

Hands and feet length and its relationship with height in adolescents from Córdoba, Argentina

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RESUMEN

Los objetivos de este estudio son estimar las dimensiones lineales de las manos y los pies en adolescentes de Córdoba (Argentina), y evaluar en qué medida la longitud de las manos y los pies puede ser predictora de la estatura durante la adolescencia. Este es un estudio transversal no aleatorizado. La muestra consistió en 434 adolescentes entre 11 y 20 años de una escuela pública en Córdoba, Argentina. Las mediciones antropométricas incluyeron longitud del pie, longitud de la mano y estatura. Se realizaron modelos lineales generalizados para determinar si la longitud de los pies y las manos predice la estatura. Los niños tienen pies (particularmente a las edades de 14-15 y 17-18+ años) y manos más grandes que las niñas para la mayoría de las edades (13-18+ años). Las niñas son más altas que los niños a edades más tempranas (11-13 años), aunque por encima de estas edades (14-18+ años) los niños muestran mayor altura que las niñas. En los niños se encontró que la longitud del pie y la mano eran mejores predictores de la estatura (R^2 ajustado de 0.65 y 0.62, respectivamente). En las niñas, los R^2 para la longitud del pie y la mano fueron de 0.44 y 0.26, respectivamente. Se observó dimorfismo sexual en la longitud de la mano y del pie, así como en la estatura, mayor entre los 14 y los 18 años, con valores más altos en los niños. La longitud del pie y la mano se comportaron como predictores moderados de la estatura durante la adolescencia, siendo más importantes en los niños.

Palabras clave:

Antropometría
Dimorfismo sexual
Estimación de estatura
Forense
Argentina

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ABSTRACT

The objectives of this study are to estimate the linear dimensions of the hands and feet in adolescents from Córdoba (Argentina), and to evaluate to what extent the length of hands and feet can be predictors of height during adolescence. This is a non-randomized cross-sectional study. The sample consisted of 434 adolescents between 11 and 20 years old from a public school in Córdoba, Argentina. Anthropometric measurements included foot length, hand length, and height. Generalized linear models were performed to determine whether the length of feet and hands predicts height. Boys have larger feet -particularly at ages 14-15 and 17-18+ years- and larger hands than girls for most ages (13-18+ years). Girls are taller than boys at younger ages (11-13 years), although above these ages (14-18+ years) boys show higher height than girls. In boys, foot and hand length were found to be better predictors of height adjusted R^2 of 0.65 and 0.62, respectively). Among girls, R^2 for foot and hand length were 0.44 and 0.26, respectively. There was sexual dimorphism in hand and foot lengths and in height, greater between the ages of 14 and 18+ years, with higher values among boys. Foot and hand length behaved as moderate predictors of height during adolescence but more important among boys.

Keywords:

Anthropometry
Sexual dimorphism
Height estimation
Forensic
Argentina

Introduction

The ontogenetic process of human growth and development has been well-studied and is a singularity of the genus *Homo* due to its duration. This process of growth and development extends beyond the first two decades of life (Rebato, 2010), encompassing changes in size, shape, and composition, all of which maintain a harmonious relationship with one another (Bajo and Mangeaud, 2010). In addition to its extended duration, it exhibits ontogenetic allometry, such as the reduction of the cranial region in proportion to the total body size. During the pubertal growth spurt, the rate and speed of growth change. The increase in total height or stature initially occurs due to an elongation of the trunk, followed by growth in the lower limbs (Tanner, 1978).

While there are classic studies -based on samples of Anglo-Saxon populations- describing the speed and rhythm of hand and foot growth (Greulich and Pyle, 1959; Tanner et al., 1983; Morrison et al., 2009), there is a general lack of evidence related to foot and hand length concerning other segments of the body. The existing evidence is generally oriented towards i) industrial activities, mainly clothing, footwear, and ergonomic design (see Hsin-Hung Tu, 2014; Mirmohammadi et al., 2016; Hajaghazadeh et al., 2018), and ii) health (reproductive health; see Irani et al., 2015), sports medicine and sportology (Elipkhanov and Nemtsev, 2013; Padilla, 2017), orthopedics, plastic surgery, medical diagnosis of rare diseases such as Rett syndrome, Prader-Willi syndrome (Borges Cauich et al., 2019), acromegaly, associations with digit ratio (2D:4D and right-left 2D:4D) (Manning, Fink and Trivers, 2023; Parpa et al., 2024), or simply the evaluation of normal growth and general maturation of the organism. In the latter case, part of the diagnosis is established by studying the growth of the hands and feet (Pozo Román, 2011; Medina Navarro, Martín Tejedor and López Sigüero, 2014). Previous studies addressed some of these issues in Spanish and Latin American populations (Beas et al., 1986; Hernández Rodríguez, 1991; Rotés Mas and González Trapote, 2003; Ávila Chaurand, Prado León and González Muñóz, 2007, Monguí Pantoja, 2011; Ebrí Torné and Ebrí Verde, 2012, González Elena, 2015; González Elena et al.,

2021a, 2021b; Apaza-Vilca and Huaman-Mamani, 2023).

In addition, the prediction of height through the dimension of a body segment, such as the length of the hand or foot, not only has value in forensic investigations but also in growth and development studies. Previous research examined the value of hand and foot dimensions, especially as predictors of height, in legal medicine and forensic anthropology (Sanli et al., 2005; Oommen, Mainker and Oommen, 2005; Danborn and Elukpo, 2008; Atamtürk and Duyar, 2008; Uhrová et al., 2011; Ahmed, 2014a, 2014b; Wakode et al., 2015; Bahmad et al., 2020; Vukotic, 2020; Atamtürk et al., 2021). Despite existing data on adolescents for other Latin American populations, as previously cited, to our knowledge, no previous data exist on hand and foot measurements of Argentine children and adolescents, nor their use for predicting height.

In this study, we aim to evaluate the linear dimensions of hands and feet and to determine to what extent they can be used as predictors of height during adolescence, in a sample of schooled adolescents from Córdoba, Argentina.

Material and methods

Setting and sample

This is a cross-sectional study conducted in two periods of time during the years 2007-2011 and 2013-2014. The sample investigated consisted of 434 (236 boys and 198 girls) 11–20-year-old students, attending at the National School of Monserrat in Córdoba, Argentina. The school is located in the historic center of the city of Córdoba (Argentina), capital of Córdoba Province in the center of the country (31° 25' 0" S, 64° 11' 0" W, ≈ 450 m). With a total population of 1,505,250 inhabitants (CNPHyV, 2022), it is the second largest city in Argentina. The school has approximately 1,600 students, both boys and girls. It is part of the National University of Córdoba and is public, free, and has a maximum admission quota. To be admitted, students must take and pass an exam. Most of the students attending the school have a middle or lower-middle socioeconomic background, according to

the Statistics Department and the Psych pedagogical Office of the school.

Physical Measurements

We selected the following measures: hand length, foot length, and height -all in cm. All measurements were taken obtained according to the techniques recommended in the Anthropometric Standardization Reference Manual (Lohman, Roche and Martorell, 1988), except for the length of the foot which was obtained as the distance, measured by the sole of the foot, between the posterior edge of the heel and the distal end of the longest toe (1st or 2nd) (Blais, Green and Anderson, 1956; Pozo Román, 2011). The hand length was measured with a small sliding caliper from the styloid process of the radius to the tip of the middle finger. The measurement was recorded to the nearest 0.1 cm. The height of each subject was measured with a Gneupel portable anthropometer (accuracy=1mm). The students were standing, barefoot, with the torso upright and the head in the Frankfort Horizontal Plane. Using the original anthropometric measurements (hand length, foot length, and height), the following indices were constructed: foot length/height index, hand length/height index, and foot length/hand length with age.

The anthropometric measures were obtained exclusively in the morning in the school's medical office. Students entered the office in groups of two or three, all of the same sex. The student being measured was shielded from the view of the others by a privacy screen. The measurements for the girls were conducted with the collaboration of the school's woman pediatrician. Due to the small number of adolescents older than 18 years-old we grouped them in the category 18+.

The anthropometric survey was elaborated following the Helsinki Protocol (1975/83) and its addenda, in compliance with the terms of National Act 25.326 on data privacy. The personnel who conducted the surveys provided information to all students explaining the purpose and scope of the study. They were also asked to bring written consent from their parents or tutors. This written parental consent specified the objectives, characteristics, and scope of the research. Parents who agreed to have their children

participate in the study were asked to complete a questionnaire that inquired about their health history and that of their children.

This study was revised and approved by the Ethics Committee: C.I.E.I.S. del Niño y del Adulto - Polo Hospitalario- Comité Institucional de Ética en la Investigación en Salud, Gobierno de Córdoba, Ministerio de Salud, Argentina.

Statistical analysis

Descriptive analyses were performed by means and deviations (SD) or frequencies and percentages. We used ANCOVA in order to evaluate the association between foot length, hand length, foot length/height ratio, hand length/height ratio, and foot length/hand length ratio with age. Sex-specific generalized linear models -with R2 estimations-were performed in order to evaluate how well foot and hand length predict height. Statistical analyses were performed using Infostat (Di Rienzo et al., 2020) and SPSS (IBM SPSS Statistics -version 20-), with a significance level of 5%.

Results

Table 1 shows the descriptive statistics of the investigated variables by sex and single age. Boys have larger feet than girls across all ages. Pre-pubertal girls have larger hands than boys and by the age of 12, hand lengths are similar in both sexes. Above these ages (13-18+ years), boys have larger hands than girls. Similarly, girls are taller than boys at younger ages (11-13 years). Above these ages (14-18 years), boys show higher height than girls. Additionally, there is a correlation between foot length and stature, with foot length/height ratios averaging percentages of 14.5% in boys and 13.8% in girls (Table 1).

Figures 1-5 (and Table 2) show the association between foot length, hand length, foot length/height ratio, hand length/height ratio, and foot length/hand length ratio with age, respectively. Foot length increases significantly with age ($p<0.0001$) (Figure 1), being the average higher in boys than in girls ($p<0.05$). Pre-pubertal girls have a larger hand on average than boys (Figure 2). Foot length/height ratio shows a negative association with age for boys but not for girls

($p < 0.0001$) (Figure 3). Hand length/height ratio is not slightly positive significant association with age in both associated with age ($p = 0.2705$) nor sex ($p = 0.7636$) boys and girls (Figure 5). (Figure 4). Hand length/foot length ratio shows a

Table 1. Descriptive statistics for anthropometric measurements by sex and age.

Age	Sex		Foot length (cm)				Hand length (cm)				Height length (cm)			
Years	Boys (n=236)	Girls (n=198)	Boys		Girls		Boys		Girls		Boys		Girls	
	N		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
11	17	15	21.9	1.3	21.2	1.7	15.6	1.7	15.3	1.3	146.7	6.1	150.4	9.1
12	61	34	22.4	1.2	21.1	1.7	15.6	0.9	15.8	1.3	150.4	7.1	152.2	7.1
13	46	38	23.4	1.1	21.4	1.4	16.4	1.1	16	0.8	156.9	7.5	157.9	7.7
14	33	31	24.0	1.6	21.9	1.1	17.2	1.5	16.4	1.1	164.2	10	158.2	6.7
15	19	23	25.1	1.2	22.0	1.1	18.0	1.2	16.8	1.3	171.9	7.0	161.1	6.4
16	14	12	24.7	1.3	22.5	1.1	18.1	1.3	17.6	1.1	172.9	7.2	161.8	8.6
17	30	24	24.5	1.3	22.4	0.8	17.9	0.9	17.2	1	174	4.4	161.8	7.0
18+	16	21	24.8	0.9	22.7	1.3	18.1	1.5	16.9	1.4	175.6	5.4	160.7	6.4

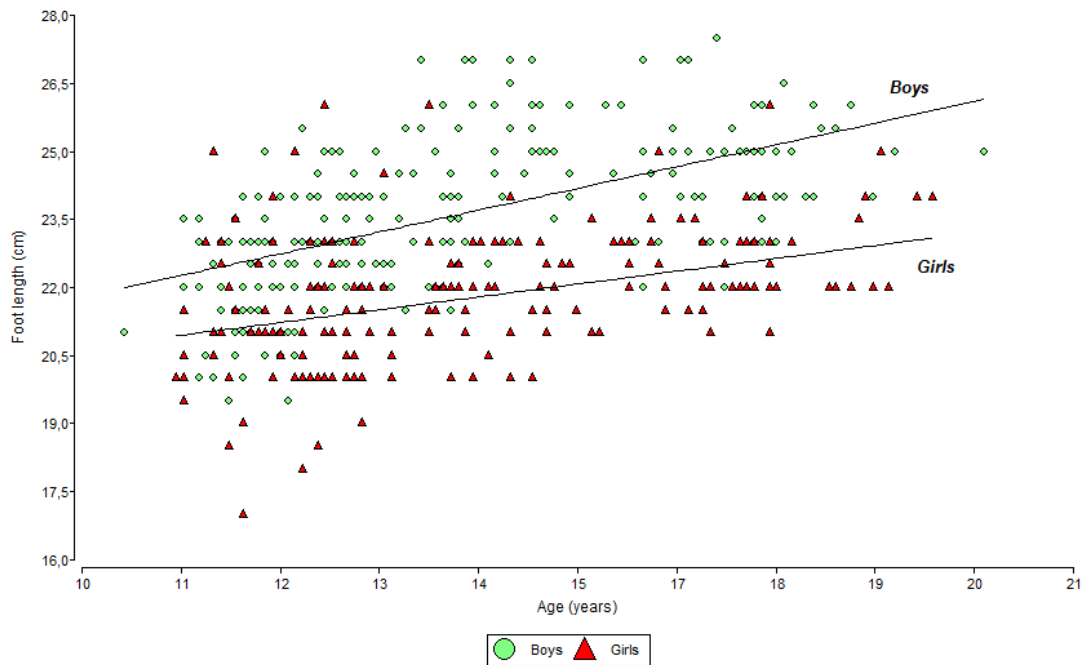


Figure 1. Association between foot length and age among boys and girls. Boys (green circle), Girls (red triangle).

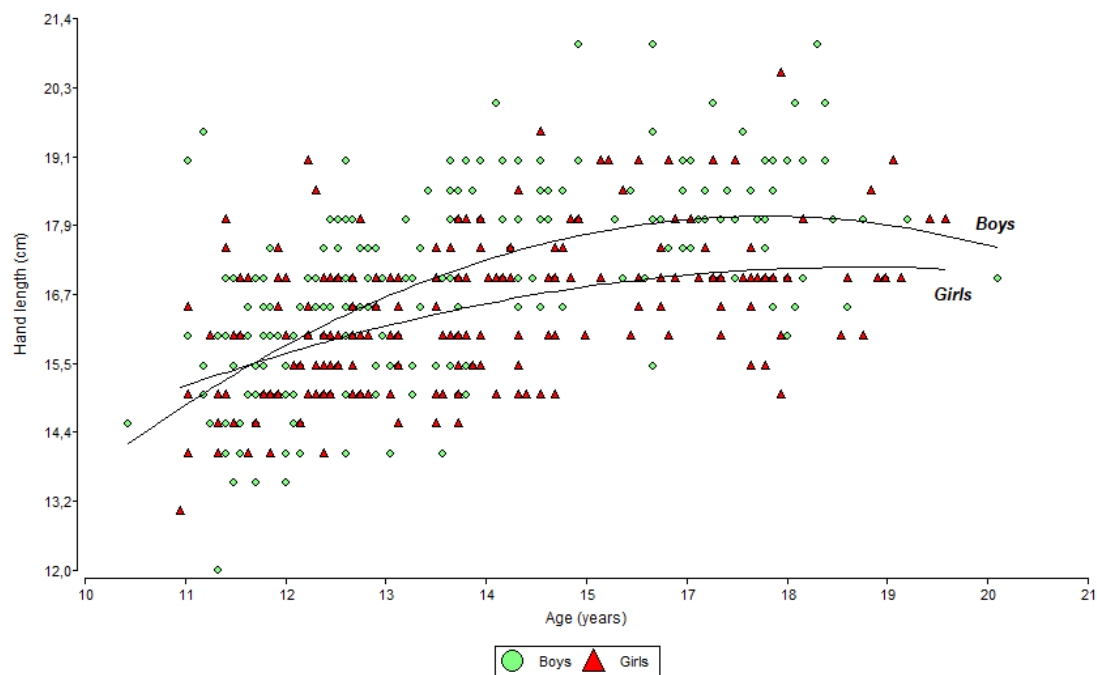


Figure 2. Association between hand length and age among boys and girls. Boys (green circle), Girls (red triangle).

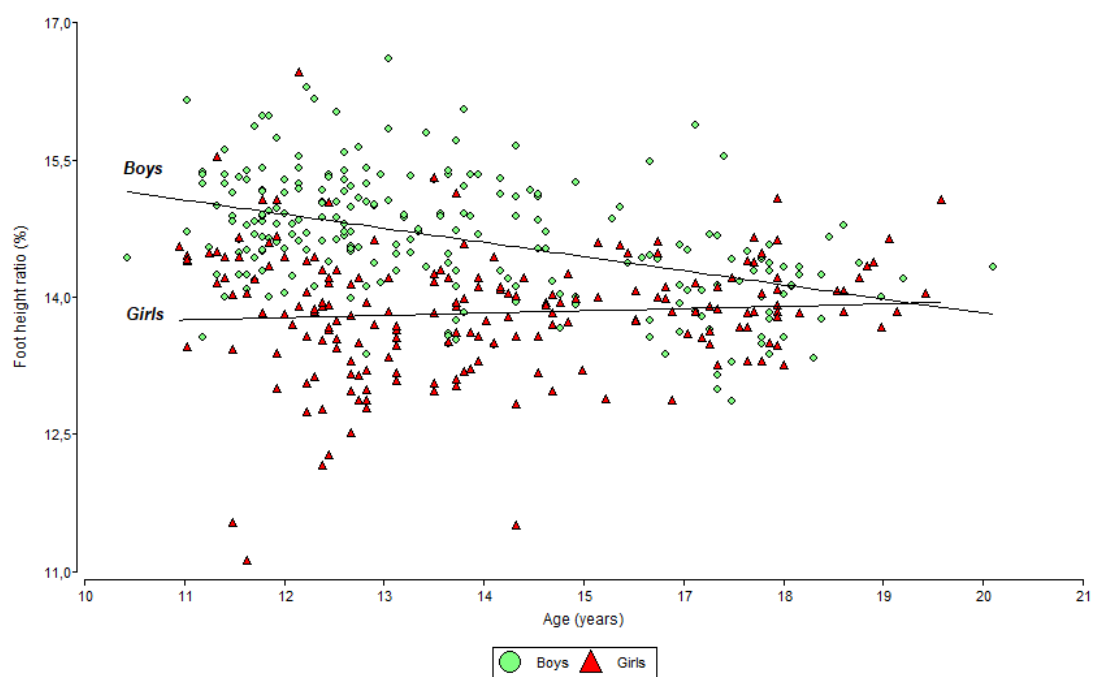


Figure 3. Association between foot/height ratio and age among boys and girls. Boys (green circle), Girls (red triangle).

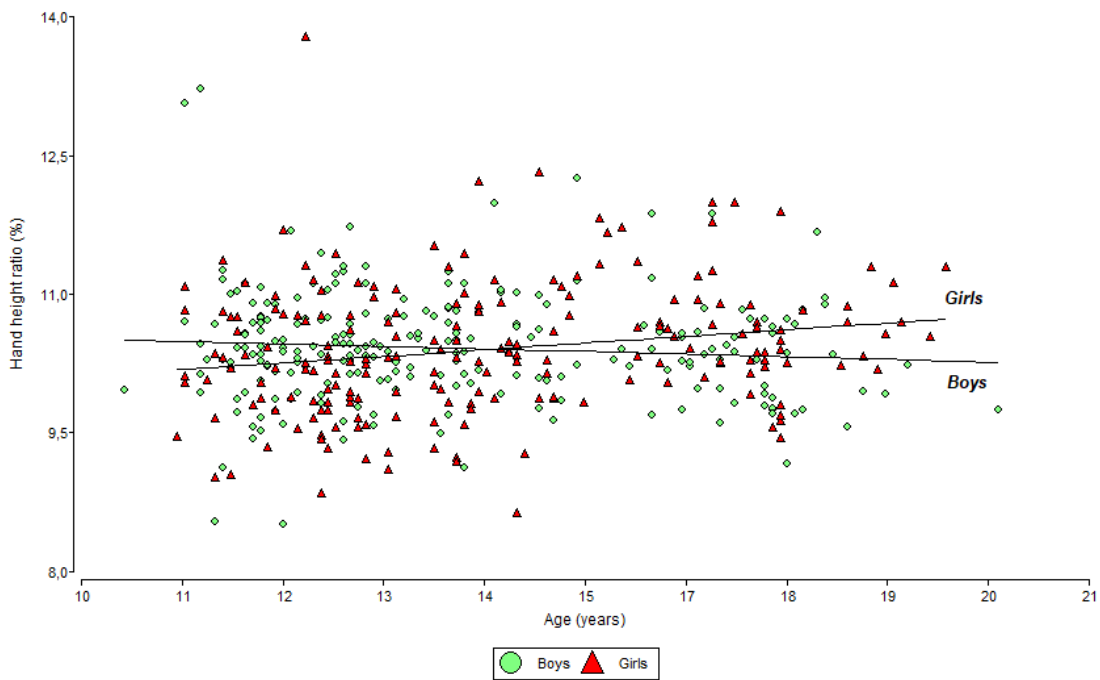


Figure 4. Association between hand/height ratio and age among boys and girls. Boys (green circle), Girls (red triangle).

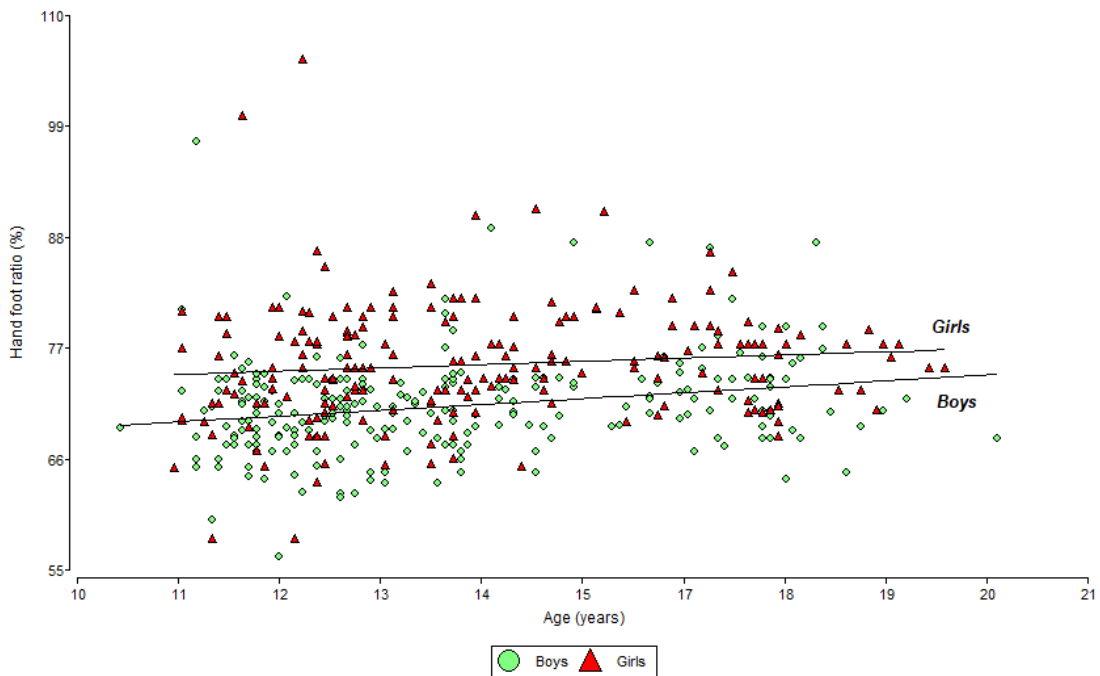


Figure 5. Association between hand/foot ratio and age among boys and girls. Boys (green circle), Girls (red triangle).

Table 2. Association of foot length, hand length, foot length/height ratio, hand length/height ratio, and foot length/hand length ratio with age.

Foot length vs. Age		
Variables	<i>p</i> -value	Slope
Age	< 0.0001	Boys 0.431
Sex	< 0.0001	Girls 0.253
Age*Sex	0.0026	
Hand length vs. Age		
Variables	<i>p</i> -value	Slope
Age	< 0.0001	Boys 0.429
Sex	< 0.0001	Girls 0.263
Age*Sex	0.0064	
Foot length/height ratio vs. Age		
Variables	<i>p</i> -value	Slope
Age	< 0.0001	Boys -0.138
Sex	< 0.0001	Girls 0.023
Age*Sex	< 0.0001	
Hand length/height ratio vs. Age		
Variables	<i>p</i> -value	Slope
Age	0.2705	Boys -0.025
Sex	0.7636	Girls 0.064
Age*Sex	0.0023	
Hand length/foot length ratio vs. Age		
Variables	<i>p</i> -value	Slope
Age	< 0.0001	Boys 0.519
Sex	< 0.0001	Girls 0.289
Age*Sex	0.3349	

Table 3 shows the associations between foot and hand lengths with height. In boys, foot and hand lengths behave similarly when predicting height (adjusted R^2 of 0.65 and 0.62, respectively). In girls, R^2 for foot length is higher than in hand length (0.44 and 0.26, respectively).

Table 4 presents the results of four predictive models for height estimation, including sex interaction. The first model considers hand length and sex, with a hand $\times$ sex interaction term (accounting for differential hand growth patterns between sexes). The second model incorporates foot length along with sex interaction. The third model uses the hand length/foot length ratio, while the fourth model includes both hand

and foot lengths as independent variables (rather than a ratio). This last model, which accounts for both hand and foot measurements, yields the highest R^2 Adjust value (close to 70%).

Table 3. Sex-specific associations of foot length and hand length with height.

	Sex	Slope	<i>p</i> -value	R^2
Foot length	Boys	6.11	<0.0001	0.654
	Girls	3.85	<0.0001	0.437
Hand length	Boys	6.24	<0.0001	0.623
	Girls	3.24	<0.0001	0.263

Table 4. Predictive models of height, accounting for sex-based interaction.

	X=Hand	X= Foot	X= Hand/foot	X ₁ = Hand, X ₂ = Foot
Constant	104.58	73.89	161.32	60.42
Sex (1=boys)	-48.25	-56.74	-44.89	-48.1
Hand	3.24	---	---	1.76
Foot	---	3.85	---	3.14
Hand/Foot	---	---	*-0.05	---
Interac Sex Hand	3	---	---	1.75
Interac Sex Foot	---	2.26	---	*0.68
Interac Sex Hand/Foot	---	---	0.67	
R ² Adjust	0.538	0.605	0.063	0.696

* $p > 0.05$

Discussion

In this study we aimed to estimate the linear dimensions of hands and feet in adolescents from Córdoba (Argentina) and evaluate to what extent the length of hands and feet can be predictors of height during adolescence. We found and expected sexual dimorphism in hand and foot lengths and in height, greater between the ages of 14 and 18+ years, with higher values among boys. We also found that foot and hands length behaved as moderate predictors of height during adolescence, but more important among boys. Our results indicate that there are differences in hand length from 15 years on. In our sample, girls have smaller feet than boys, and therefore their hand length/foot length ratio is higher. Danborn and Elukpo (2008) showed that, in adulthood, hand length can be predicted from foot length and vice versa, for each sex. Our work supports this finding, although it emphasizes the need to establish a specific equation for each population or ethnic group, as sizes and sex differences vary among them. Other studies, such as those by Oommen, Mainker and Oommen (2005), also support this conclusion.

Foot length is a measure associated with gestational age and a predictor of birth weight (Grande, Gutiérrez and Argüelles, 1993; Ravisankar et al., 2025). Some studies suggest that the final size and shape of the foot is reached during adolescence, at 16 years of age in boys and 14 in girls (Krishan, 2008; Igbigbi, Ominde and Adibeli, 2018). In boys of our sample, the foot, at least in length, continues to grow

until 18 years of age. In addition, foot length is strongly associated with stature in both sexes. These were expected results, considering that the entire body in a bipedal posture rest on the feet. Foot length correlates well with stature, with a foot length/height ratio averaging approximately 15% in modern human populations (Ruff et al., 2021). In our study, the average of this percentage was 14.5% in boys and 13.8% in girls. Foot length/height ratio also showed a pattern of allometric growth that differs by sex. In boys, it is clearly observed that as height increases, foot length also grows, but to a lesser extent. This growth pattern is not as evident in girls, who in the sample we studied exhibit a similar foot-to-height ratio across all ages. We also described sex differences in foot length from the age of 12. For all ages, the difference favors boys.

Height represents the most important anthropometric indicator for describing overall body growth during childhood and adolescence (Tanner, 1978; Rebato, 2010). It also serves as a reference for measuring the relative and/or proportional (allometric) growth of other body parts in relation to it, such as the growth of upper and lower limbs and extremities (hands, feet). In our study, there are no sex differences until the age of 14+, where the height of boys is greater than that of girls. When comparing the height growth of boys and girls in our study with the reference values published by the Argentine Society of Pediatrics (SAP) (Lejarraga et al., 2009), we observed that the increments—by sex and age—were similar in both samples. Based on this comparison, we assume normal

growth patterns in both male and female students at Monserrat.

We also evaluated to what extent the length of hands and feet can be predictors of height during adolescence. In addition to the well-known evidence of anthropometric measures like sitting height as a predictor of height in adolescence (Caussade, 2008; Popovic, 2019), other studies have described the use of hand or foot length to predict height in India (Oommen, Mainker and Oommen, 2005; Wakode et al., 2015), Turkey (Anil et al., 1997; Sanli et al., 2005), and Nigeria (Danborno and Elukpo, 2008). Some authors also suggest that in forensic studies, the best predictor of an individual's stature is foot length (Singh et al., 2019). In addition, some of these studies used an index constructed with the length and width of the hand (Oommen, Mainker and Oommen, 2005; Sanli et al., 2005; Danborno and Elukpo, 2008) or a multiplication factor (Wakode et al., 2015). These studies suggest that once height growth is complete, hand length can be used as a predictor of it (Ozaslan et al., 2012; Igbigbi, Ominde and Adibeli, 2018). These samples were formed by individuals who were in their final stage of growth or 5-10 years of prepubertal children (Ibegbu et al., 2015), while our sample was more representative of the spectrum of the pubertal spurt and the dynamics of early adolescence. Consequently, our results are not totally comparable with these. When we used a model to predict adolescent height that incorporated both variables (hand length and foot length), the results showed greater explanatory power. In our study, we provided evidence for the moderate potential of foot and hand length on predicting height among Argentinean adolescents. Also, we showed a moderate contribution of hand length to predict height in boys but not in girls.

Strengths and limitations

Among the strengths of this study, and to the best of our knowledge, no published data exists on hand and foot measurements of Argentine children and adolescents, which is why we believe the data presented in this study is a valuable contribution to the topic. Nevertheless, as mentioned, we lack Argentine comparison values, although there is published data on adolescents from other Latin American populations.

A limitation of the study is its cross-sectional nature, which needs to be accounted for when interpreting our results, particularly those related with the growth process of adolescents. Another limitation is that only foot length was measured, without including width, to construct a length/width proportionality index that could be useful in orthopedics and industry. However, this was not part of the original objectives of this study. The data we obtained and analyzed were part of a broader study that included many more body variables and we deemed it inappropriate for participants (minors in this case) to spend more than half an hour outside of class being measured. We believe this work could be improved with a more specific future study focusing on both hands and feet.

In conclusion, this study provides the first evidence of anthropometric data of foot and hand length for Argentinean adolescents, revealing expected sex-specific differences favoring boys. Our results support the use of both foot and hand length as predictors of height, particularly among boys. Making data on feet and hands available is relevant due to the potential benefits it provides to medicine, sports science, industry, and ergonomics, among others.

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