, Barnes A, et al. Norms for hand grip strength. *Arch Dis Child* 1984; 59: 453–459. DOI: 10.1136/adc.59.5.453.