Jornal de Pediatria 2022;**98(6)**: 590−598

Jornal de
Pediatria
www.jped.com.br

ORIGINAL ARTICLE

Normative values for handgrip strength in Colombian children and adolescents from 6 to 17 years of age: estimation using quantile regression

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Received 13 December 2021; accepted 21 February 2022
Available online 27 April 2022

KEYWORDS
Muscle strength;
Adolescent;
Child;
Muscle strength dynamometer;
Physical fitness

Abstract
Objective: The objective of this study is twofold: i) to estimate the normative values for handgrip strength and relative handgrip strength, specific to sex and age, for Colombian children and adolescents from 6 to 17 years of age using quantile regression models and ii) to compare the normative values for handgrip strength and relative handgrip strength in Colombian children and adolescents with those in children and adolescents in different countries.
Method: This was a cross-sectional analysis of a sample of 2647 youngsters. Handgrip strength was evaluated with a TKK 5101 digital dynamometer (Takei Scientific Instruments Co., Ltd., Tokyo, Japan). The relative handgrip strength was estimated according to weight in kilograms. The normative values were estimated to handgrip strength and relative handgrip strength through quantile regression models for the percentiles P_5, P_{10}, P_{25}, P_{50}, P_{75}, P_{90}, and P_{95} developed independently for each sex. All analyses were adjusted for the expansion factor.
Results: The values for handgrip strength were considerably higher in males than in females in all age ranges. Additionally, as age increased for both sexes, the values for handgrip strength increased. The percentiles by sex and age for relative handgrip strength show for males a proportional increase according to age; for females, this did not occur.
Conclusions: When making comparisons with international studies, variability is observed in the methodologies used to evaluate handgrip strength and estimation methods, which could influence the discrepancies between the different reports.

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https://doi.org/10.1016/j.jped.2022.02.004
0021-7557/

Introduction

Handgrip strength (HS) is a robust indicator of the biological health of children and adolescents.[1-4] For example, it has been reported that children and adolescents with high HS values have higher bone mineral density levels.[2] Additionally, an inverse relationship between HS and the presence of overweight,[4] metabolic syndrome[3] or dyslipidemia[4] has also been reported. HS has a series of benefits that make it an excellent indicator for evaluating the muscular capacity of an individual, as follows: it is a test whose application is simple,[5] that does not require complex logistics for its measurement,[6] that is economical,[5,7] and that has a strong correlation with other indicators of physical abilities related to health, regardless of age, sex or sexual maturation.[5,6] Additionally, when this indicator is divided by body mass, it is possible to estimate relative handgrip strength ($HS_{Relative}$), which is reportedly a more robust indicator than HS alone.[7,8] Additionally, HS adjusted by body mass index has been recently used.

Despite being a robust marker of the biological health of children and adolescents,[1-4] there are no normative values at the international level for the child and adolescent population, thus limiting the classification of an individual in a standardized way. This is because there are no universal criteria for the evaluation of HS. Among the components that contribute to the lack of standardized values are i) the variability in the methodologies used to measure and estimate HS in each subject, ii) dynamometer technology, or iii) a mixture of the two,[9] which means that the results of one population cannot be inferred to another. For this reason, it is recommended that normative values be developed for specific geographical areas that allow for public health surveillance processes[10] or follow-ups over time in the same population.[11]

While several studies have reported the normative values for HS in children and adolescents from different countries in Europe,[12-20] the United States,[21-24] Oceania,[25] and Asia,[26,27] the number of studies in children and adolescents in Latin America is low.[28-33] The reports generally are focused on estimating the normative values for HS,[12-33] but only a few reports have described the normative values for $HS_{Relative}$,[22,28,30] although the latter has been reported to be a more robust indicator.[7,8]

Most studies that have reported the normative values for HS in children and adolescents[13,14,16,18,20,22,25,26,28-33] have used the Lambda-Mu-Sigma method (LMS),[34] which has a series of limitations: it does not include covariates other than sex or age, it is not flexible regarding the conditional distribution of the variable to be modeled,[35] and it has strong assumptions about the distribution of the response variable, which are generally not met when there are atypical values for the variable of interest.[35] For this reason, the objectives of this study are twofold: i) to estimate the normative values for HS and $HS_{Relative}$, specific to sex and age, for Colombian children and adolescents from 6 to 17 years of age using quantile regression models[35-39] and ii) to compare the normative values for the HS and $HS_{Relative}$ in Colombian children and adolescents with those reported in children and adolescents around the world.[12-33]

Methods

Type of study, population and sample

This is an analytical cross-sectional study and a secondary analysis of the National Survey of the Nutritional Situation of 2015 (Ensin-2015) of Colombia[40]; it was conducted during the years 2014 and 2017. The study comprised individuals from the noninstitutional civilian population who were permanent residents of households within the entire national territory. The sample design used in Ensin-2015 was probabilistic, clustered, stratified and multistage. HS was measured in 2647 children and adolescents between 6 and 17.9 years of age. More details of the sample design are published in Annex 11 of Ensin-2015.[40]

Procedures

For the sociodemographic characterization of children and adolescents, the following information was obtained: sex, age, ethnicity (*indigenous, "black, mulatto, Afro-Colombian" or without ethnicity*), and area of residence (*Urban or rural*), and social security status (*contributory, subsidized, unaffiliated*). The socioeconomic status of each household was estimated by means of the Filmer−Pritchett Wealth Index. This variable was categorized into quartiles, and the lowest quartiles were considered the most vulnerable in society. For the measurement of body mass, an electronic scale, namely SECA 874 (Seca Co., Ltd., Hamburg, Germany), has an accuracy of ± 100 gs for weights less than 50 kg and ≥0.15% for weights greater than 50 kg, was used. For this measurement, children were barefoot and dressed in light clothing.

Evaluation of grip strength

HS was evaluated with a Takei TKK 5101 digital dynamometer (Takei Scientific Instruments Co., Ltd., Tokyo, Japan) with an analog grip and an adjustable handle, according to the size of each hand at an interval of 5−100 kg and with a precision of 0.1 kg. For the evaluation, the child or adolescent was placed in a bipedal position, with the shoulder in adduction and neutral rotation and the arms positioned perpendicularly without contacting the body. The child or adolescent stood with his or her feet hip-width apart, with the arm extended to the side of the body, without touching it. It was explained to him that he should remain upright, with his head held high and without bending over when pressing the device. After the subject took the indicated position, the dynamometer was adjusted to the size of the individual's hand. The subject was told to squeeze that handle as hard as possible and was then told to take a breath and exhale while squeezing. The participants were instructed to press the dynamometer for 3 to 5 s. Two or three tests was performed for each upper limb. The highest score on each hand was taken as valid.

Bibliographic search

To address to the second objective, a search was carried out for research studies that presented normative values. This was developed within the framework of the *scoping review* process that is being developed by the authors' research group in parallel to this report. The objective of this *scoping review* was to characterize the studies that have evaluated the factors associated with different physical fitness health-related (PF-HR). The *scoping review* studies were identified from January 1990 to September 2020 using the following bibliographic databases: i) MEDLINE; ii) Web of Science; iii) ScienceDirect; iv.) SciELO; and v.) SPORTDiscus (EBSCO).

Statistical analysis

Initially, an exploratory analysis of the data was performed. Subsequently, a univariate description of the sociodemographic characteristics was performed, a description of the qualitative variables was carried out by means of absolute frequencies and percentage frequencies, quantitative variables were expressed as averages and standard deviations, and the sample was described by sex. The normative values for HS were estimated using the average value and the maximum value of the valid measurements in each child and adolescent, and in both cases, the normative values for $HS_{Relative}$ were also estimated ($HS_{Relative}$ is the ratio between HS and weight in kilograms). The quantile regression models were estimated independently by sex for the percentiles P_5, P_{10}, P_{25}, P_{50}, P_{75}, P_{90}, and P_{95}.[35-39] All statistical procedures performed in the present analysis were adjusted for the expansion factor. The normative values using maximum value are shown in Supplementary Table 1. The authors also estimate normative values for HS adjusted by body mass index and stature (Supplementary Table 2).

Ethical considerations

Permission was obtained for the use of the database through the office of the Sub-Directorate of Monitoring and Evaluation of the Colombian Institute of Family Welfare to use the information for research purposes. La Ensin-2015[40] was conducted according to the guidelines described in the Declaration of Helsinki. Because all participants were minors, they agreed to participate in the study by providing written informed consent together with their guardians, who indicated their approval with their informed consent. A complete description of the nature and purpose of the study and its experimental risks was provided to all participants. The Ethics Committee of Profamilia granted ethical approval before data collection.

Results

The sample consisted of 2647 children and adolescents (1072 girls; 40.2%) aged between 6 and 17 years. In total, 8.6% were indigenous, and 10.6% were black, mulatto or Afro-Colombian; 72.9% were from municipal capitols, and 15.9% came from quartile 4 of the wealth index. The other sociodemographic characteristics are shown in Table 1.

The percentiles by sex and age for HS and $HS_{Relative}$ estimated with the average value of each child and adolescent are shown in Table 2. Regardless of sex, with increasing age, scores for HS increased, and a similar trend was noted in the estimation of the percentiles of HS, when the maximum value of each individual was used (Supplementary Table 1); in both scenarios, males had higher HS values. For males, a proportional increase in the $HS_{Relative}$ value was observed according to age. For females, this did not occur since the values in the different percentiles remained similar among the different age groups. In the case of $HS_{Relative}$ estimated with the maximum value, a similar trend was observed for both males and females (Supplementary Table 1). These estimates were made with data from 2549 children and adolescents because 98 data points for weight were lost.

For the comparison with the results of the present study, initially, a total of 37 reports were selected from electronic and manual searches. Of these, 12 studies were excluded. The main reason for exclusion was that the study reported percentile values in a graph, so it was not possible to extract the point value of the estimates. Finally, 24 reports were selected for comparison. In these studies, the publication period varied between 2005 and 2020; 50.0% of the reports were published in the last 5 years; 35% of the studies were conducted in Europe, and approximately 20% were conducted in South America. The most common estimation method was the LMS, which was used in approximately half of the reports found. The most commonly used dynamometer reference was the *TKK 5401, Grip-A, Takei (Tokyo, Japan)*, used in approximately 1 out of every 6 studies. The cited studies' methodological characteristics are shown in Supplementary Table 3.

Discussion

The normative values for HS are consistent with the magnitude and direction related to sex and age previously reported in different studies around the world,[12-33] in which male children and adolescents had consistently higher scores than their female peers.[12-33] It is also consistent with an increase in the HS value proportional to age in both males and females.[12-33]

When compared with specific studies, it was found that, according to the present report, Colombian children (males aged 6 to 10 years) had higher scores than their peers in Peru,[32] Spain[19] and Hong Kong in 2015/16;[27] however, they had lower values than their peers in Europe[17] and the USA.[21-24] Among girls (aged 6 to 10 years), Colombian girls had higher values than girls in Peru[32] and lower values than their peers in Europe,[14,16,17] the USA,[21-24] and South America,[28,29,33] and Hong Kong.[27] Among both males and females (aged 11 to 17.9 years), Colombian adolescents had higher values than their peers in Peru[32] and the Colombian indigenous population[31] and lower values than adolescents in Europe,[13-15,17-19] the USA[21-23] and Australia[25] (Tables 3 and 4).

A report in Colombia[33] with the same data as that of the present analysis estimated the normative values with the LMS method[34] and reported that among males, the values between 7 and 14 years of age in the P_{50} were higher but that after 15 years of age, the P_{50} estimated by quantile regression was higher. Among females, it was observed that with the LMS method[33] up to 11 years of age, the P_{50} was higher, but beginning at 12 years, the differences in the P_{50} were minimal.[33] Tables 3 and 4 show the details of the comparisons with different studies around the world.[12-33]

Table 1 Sociodemographic characteristics of the sample.

	Male n = 1575	Female n = 1072	Total n = 2647
Age $\bar{x}$ [s]	13.4 [3.0]	12.4 [3.4]	13.0 [3.2]
Ethnicity n (%)			
Indigenous	156 (6.1%)	184 (12.3%)	340 (8.6%)
Black, mulatto, Afro-Colombian	152 (9.8%)	84 (11.8%)	236 (10.6%)
Without ethnicity	1255 (84.0%)	789 (76.0%)	2044 (80.8%)
Area of residence n (%*)			
Urban	1166 (73.7%)	850 (71.8%)	2016 (72.9%)
Rural	409 (26.3%)	222 (28.2%)	631 (27.1%)
Social security status n (%*)			
Contributory	491 (40.2%)	292 (36.5%)	783 (38.7%)
Subsidized	1011 (56.0%)	745 (61.4%)	1756 (58.2%)
Unaffiliated	68 (3.8%)	28 (2.2%)	96 (3.1%)
Wealth index quartile n (%*)			
First Quartile	826 (42.6%)	603 (43.5%)	1429 (43.0%)
Second Quartile	362 (23.0%)	227 (21.9%)	589 (22.6%)
Third Quartile	238 (19.5%)	149 (17.3%)	387 (18.6%)
Fourth Quartile	149 (14.9%)	93 (17.3%)	242 (15.9%)

$\bar{x}$, mean; s, standard deviation; n, absolute frequency, %, percentage frequency. It is not correct to calculate the percentages from the "n" presented in this table; these calculations were taken from weighted values given to each participant.

Regarding $HS_{Relative}$, only 3 reports were found worldwide.[22,28,30] The children and adolescents in the present study had higher values than South American children[28,30] and lower values than Americans.[22] Among girls and adolescents, only values that were higher than those from a study in South America were found.[28] Tables 3 and 4 show the details of the comparisons with the normative values for $HS_{Relative}$.[22,28,30]

One difficulty in performing the comparison with other studies is the diversity of methodologies in different phases of the research. The first difference was the number of measurements and the value that was regarded as valid as the HS score assigned to the subject; for example, some studies do not explain the quantity of trials used in each hand,[17,25] others use the average value of the best attempt of 2 measurements in each hand,[12,26,30] and others use the maximum value of 2 attempts in the dominant hand,[15] with other studies preferring different approaches.[16,19-24,28,29,31,33] This may explain some of the variability in the results, as it has been reported that among right-handed subjects, HS can be 10% higher in the dominant hand but that among left-handed subjects, HS in both hands is equal.[41] In the present study, the average and maximum values for each child and adolescent were used because there is no specific criterion to determine which is the value of the valid HS for each subject (The normative values using maximum scores are shown in Supplementary Table 1). For example, some authors have reported that one of the strategies to reduce the measurement error is to use the average HS value;[9] on the other hand, some international guidelines have recommended using the highest HS value.[42]

The second difference regards the positioning of the arm for the measurement. Generally, the measurement is made with the elbow extended.[12,15,17,19,21,23,24,30,31,33] In some reports, HS was evaluated with the elbow flexed,[23] but in others, this aspect is not described.[13,14,16,18,20,22,25-29,32] The third difference pertains to the technology and brand of the dynamometer. The investigations used mainly the TKK 5401, Grip-A, Takei (Tokyo, Japan);[16,21,22,32] Fred Sammons, Inc. (Burr Ridge, IL: USA);[24,28,29] and TKK 5101, Takei (Tokyo, Japan)[17,20] dynamometers, but others were also used.[12,14,15,23,30,31,33] Finally, another point that could be added to the variability of the results is the proposed estimation method, as the most used was the LMS.[34] Of the studies that were included in the discussion of this work, approximately 50% reported having used this method.[13,14,16,18,20,22,25,26,28-33] Other methods reported include generalized additive models,[12,17] generalized linear models,[21,23,24] and quantile regression,[15] but in some cases, the model is not reported.[19,27]

Despite the benefits offered by the LMS,[34] it was decided to estimate the models through quantile regression, based on the fact that it is a less rigid approach to estimating the normative values than the LMS.[35] This is because, among its characteristics, it does not make any assumption about the distribution of the variable to be modeled.[36,37] It is robust to the presence of heteroscedasticity and atypical values because its parameters are estimated by minimizing the sum of the weighted absolute values for the residuals, which makes it more robust.[38] Additionally, when the errors have a non-normal distribution, the estimators in the quantile regression models are efficient.[39] When used to estimate normative values, it has the ability to generate models that include previous measurements of the target variable or even of other covariates,[38,39] while the estimation with the LMS method does not allow covariates,[34] that is, the LMS allows only cross-sectional analyses,[34] while quantile regression allows longitudinal and cross-sectional analyses.[38,39] A point of interest is that both the LMS and the quantile regression generate concordant reports.[35] One of the

Table 2 Sex and age-specific percentile values using quantile regression for the absolute handgrip strength and relative handgrip strength (using mean value of each subject) among Colombian aged 6–17.9 years.

	Absolute handgrip strength								Relative handgrip strength							
Male	n	P_5	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{95}	n	P_5	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{95}
6.0 to 6.9 years	**54**	6.5	6.7	7.4	8.7	10.5	13.9	15.0	**52**	0.238	0.281	0.338	0.379	0.471	0.630	NA
7.0 to 7.9 years	**52**	8.2	8.8	9.9	9.9	10.8	12.7	14.3	**49**	0.313	0.354	0.424	0.440	0.505	0.521	0.491
8.0 to 8.9 years	**60**	8.0	8.0	9.9	11.3	13.6	16.2	20.5	**59**	0.261	0.309	0.373	0.407	0.493	0.637	0.621
9.0 to 9.9 years	**64**	9.3	10.4	11.3	14.0	14.7	15.1	15.5	**64**	0.339	0.370	0.448	0.488	0.532	0.548	0.582
10.0 to 10.9 years	**67**	10.9	11.7	13.5	14.3	15.5	18.0	19.4	**65**	0.317	0.328	0.436	0.477	0.506	0.606	0.505
11.0 to 11.9 years	**58**	11.8	12.8	14.6	16.1	18.9	22.2	23.2	**57**	0.285	0.331	0.408	0.426	0.520	0.651	0.597
12.0 to 12.9 years	**57**	10.4	14.5	15.0	18.5	21.0	25.3	31.0	**57**	0.301	0.318	0.422	0.485	0.547	0.605	0.581
13.0 to 13.9 years	**244**	14.4	15.8	19.6	23.2	27.5	31.7	33.7	**237**	0.335	0.368	0.409	0.498	0.572	0.658	0.573
14.0 to 14.9 years	**216**	18.8	19.7	21.9	26.5	31.3	34.7	36.7	**207**	0.378	0.378	0.451	0.528	0.603	0.678	0.677
15.0 to 15.9 years	**230**	20.3	23.3	26.6	30.7	36.3	39.0	42.8	**221**	0.376	0.426	0.490	0.573	0.631	0.695	0.558
16.0 to 16.9 years	**252**	24.5	27.3	30.5	34.2	38.3	41.9	43.9	**242**	0.440	0.465	0.499	0.573	0.643	0.696	0.587
17.0 to 17.9 years	**221**	24.2	27.1	30.1	35.7	39.4	44.7	47.8	**209**	0.422	0.475	0.516	0.604	0.676	0.747	0.543
Female																
6.0 to 6.9 years	**66**	5.7	5.9	6.7	7.8	10.7	12.4	14.6	**63**	0.293	0.293	0.339	0.346	0.424	0.617	NA
7.0 to 7.9 years	**72**	7.1	7.6	8.3	8.3	9.7	11.0	11.1	**71**	0.293	0.313	0.356	0.417	0.430	0.472	0.491
8.0 to 8.9 years	**64**	6.4	6.8	7.4	9.9	12.8	15.4	16.1	**63**	0.209	0.275	0.313	0.398	0.451	0.608	0.621
9.0 to 9.9 years	**60**	8.6	8.8	9.4	11.5	12.9	15.5	17.1	**57**	0.272	0.306	0.372	0.427	0.468	0.494	0.582
10.0 to 10.9 years	**63**	10.1	10.7	12.9	14.4	16.9	19.0	20.9	**61**	0.227	0.260	0.374	0.403	0.471	0.502	0.505
11.0 to 11.9 years	**79**	10.8	10.8	12.1	13.6	16.2	20.1	21.9	**77**	0.282	0.297	0.320	0.356	0.483	0.510	0.597
12.0 to 12.9 years	**65**	12.3	13.9	14.3	18.5	20.7	23.8	27.7	**60**	0.317	0.317	0.380	0.429	0.499	0.566	0.581
13.0 to 13.9 years	**136**	11.8	13.8	16.9	19.9	22.0	24.4	25.6	**134**	0.264	0.301	0.355	0.413	0.453	0.506	0.573
14.0 to 14.9 years	**108**	11.0	13.5	16.1	20.1	23.6	26.6	33.6	**107**	0.229	0.292	0.348	0.412	0.453	0.541	0.677
15.0 to 15.9 years	**115**	15.0	15.9	18.3	21.1	23.9	26.8	28.8	**105**	0.293	0.330	0.352	0.412	0.456	0.505	0.558
16.0 to 16.9 years	**132**	14.1	15.9	18.2	22.3	26.1	29.4	30.2	**125**	0.261	0.288	0.328	0.388	0.453	0.507	0.587
17.0 to 17.9 years	**112**	14.4	14.6	19.4	23.2	25.0	25.8	27.4	**107**	0.253	0.297	0.347	0.386	0.441	0.480	0.543

These models were estimated independently for each sex; all analysis were adjusted by sampling weight (expansion factor) from the values given to each subject. These models were estimated using the mean value of the handgrip strength measurements in each hand *(right hand + left hand) / 2*; additionally, the relative handgrip strength was adjusted by weight.

Table 3 Male reference values (50th percentile) for absolute handgrip strength (kg) and relative handgrip strength (adjusted by weight) from cited studies.

Absolute handgrip strength															
Author	Publication year	Country	n	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years
Martínez-Torres et al. $_{\text{Average value}}$	2022	Colombia	1575	8.7	9.9	11.3	14.0	14.3	16.1	18.5	23.2	26.5	30.7	34.2	35.7
Martínez-Torres et al. $_{\text{Maximum value}}$	2022	Colombia	1575	8.9	10.1	11.5	14.6	14.4	16.5	20.0	23.9	27.6	32.0	35.4	36.8
Ramírez-Vélez et al.[33]	2021	Colombia	1575	8.4	**10.7**	**13.1**	**15.5**	**18.0**	**20.5**	**23.0**	**25.6**	**28.1**	30.4	**32.6**	34.5
García-Hermoso et al.[28]	2021	Chile	1325			**11.5**	14.0	**15.8**	**17.2**	**21.0**					
Cadenas-Sanchez et al.[12]	2019	Spain	1678	**10.4**											
Kocher et al.[21]	2019	USA	2384	**10.8**	**12.6**	**14.4**	**16.5**	**18.6**	**21.2**	**23.8**	**29.2**	**34.3**	**39.3**	**40.8**	**42.8**
Tomkinson et al.[13]	2018	24 countries[c]	102,685				**15.3**	**16.8**	**19.0**	**22.6**	**28.4**	**34.6**	**39.5**	**42.9**	**45.0**
Gómez-Campos et al.[29,b]	2018	Chile	2269	**9.3**	**10.7**	**12.0**	13.5	**15.5**	**18.5**	**22.4**	**27.2**	**32.0**	**36.5**	**40.0**	**42.5**
Ramírez-Vélez et al.[30]	2017	Colombia	3129				12.9	14.1	15.6	17.5	21.1	23.8	28.5	31.1	**37.2**
Laurson et al.[22,a]	2017	USA	597	**11.0**	**12.9**	**14.6**	**16.6**	**18.8**	**22.2**	**25.7**	**30.1**	**35.0**	**39.6**		
Lee et al.[26]	2017	South Korea	7688								**24.8**	**29.5**	**33.2**	**36.0**	**37.3**
Kocher et al.[24]	2017	Hawaii	1301	**11.0**	**14.0**	**16.0**	**19.0**	**21.5**	**25.0**	**29.5**	**35.5**	**42.0**			
Bohannon et al.[23]	2017	USA	1331	**10.0**	**11.4**	**13.0**	**16.1**	**17.7**	**20.3**	**23.4**	**29.0**	**33.7**	**37.5**	**39.6**	**44.6**
Hong Kong government[27,a]	2016	Hong Kong	3969	8.5	9.8	**11.5**	13.0	**14.8**	**16.5**	18.3					
Ramos-Sepúlveda et al.[31]	2016	Colombia	319					13.9	13.9	14.7	17.2	19.3	23.5	27.4	32.9
Dobosz et al.[14]	2015	Poland	25,430		**11.4**	**13.9**	**16.0**	**18.6**	**21.0**	**24.5**	**30.1**	**36.4**	**42.1**	**46.4**	**49.2**
Saint Maurice et al.[15]	2015	Hungary	432						**21.4**	**21.7**	**25.0**	**30.0**	**35.4**	**40.0**	**42.6**
Roriz de Oliveira et al.[16]	2014	Portugal	1985	8.1	9.9	**11.6**	13.6	**15.6**							
De Miguel-Etayo et al.[17]	2014	8 countries[c]	3163	**9.6**	**11.3**	**13.1**									
Catley et al.[25]	2013	Australia	NC				**16.4**	**19.0**	**21.2**	**22.7**	**25.8**	**30.7**	**36.5**		
Bustamante et al.[32]	2012	Peru	3688	6.9	8.0	9.2	10.9	12.6	14.2	16.6	20.0	24.4	28.2	31.9	34.4
Ortega et al.[18]	2011	10 countries[c]	1683								**26.2**	**32.2**	**37.7**	**41.8**	**45.1**
Hong Kong government[27,a]	2011	Hong Kong	2943	7.7	**10.0**	**11.5**	13.0	**15.0**	**17.0**	**19.5**					
Marrodán Serrano et al.[19,b]	2009	Spain	1176	8.6	9.2	10.6	12.0	14.7	**17.6**	**20.9**	**24.4**	**31.6**	**34.9**	**36.5**	**40.4**
Hong Kong government[27,a]	2005	Hong Kong	3626	7.7	**10.0**	**11.5**	13.3	**15.0**	**17.5**	**21.5**					
Ortega et al.[20,a]	2005	Spain	1357								**26.1**	**32.2**	**35.5**	**38.3**	**39.3**
Relative handgrip strength															
Author	Publication year	Country	n	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years
Martínez-Torres et al. $_{\text{Average value}}$	2021	Colombia	1575	0.379	0.440	0.407	0.488	0.477	0.426	0.485	0.498	0.528	0.573	0.573	0.604
Martínez-Torres et al. $_{\text{Maximum value}}$	2021	Colombia	1575	0.391	0.449	0.422	0.513	0.495	0.446	0.508	0.507	0.550	0.582	0.585	0.618
García-Hermoso et al.[28]	2021	Chile	1325			0.350	0.370	0.390	0.380	0.400					
Laurson et al.[22,a]	2017	USA	597	0.470	**0.476**	**0.474**	0.472	**0.478**	**0.490**	**0.508**	**0.529**	**0.553**	**0.575**		
Ramírez-Vélez et al.[30]	2017	Colombia	3129				0.410	0.410	**0.430**	0.450	0.480	0.500	0.550	0.560	0.560

[a] The original report showed the sum of two attempts; for comparative purposes of this table, the authors divided that value for 2.
[b] Estimated model in right hand.
[c] All countries were from Europe.
Values show in bold are superior to found in the present report compared with average value.
Methodology specification from cited studies is summarized in supplementary Table 3.

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Table 4 Female reference values (50th percentile) for absolute handgrip strength (kg) and relative handgrip strength (adjusted by weight) from cited studies.

Absolute handgrip strength															
Author	Publication year	Country	n	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years
Martínez-Torres et al. Average value	2022	Colombia	1072	7.8	8.3	9.9	11.5	14.4	13.6	18.5	19.9	20.1	21.1	22.3	23.2
Martínez-Torres et al. Maximum value	2022	Colombia	1072	8.5	8.6	10.1	11.9	14.5	14.0	18.9	20.4	20.3	22.2	23.5	23.4
Ramírez-Vélez et al.[33]	2021	Colombia	1072	**8.9**	**10.5**	**12.1**	**13.7**	**15.2**	**16.7**	18.2	19.5	**20.7**	**21.7**	**22.6**	**23.4**
García-Hermoso et al.[28]	2021	Chile	705			9.0	**11.7**	**15.0**	**16.0**	**19.1**					
Cadenas-Sanchez et al.[12]	2019	Spain	1501	**9.4**											
Kocher et al.[21]	2019	USA	2281	**10.3**	**11.6**	**13.3**	**15.3**	**17.9**	**20.9**	**23.9**	**25.3**	**26.7**	**27.6**	**28.2**	**28.4**
Tomkinson et al.[13]	2018	24 countries[c]	100,609				**13.6**	**15.2**	**17.5**	**20.6**	**24.6**	**27.1**	**28.0**	**28.2**	**28.4**
Gómez-Campos et al.[29,b]	2018	Chile	2374	**8.0**	**9.3**	**10.9**	**12.7**	**14.9**	**17.5**	**20.2**	**22.6**	**24.4**	**25.5**	**25.9**	**25.9**
Ramírez-Vélez et al.[30]	2017	Colombia	4139				**12.7**	13.4	**15.3**	18.1	19.5	**21.9**	**21.5**	**22.7**	**23.3**
Laurson et al.[22,a]	2017	USA	601	**10.6**	**11.9**	**13.6**	**15.4**	**17.5**	**20.7**	**24.0**	**25.9**	**26.8**	**27.4**		
Lee et al.[26]	2017	South Korea	7106								**20.4**	**21.6**	**22.2**	22.3	23.2
Kocher et al.[24]	2017	Hawaii	1326	**10.5**	**12.5**	**14.0**	**17.0**	**19.5**	**24.5**	**27.0**	**30.5**	**31.5**			
Bohannon et al.[23]	2017	USA	1335	**9.2**	**11.3**	**12.5**	**14.2**	**17.4**	**20.1**	**23.6**	**25.0**	**26.7**	**27.6**	**27.6**	**28.7**
Hong Kong government[27,a]	2016	Hong Kong	3435	7.8	**9.0**	**10.5**	**12.5**	14.3	**16.5**	**19.5**					
Ramos-Sepúlveda et al.[31]	2016	Colombia	257					13.9	**13.9**	13.9	15.3	17.7	19.9	17.0	19.3
Dobosz et al.[14]	2015	Poland	23,411		**10.0**	**11.9**	**14.0**	**16.5**	**19.4**	**22.5**	**25.3**	**27.3**	**28.5**	**29.4**	**29.8**
Saint Maurice et al.[15]	2015	Hungary	654						**20.0**	**19.5**	19.6	**20.3**	**21.6**	**23.5**	**26.1**
Roriz de Oliveira et al.[16]	2014	Portugal	1819	7.6	**9.1**	**10.8**	**12.5**	**14.7**							
De Miguel-Etayo et al.[17]	2014	8 countries[c]	3329	**8.6**	**10.2**	**11.9**									
Catley et al.[25]	2013	Australia	NC				**14.4**	**17.1**	**18.8**	**21.4**	**23.6**	**25.4**	**26.9**		
Bustamante et al.[32]	2012	Peru	4155	6.2	7.0	8.3	9.9	11.9	**14.1**	16.2	18.0	19.6	20.5	21.3	22.0
Ortega et al.[18]	2011	10 countries[c]	1845								**23.6**	**25.2**	**26.2**	**26.6**	27.6
Hong Kong government[27,a]	2011	Hong Kong	2943	7.8	**9.5**	**10.8**	**12.5**	14.3	**17.0**	**19.5**					
Marrodán Serrano et al.[19,b]	2009	Spain	949	7.4	**8.7**	**10.4**	11.2	13.6	**16.5**	**19.4**	**21.5**	**22.7**	**23.6**	**23.9**	24.6
Hong Kong government[27,a]	2005	Hong Kong	3362	7.8	**9.0**	**10.5**	**12.3**	**14.5**	**17.3**	**20.0**					
Ortega et al.[20a]	2005	Spain	1502								**24.1**	**24.5**	**25.3**	**25.9**	24.9
Relative handgrip strength															
Author	Publication year	Country	n	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years
Martínez-Torres et al. Average value	2021	Colombia	1072	0.346	0.417	0.398	0.427	0.403	0.356	0.429	0.413	0.412	0.412	0.388	0.386
Martínez-Torres et al. Maximum value	2021	Colombia	1072	0.394	0.428	0.405	0.442	0.424	0.364	0.454	0.431	0.414	0.427	0.404	0.410
García-Hermoso et al.[28]	2021	Chile	705			0.280	0.320	0.360	0.370	0.370					
Laurson et al.[22,a]	2017	USA	601	**0.460**	**0.460**	**0.461**	**0.461**	**0.462**	**0.462**	**0.462**	**0.463**	**0.463**	**0.464**		
Ramírez-Vélez et al.[30]	2017	Colombia	4139				0.380	0.400	**0.420**	0.420	0.420	**0.420**	**0.420**	**0.430**	0.420

[a] The original report showed the sum of two attempts; for comparative purposes of this table, the authors divided that value for 2.
[b] Estimated model in right hand.
[c] All countries were from Europe.
Values show in bold are superior to found in the present report compared with average value
Methodology specification from cited studies is summarized in Supplementary Table 3.

disadvantages of quantile regression is that it is not present in all statistical software, which has hindered its application; for example, in the *Statistical Package for the Social Sciences "SPSS"*, it was included only up to version 26 of 2019.

The present study has several strengths. First, this is a representative sample of Colombia. Second, this was a study of children and adolescents aged from 6 to 17 years, which is an advantageous period in the human life cycle to enable effective promotion and prevention strategies to improve PF-HR levels. There are also limitations in the present study. First, the authors did not include the potential impact of recognized variables on HS, such as physical activity levels, on the centile values presented. Second, available data did not evaluate important characteristics associated with HS, such as sex hormone levels, sexual maturation, and environmental health background. However, such limitations do not compromise the results obtained when validating the present study's results. To fully understand the development of HS during childhood and adolescence, longitudinal studies that take into account the rhythm and time of growth and maturation are required.

Conclusion

The present report presents the specific normative values by sex and age of HS and $HS_{Relative}$ in Colombian children and adolescents from 6 to 17 years of age. Male children and adolescents showed consistently higher HS values than their female peers in all age groups. Regardless of sex, higher HS values were observed. Several discrepancies were observed between the methodologies used to generate normative values for HS in children and adolescents, including the number of attempts that were made in each subject, dynamometer technology, measurement procedures used to evaluate HS, and statistical methods used in the estimations. This could influence the discrepancies between the different reports. The data in this report suggest that the normative values for HS and $HS_{Relative}$ for populations on other continents do not represent the Colombian population.

Funding

The Ensin-2015 was conducted during the years 2014 and 2017 and was funded by the Instituto Colombiano de Bienestar Familiar. Additionally, the authors have been supported by Universidad de Pamplona, Colombia; and, Universidad de Antioquia, Colombia.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

The Ensin-2015 was conducted during the years 2014 and 2017 and was funded by the Instituto Colombiano de Bienestar Familiar.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jped.2022.02.004.

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