Vertical Jump and Leg Power Normative Data for Colombian Schoolchildren Aged 9–17.9 Years: The FUPRECOL Study

Robinson Ramírez-Vélez,[1] Jorge E. Correa-Bautista,[1] Felipe Lobelo,[2] Eduardo L. Cadore,[3] Alicia M. Alonso-Martinez,[4] and Mikel Izquierdo[4,5]

[1]*Center of Studies in Physical Activity Measurements, School of Medicine and Health Sciences, University of Rosario, Bogotá, DC, Colombia;* [2]*Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, Georgia;* [3]*Exercise Research Laboratory, School of Physical Education, Federal University of Rio Grande do Sul, Porto Alegre, Brazil;* [4]*Department of Health Sciences, Public University of Navarra, Pamplona, Spain; and* [5]*Faculty of Physical Culture, Sport and Recreation, Santo Tomás University, Bogotá, DC, Colombia*

Abstract

Ramírez-Vélez, R, Correa-Bautista, JE, Lobelo, F, Cadore, EL, Alonso-Martinez, AM, and Izquierdo, M. Vertical jump and leg power normative data for Colombian schoolchildren aged 9–17.9 years: the FUPRECOL study. *J Strength Cond Res* 31(4): 990–998, 2017—The aims of the present study were to generate normative vertical jump height and predicted peak power (P_{peak}) data for 9- to 17.9-year-olds and to investigate between-sex and age group differences in these measures. This was a cross-sectional study of 7,614 healthy schoolchildren (boys $n = 3{,}258$ and girls $n = 4{,}356$, mean [*SD*] age 12.8 [2.3] years). Each participant performed 2 countermovement jumps; jump height was calculated using a Takei 5414 Jump-DF Digital Vertical (Takei Scientific Instruments Co., Ltd.). The highest jump was used for analysis and in the calculation of predicted P_{peak}. Centile smoothed curves, percentiles, and tables for the 3rd, 10th, 25th, 50th, 75th, 90th, and 97th percentiles were calculated using Cole's LMS (L [curve Box-Cox], M [curve median], and S [curve coefficient of variation]) method. The 2-way analysis of variance tests showed that maximum jump height (in centimeters) and predicted P_{peak} (in watts) were higher in boys than in girls ($p < 0.01$). Post hoc analyses within sexes showed yearly increases in jump height and P_{peak} in all ages. In boys, the maximum jump height and predicted P_{peak} 50th percentile ranged from 24.0 to 38.0 cm and from 845.5 to 3061.6 W, respectively. In girls, the 50th percentile for jump height ranged from 22.3 to 27.0 cm, and the predicted P_{peak} was 710.1–2036.4 W. For girls, jump height increased yearly from 9 to 17.9 years old. Our results provide, for the first time, sex- and age-specific vertical jump height and predicted P_{peak} reference standards for Colombian schoolchildren aged 9–17.9 years.

Key Words strength, biomechanics, adolescent, percentile, jumping, muscular power

Introduction

Anaerobic power refers to the ability to perform high-intensity exercise for a fraction of a second to several minutes (e.g., distance jumped, weight lifted) (21). Typically, this energy system is assessed by testing maximal effort in cycling, running, or jumping (7). Jump testing is potentially very useful because many sports and work activities involve either jumping or movements similar to jumping, such as lifting heavy objects ballistically. The vertical jump (VJ) test is a simple method for calculating peak leg power using prediction equations based on jump height and body mass (29). This test measures the vertical displacement of the center of mass between standing on the ground and at the apex of a jump (31). Jumping primarily involves the gluteal and quadriceps muscles, which are instrumental in many sport and work activities (2,11).

Raw measures of jump height may have some use in performance appraisal, but ideally, an estimate of peak leg power should accompany jump height normative data because this provides insight beyond the outcome of the jump itself (29). For example, 2 individuals of different body weight might be able to jump vertically the exact same distance, therefore calculating power values could provide additional information to that given by jump height alone (11). However, the heavier individuals' jump would show the ability to generate greater power, which could provide an advantage in activities which involve manipulation of mass outside the body (e.g., helping to identify talented athletes).

Typically, VJ can be measured using relatively inexpensive, portable, and easy-to-use tools (23,26,28) and is a reliable (2,11,22) and valid (3) method for strength assessment.

Address correspondence to Mikel Izquierdo, mikel.izquierdo@gmail.com.

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TABLE 1. Descriptive statistics for anthropometric and jump height and peak power in 9- to 17.9-year-old Colombian schoolchildren.*†

Sex	n	Body mass (kg)	Height (cm)	Body mass index ($kg \cdot m^{-2}$)	Maximum jump height (cm)	Difference		P_{peak} (W)
						D (cm)	%	
Boys								
9–9.9	236	32.1 (7.5)	133.5 (6.5)	17.8 (3.1)	24.0 (4.9)‡			868.0 (462.4)§
10–10.9	440	34.5 (8.5)	137.3 (7.4)§	18.1 (3.3)	25.4 (5.0)‡	1.4	6.1	1,057.4 (489.7)§
11–11.9	414	37.2 (8.8)§	141.9 (8.2)§	18.3 (3.2)	26.9 (4.7)‡	2.9	6.5	1,277.1 (465.8)§
12–12.9	368	41.3 (9.1)§	147.1 (8.2)§	18.9 (3.2)	27.9 (5.1)‡	3.9	6.7	1,529.7 (520.1)§
13–13.9	379	46.0 (9.8)§	153.5 (9.3)§	19.4 (3.3)‡	30.5 (6.3)‡	6.5	7.3	1,879.8 (588.1)‡
14–14.9	415	50.0 (9.7)§	158.9 (9.1)‡	19.7 (3.0)‡	32.2 (6.6)‡	8.2	7.7	2,174.5 (646.4)‡
15–15.9	407	54.4 (9.7)§	163.3 (8.9)‡	20.3 (3.0)‡	35.1 (6.6)‡	11.1	8.4	2,544.1 (651.6)‡
16–16.9	358	57.7 (8.7)‡	166.7 (7.2)‡	20.8 (2.9)‡	36.2 (6.8)‡	12.2	8.7	2,761.1 (571.4)‡
17–17.9	241	60.8 (10.3)‡	168.1 (7.4)‡	21.5 (3.3)‡	37.6 (7.2)‡	13.6	9.0	2,986.3 (658.5)‡
Total	3,258	45.5 (13.0)§	151.9 (14.1)‡	19.4 (3.3)‡	30.5 (7.4)‡			1,877.5 (887.0)‡
Girls								
9–9.9	308	32.1 (7.4)	134.6 (7.6)	17.6 (3.0)	22.3 (5.0)			773.1 (467.2)
10–10.9	672	35.0 (7.9)	138.4 (7.6)	18.1 (3.0)	24.0 (4.6)	1.7	5.4	995.7 (456.8)
11–11.9	619	38.3 (7.9)	143.7 (7.5)	18.4 (2.9)	24.9 (4.6)	2.6	5.6	1,198.3 (429.4)
12–12.9	506	42.8 (8.6)	148.5 (7.3)	19.3 (3.0)	25.5 (4.6)	3.2	5.7	1,431.0 (483.3)
13–13.9	456	47.4 (9.0)	152.4 (6.3)	20.3 (3.2)	25.5 (5.3)	3.2	5.7	1,628.1 (504.3)
14–14.9	582	51.0 (8.9)	154.6 (6.5)	21.3 (3.3)	26.1 (5.2)	3.8	5.8	1,841.0 (512.8)
15–15.9	493	52.7 (8.6)	155.7 (6.8)	21.7 (3.1)	26.4 (5.1)	4.1	5.9	1,934.4 (483.6)
16–16.9	433	53.9 (8.6)	156.4 (5.8)	22.0 (3.1)	26.7 (6.9)	4.4	6.0	2,010.2 (579.4)
17–17.9	287	55.1 (9.3)	156.8 (6.5)	22.4 (3.6)	27.6 (5.7)	5.3	6.2	2,115.4 (541.6)
Total	4,356	44.8 (11.5)	148.7 (10.1)	20.0 (3.5)	25.4 (5.3)			1,527.7 (647.6)

*Data values are reported as mean (±) (*SD*).
†D = between-year differences (9–9.9, 10–10.9, 11–11.9, 12–12.9, 13–13.9, 14–14.9, 15–15.9, 16–16.9, 17–17.9 years) in absolute scores; % = relative change in jump height.
‡Significant difference between boys and girls within the same age group: $p < 0.0001$.
§Significant difference between boys and girls within the same age group: $p < 0.01$.

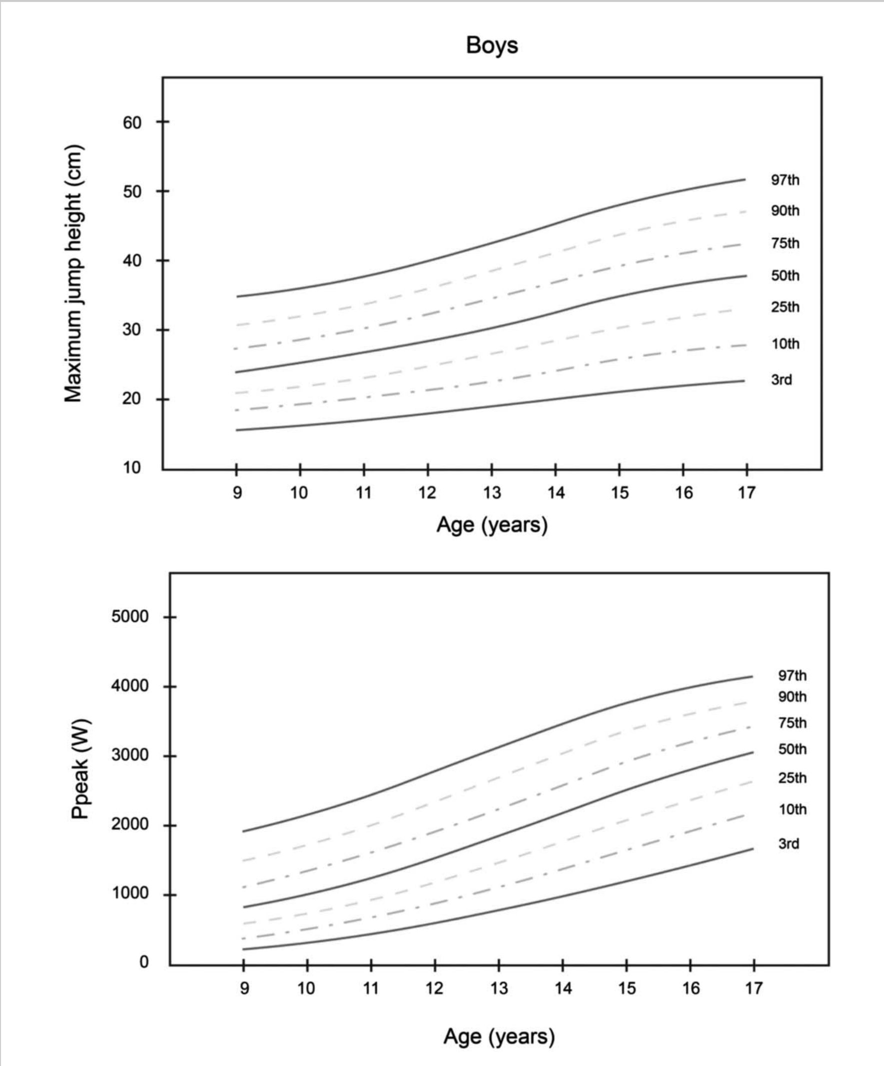

Figure 1. Centile curves for vertical jump height (in centimeters) and predicted peak power (in watts) in boys and age.

However, the majority of published VJ reference values are for schoolchildren from high-income countries in North America (18), Canada (19), Europe (29), and Africa (1). In contrast, there is a scarcity of reference values for children using harmonized measures of fitness in Latin America (9,22) and other low-to-middle-income countries undergoing nutritional transitions (17,22), making it impossible to evaluate secular trends within these regions. There are no such data available for school-aged Colombian children and adolescents.

Therefore, the aims of the present study were to generate normative VJ and predicted peak power data for 9- to 17.9-year-olds and to investigate between-sex and age group differences in these measures.

Methods

Experimental Approach to the Problem

During the 2014–2015 school year, we conducted a cross-sectional component of the FUPRECOL study (in Spanish, ASOCIACIÓN DE LA FUERZA PRENSIL CON MANIFESTACIONES DE RIESGO CARDIOVASCULAR TEMPRANAS EN NIÑOS Y ADOLESCENTES COLOMBIANOS). Briefly, this study aimed to examine the relationships between physical fitness levels in children and adolescents with cardiometabolic risk factors and healthy habits. These data were used to evaluate their health status (20,22,24) and to establish reference values for anthropometric, metabolic, and physical fitness among children and adolescents aged 9–17.9 years in Bogota, Colombia.

A convenience sample of volunteers was included and grouped by sex and age in 1-year increments (a total of 9 groups). Power calculations were based on the mean of maximum jump height (in centimeters) from the first 200 participants in the ongoing data collection (range, 20–35 cm), with a group *SD* of approximately 5.2 cm. The significance level was set to 0.05, and the required power was set to at least 0.80. The sample size was estimated to be

Collective VJ can be assessed using various strength performance tests, such as the countermovement jump, standing broad jump test, Abalakov jump test, and Sargent jump and leg press (12,26). Sex- and age-specific normative values for VJ in young people have been published (18,19). For children, only 2 studies attempted to develop normative data tables for the VJ (1,29). For example, the sample used by Bovet et al. (1) was African descent, with minorities of Caucasian, Indian, Chinese, and mixed origins, and it is not clear whether their lower-body explosive power is comparable with the broad range of jump abilities seen in the wider pediatric population. Thus, there is a need to refine and improve the methods used to estimate jumping performance, currently available to practitioners and coaches. To date, predicted peak leg power for jumping has not been reported for Latin American schoolchildren.

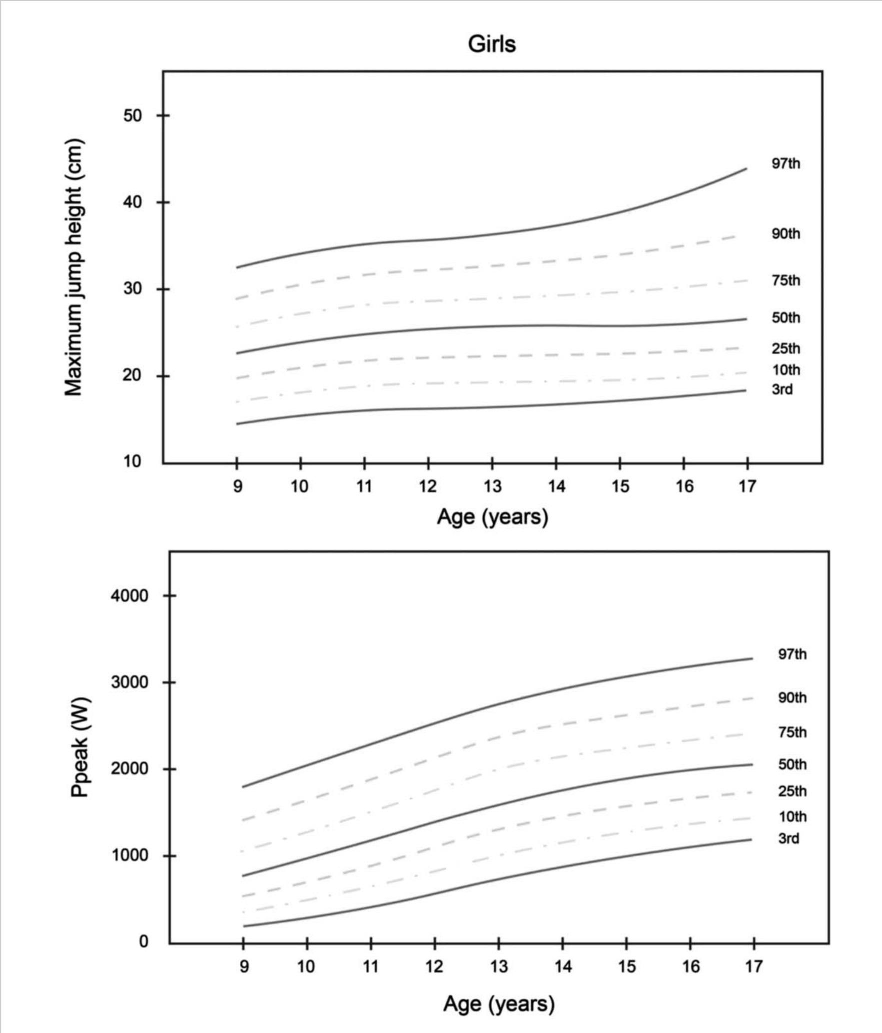

Figure 2. Centile curves for vertical jump height (in centimeters) and predicted peak power (in watts) in girls and age.

approximately 200–400 participants per group. Exclusion factors included a clinical diagnosis of cardiovascular disease, diabetes mellitus type 1 or 2, pregnancy, the use of alcohol or drugs, and, in general, the presence of any disease not directly associated with nutrition. Exclusion from the study was made effective a posteriori and without the students' knowledge to avoid any undesired situations.

Subjects

The sample comprised 7,614 healthy Colombian schoolchildren (boys $n = 3{,}258$ and girls $n = 4{,}356$, mean ± *SD* age 12.8 [2.3] years, body mass 45.1 [12.1] kg, height 1.50 [0.1] m, body mass index (BMI) 19.7 [3.4] $kg \cdot m^{-2}$). The schoolchildren were of low-to-middle socioeconomic status (1–3 as defined by the Colombian government) and enrolled in public elementary and high schools (between grades 5 and 11) in the capital district of Bogota in a municipality in the Cundinamarca Department in the Andean region. This region is located at approximately 4°35′56″N 74°04′51″W and at an elevation of approximately 2,625 m (min: 2,500 m, max: 3,250 m) above sea level. Bogota is considered an urban area with 7,862,277 inhabitants (6).

The study was approved by the institutional review board for use of human subject research in addition to the Rosario University Board (Code Nº CEI-ABN026-000262). Potential subjects and their parents or guardian (s) were informed of the purpose, benefits, and potential risks of the study, and then provided written informed consent to participate. The protocol was in accordance with the latest revision of the Declaration of Helsinki (as revised in Hong Kong in 1989 and in Edinburgh, Scotland, in 2000) and current Colombian laws governing clinical research on human subjects (Resolution 008430/1993 Ministry of Health).

Procedures

Anthropometric variables were measured by a level 2 anthropometrist certified by the International Society for the Advancement of Kinanthropometry (ISAK), in accordance with the ISAK guidelines (15), at the same time (7:00–10:00 AM) in the morning following an overnight fast. Body weight was measured with subjects wearing their underwear and without shoes using electronic scales (Tanita BC544; Tanita, Tokyo, Japan) with a low technical error of measurement (TEM = 0.510%). Height was measured using a mechanical stadiometer platform (Seca 274; Seca Hamburg, Germany; TEM = 0.019%). Body mass index was calculated as the body weight in kilograms divided by the square of height in meters. The data were recorded on paper by the FUPRECOL evaluators (22).

The VJ (in centimeters) was measured using a standard mat (Takei 5414 Jump-DF digital vertical; Takei Scientific Instruments Co., Ltd., Niigata, Japan) and then performed a countermovement jump with arms on waist. Each

Table 2. Vertical jump height (in centimeters) and predicted peak power (in watts) percentiles in boys and in girls by age.*

	n	M	*SD*	P_3	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{97}
Boys										
Jump height										
9–9.9	236	24.0	4.9	16.6	18.0	20.5	24.0	26.5	29.5	35.3
10–10.9	440	25.4	5.0	16.0	19.5	22.0	25.0	28.5	32.0	35.0
11–11.9	414	26.9	4.7	18.0	21.0	24.0	27.0	30.5	32.5	35.8
12–12.9	368	27.9	5.1	19.0	22.0	24.5	27.5	31.5	34.5	38.0
13–13.9	379	30.5	6.3	19.7	23.0	26.5	30.5	34.5	39.0	44.0
14–14.9	415	32.2	6.6	20.0	23.5	28.0	32.0	36.5	41.5	44.0
15–15.9	407	35.1	6.6	22.5	26.0	31.0	35.5	40.0	43.0	47.0
16–16.9	358	36.2	6.8	23.5	28.0	31.5	36.5	40.5	45.1	49.1
17–17.9	241	37.6	7.2	22.5	28.0	33.0	38.0	42.0	47.0	50.0
Total	3,258	30.5	7.4	18.4	21.5	25.0	30.0	35.5	41.0	45.5
Peak power										
9–9.9	236	868.0	462.4	197.3	349.7	576.4	845.5	1,054.3	1,450.9	1,898.0
10–10.9	440	1,057.4	489.7	249.9	489.2	747.0	1,017.6	1,298.9	1,632.6	2,099.2
11–11.9	414	1,277.1	465.8	464.6	727.5	945.2	1,221.7	1,569.0	1,887.6	2,266.1
12–12.9	368	1,529.7	520.1	638.1	893.7	1,146.3	1,501.0	1,845.7	2,244.8	2,603.6
13–13.9	379	1,879.8	588.1	914.5	1,115.8	1,458.0	1,846.6	2,286.6	2,627.5	2,990.5
14–14.9	415	2,174.5	646.4	987.9	1,362.9	1,758.7	2,140.6	2,595.4	3,066.3	3,388.0
15–15.9	407	2,544.1	651.6	1,246.0	1,682.5	2,125.1	2,576.2	2,971.1	3,332.0	3,785.5
16–16.9	358	2,761.1	571.4	1,597.4	2,006.8	2,438.3	2,756.9	3,170.4	3,495.7	3,770.7
17–17.9	241	2,986.3	658.5	1,399.8	2,167.3	2,525.4	3,061.6	3,396.8	3,728.1	4,226.6
Total	3,258	1,877.5	887.0	474.8	797.2	1,147.9	1,775.7	2,553.0	3,108.1	3,573.6
Girls										
Jump height										
9–9.9	308	22.3	5.0	14.0	16.0	19.0	22.3	25.0	29.0	32.0
10–10.9	672	24.0	4.6	15.5	18.0	20.5	24.0	27.0	29.5	33.0
11–11.9	619	24.9	4.6	16.5	19.5	22.0	25.0	27.5	31.0	33.5
12–12.9	506	25.5	4.6	17.0	20.0	22.5	25.5	28.5	31.5	34.5
13–13.9	456	25.5	5.3	15.5	19.0	22.0	25.5	28.5	32.0	36.1
14–14.9	582	26.1	5.2	17.0	20.0	22.5	25.5	29.5	32.5	36.5
15–15.9	493	26.4	5.1	17.0	20.2	23.0	26.0	29.5	32.5	36.5
16–16.9	433	26.7	6.9	17.0	20.5	23.0	26.5	30.0	33.0	37.0
17–17.9	287	27.6	5.7	19.3	21.5	23.5	27.0	30.5	35.0	41.0
Total	4,356	25.4	5.3	16.0	19.0	22.0	25.0	28.5	31.5	35.5
Peak power										
9–9.9	308	773.1	467.2	114.1	250.1	422.9	710.1	1,018.6	1,358.3	1,806.1
10–10.9	672	995.7	456.8	259.6	443.6	675.9	949.7	1,249.4	1,567.0	2,024.2
11–11.9	619	1,198.3	429.4	455.9	680.2	898.1	1,181.2	1,449.4	1,722.5	2,150.6
12–12.9	506	1,431.0	483.3	655.3	890.4	1,100.1	1,381.9	1,715.7	2,031.0	2,460.9
13–13.9	456	1,628.1	504.3	807.5	1,004.4	1,261.6	1,612.4	1,914.8	2,274.5	2,683.6
14–14.9	582	1,841.0	512.8	962.9	1,211.2	1,477.2	1,792.5	2,191.1	2,529.3	2,905.0
15–15.9	493	1,934.4	483.6	1,059.4	1,319.7	1,624.1	1,942.2	2,226.3	2,559.6	2,898.0
16–16.9	433	2,010.2	579.4	1,117.8	1,357.3	1,670.4	1,998.4	2,288.3	2,674.6	3,106.5
17–17.9	287	2,115.4	541.6	1,254.6	1,505.5	1,737.5	2,036.4	2,387.5	2,908.0	3,369.5
Total	4,356	1,527.7	647.6	397.2	711.7	1,059.0	1,506.0	1,963.9	2,334.3	2,780.8

*M = mean; *SD* = standard deviation; P = percentile.

individual performed 1–3 submaximal practice jumps, then jumped for maximal height 2 times with 1 minute allowed for recovery between attempts. The jump began from a standing position, with plantigrade foot and the leg vertically aligned (i.e., knee angle approximately 180°). On instruction, the countermovement was performed and the knees flexed to approximately 90° before rapid extension and take-off. Landing (initial contact with the jump mat) and the knee angle extended at approximately 180°. If these criteria were not met, the jump was performed again (29). All the personnel were trained in testing and calibration procedures and maintained a calibration log. Two assessors

TABLE 3. Reference values (50th percentile) for vertical jump height (in centimeters) from cited studies.

Sex and age	FUPRECOL study (n = 7,614)	England (n = 1,845)	Republic of Seychelles* (n = 4,599)
Boys			
9–9.9	24		
10–10.9	25	21	
11–11.9	27	27	
12–12.9	27	30	30
13–13.9	30	32	33
14–14.9	32	36	36
15–15.9	35	37	39
16–16.9	36		
17–17.9	38		
Girls			
9–9.9	22		
10–10.9	24	22	
11–11.9	25	25	
12–12.9	25	27	28
13–13.9	25	26	29
14–14.9	25	28	30
15–15.9	26	28	30
16–16.9	26		
17–17.9	27		

*From Indian Ocean and African region.

were trained in the use of the VJ mat and the implementation of the protocol, which they practiced before the assessments. The VJ measurements in a subsample (n = 229, median age = 12.8 ± 2.4 years, 46.2 ± 12.4 kg, 1.50 ± 0.1 m, 19.9 ± 3.1 $kg\cdot m^{-2}$) were recorded to ensure reproducibility on the day of the study. The reproducibility of our data was $R = 0.88$. Intrarater reliability was assessed by determining the intraclass correlation coefficient (intraclass correlation coefficient = 0.85, 95% confidence interval [CI] = 0.75–0.93). The systematic error when the VJ assessments were performed twice was −1.171 (*SD* 10.148) cm (95% CI = −21.063 to 18.720; n = 207) (22).

Each child was allowed 2 jumps using the correct technique. The best jump height was recorded and incorporated into the power prediction equation. The prediction equation of Sayers et al. (28) was used to predict peak leg power: P_{peak} (W): 60.7 × (VJ [cm]) + 45.3 × (body mass [kg]) − 2,055. To date, no prediction equation has been validated for children, thus the Sayers equation was used, which incorporates jump height and the participant's mass. This equation, developed from jumps performed on a force plate, has a reported difference in adults of 2.7% with power calculated from the force plate (28). The Sayers equation is an improvement on the Lewis formula ($P_{peak}\ [W]:\ \sqrt{4.9 \times \text{body mass[kg]}} \times \sqrt{\text{VJ[m]} \times 9.8}$), which has been reported to underestimate predicted peak power by 70% (12). It has also been recommended as a replacement for the Lewis formula for physical assessment appraisals (19,29).

Statistical Analyses

Anthropometric and VJ characteristics from the study sample are presented as the mean with *SD*. Normality for selected variables was verified using histograms and Q-Q plots. Data were then split by sex; a 2-way analysis of variance (ANOVA) with post hoc tests (Bonferroni) was used to identify differences between age groups within sexes. The LMS method assumes that the outcome variable has a normal distribution after a Box–Cox power transformation is applied, using the LMS method implemented in LMSChartMaker Pro Version 2.54 (Medical Research Council, London, United Kingdom, http://www.healthforallchildren.com/shop-base/software/lmschartmaker-light/). Smoothed and specific curves for each age were obtained via a penalized maximum likelihood with the following abbreviations: M (median), L (Box–Cox transformation), and S (coefficient of variation) (5). The appropriate number of degrees of freedom was selected on the basis of the deviance, Q tests, and worm plots, following the suggestions of Royston and Wright (25). The 3rd, 10th, 25th, 50th, 75th, 90th, and 97th smoothing centiles were chosen as age- and gender-specific reference values. We used SPSS V. 21.0 software for Windows (SPSS, Chicago, IL, USA) for all but the LMS method calculations. Statistical significance was set at $p \leq 0.05$.

RESULTS

Descriptive Characteristics

Descriptive statistics by gender are shown in Table 1. All the anthropometric variables, except the BMI (aged 9–12.9 years), were higher in boys than in girls ($p < 0.01$). The 2-way ANOVA tests showed that maximum jump height (in centimeters) and predicted P_{peak} (in watts) were higher in boys than in girls ($p < 0.01$). Post hoc analyses within sexes showed yearly increases in jump height and P_{peak} in all ages.

Centile Curves and Reference Values

Smoothed LMS curves (3rd, 10th, 25th, 50th, 75th, 90th, and 97th percentile) for boys and girls of the maximum jump height (in centimeters) and predicted P_{peak} (in watts) are illustrated in Figures 1 and 2. The equivalent numerical values are available in Table 2. Together, these data show that boys performed better on the tests at all ages compared with girls. In boys, the maximum jump height and predicted P_{peak} 50th percentile ranged from 24.0 to 38.0 cm and from 845.5 to 3061.6 W, respectively. In girls, the 50th percentile for jump height was 22.3–27.0 cm, and the predicted P_{peak} was 710.1–2,036.4 W. For girls, jump height increased yearly from 9 to 17.9 years of age.

Vertical Jump Height Differences: Comparisons With Previous Research

Finally, comparisons between the 50th percentile values for VJ height (in centimeters) from this study are presented in Table 3. We found that Colombian schoolchildren have lower values than children and adolescents from England and the Republic of Seychelles.

Discussion

This study aimed to generate normative VJ and predicted peak power (P_{peak}) data for 9- to 17.9-year-olds from Bogota, Colombia, and to investigate between-sex and age group differences in these outcomes. The main findings of the present study were that maximum jump height (in centimeters) and predicted P_{peak} (in watts) gradually increased in all ages and were higher in boys than in girls. These results are important because they provide normative values for anaerobic power for Colombian children and adolescents; this variable is strongly associated with functional status and motor performance in youth.

Our data are based on samples of 200–600 schoolchildren of each sex by age group and thus may better describe the patterns of VJ in both genders. England (27) and Republic of Seychelles (1) studies have used large samples, comprising 1,845 (10–16 years old) and 4,599 subjects (12–16 years old), respectively, but contain no data regarding Colombian children and adolescents. We observed moderate but significant differences (5%) between the sexes in 16- to 17.9-years-olds, which increased to 13% (boys) and 5% (girls) by ages 17–17.9 years. In adolescents (aged 14– 16.9 year), the latter magnitude of between-gender differences is similar to subjects from Republic of Seychelles (8–12%) but lower than other England sample (2–3%). In children (aged 10–12.9 years), we observed small but not significant differences (1–3%), similar to findings reported in UK schoolchildren (4%). The differences may reflect higher anaerobic fitness among international samples, fundamental differences in testing protocols, body composition or stage maturation, or some combination of explanations. In the context of VJ, in particular, Taylor (29) and Malina et al. (14) have noted that neglecting the body size effect in such movements may result in inconsistent or incorrect conclusions being drawn from such data.

The data reported here showing yearly increases in jump height are in agreement with the results reported in studies assessing VJ performance in children from primary and secondary school (10–15 years) from the East of England (29) and in secondary school children (12–15 years) from the Republic of Seychelles (1). In addition, other studies assessing children through different jump tests, such as the standing broad jump, have also shown gradual increases in jump performance in all ages (27,30). In the present study, there was an increase in jump height through maturation, especially in boys, whereas girls showed a trend toward a plateau in jump height between 14 and 16 years of age and increased further in all percentiles between 15 and 17 years. This plateau in jump height is consistent with the findings of Taylor et al. (29), who found a VJ plateau after 12 years, and also with the findings of Fortier et al. (8), who reported an increase in standing long jump performance for girls up to the age of 12 years, followed by a plateau.

Although we observed a plateau in jump height for girls between 14 and 16 years, the same was not observed in P_{peak}, which is most likely associated with gradual increases in the body mass for all ages in boys and girls (Table 1). Body mass and jump height are incorporated into the Sayers equation to predict peak. Either component results in improved P_{peak} performance. This interaction among explosive leg power, dynamic leg strength, stretch-shortening cycle ability, and arm–leg coordination (13,16). Therefore, all these factors are expected to improve during biological maturation, which explains the yearly increases in P_{peak} in boys and girls observed in the present study.

In the present study, boys jumped significantly higher than girls at all ages, with greater differences observed after the age of 13. This difference between boys and girls has been shown previously for VJ performance (1,4,29) and also for other lower-limb power tests (1,4,10,22). The marked differences observed especially after the age of 13 may be explained by greater increases in the lean mass in boys and greater increases in adiposity in girls because of puberty (14).

The VJ height of the Colombian children assessed in the present study was lower at most ages when compared with children from England (29) and the Republic of Seychelles (1). It is not clear why such differences exist, but factors such as local physical activity levels, nutritional outcomes, and jump assessment criteria could partially explain these differences. However, the influence of these factors remains speculative and should be investigated further.

This is the first study to provide measures of anaerobic power values America. It should be highlighted that VJ height and power are outcomes associated with several other neuromuscular outcomes in children (4). Moreover, poor anaerobic power is associated with cardiometabolic health in youth and with the risk of future functional decline, morbidity, and mortality (2,11).

This study had some limitations. First, it included participants from only a single region in Colombia; therefore, inferences to all Colombian children and adolescents should be made cautiously. Second, we have not considered the potential impact of recognized determinants of VJ, such as diet, physical activity patterns, sex hormone levels, sexual maturation, and ethnic factors that modulate growth and levels of anaerobic capacity. However, because our study was cross-sectional, a cohort effect may have occurred, and as a consequence, our estimations of jumping power levels could not be extrapolated from previous cohorts (5,6,10,12,29). This is an area for future research. Nevertheless, such limitations did not compromise the results obtained here because they were similar regarding total score by gender and similar to those reported in other studies carried out in Colombian children (10).

Practical Applications

The VJ has become one of the most convenient tests used to evaluate anaerobic capacity and the effectiveness of anaerobic training programs for a variety of power sports. However, its use and interpretation as an evaluative measurement in physical activity tests are limited because there are few published reference values available for children and adolescents. Our results provide, for the first time, sex- and age-specific VJ height and predicted P_{peak} reference standards for Colombian schoolchildren aged 9–17.9 years. The data provided in the present study will be useful in the assessment of risk of poor health outcomes in youth and in the identification of schoolchildren who are well suited for anaerobic performance.

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References

1. Bovet, P, Auguste, R, and Burdette, H. Strong inverse association between physical fitness and overweight in adolescents: A large school-based survey. *Int J Behav Nutr Phys Act* 4: 24, 2007.
2. Bui, HT, Farinas, MI, Fortin, AM, Comtois, AS, and Leone, M. Comparison and analysis of three different methods to evaluate vertical jump height. *Clin Physiol Funct Imaging* 35: 203–209, 2015.
3. Casartelli, N, Müller, R, and Maffiuletti, NA. Validity and reliability of the Myotest accelerometric system for the assessment of vertical jump height. *J Strength Cond Res* 24: 3186–3193, 2010.
4. Castro-Piñero, J, Artero, EG, España-Romero, V, Ortega, FB, Sjöström, M, Suni, J, and Ruiz, JR. Criterion-related validity of field-based fitness tests in youth: A systematic review. *Br J Sports Med* 44: 934–943, 2010.
5. Cole, TJ and Green, PJ. Smoothing reference centile curves: The LMS method and penalized likelihood. *Stat Med* 11: 1305–1319, 1992.
6. The National Administrative Department of Statistics (DANE). Analysis of the results by ethnic group in 2005 [in Spanish]. Bogotá, Colombia: The National Administrative Department of Statistics (DANE), 2007.
7. Driss, T and Vandewalle, H. The measurement of maximal (anaerobic) power output on a cycle ergometer: A critical review. *Biomed Res Int* 2013: 589361, 2013.
8. Fortier, MD, Katzmarzyk, PT, Malina, RM, and Bouchard, C. Seven-year stability of physical activity and musculoskeletal fitness in the Canadian population. *Med Sci Sports Exerc* 33: 1905–1911, 2001.
9. González, SA, Sarmiento, OL, Cohen, DD, Camargo, DM, Correa, JE, Páez, DC, and Ramírez-Vélez, R. Results from Colombia's 2014 report card on physical activity for children and youth. *J Phys Act Health* 11: S33–S44, 2014.
10. Gulías-González, R, Sánchez-López, M, Olivas-Bravo, Á, Solera-Martínez, M, and Martínez-Vizcaíno, V. Physical fitness in Spanish schoolchildren aged 6-12 years: reference values of the battery EUROFIT and associated cardiovascular risk. *J Sch Health* 84: 625–635, 2014.
11. Gutiérrez-Davila, M, Campos, J, and Navarro, E. A comparison of two landing styles in a two-foot vertical jump. *J Strength Cond Res* 23: 325–331, 2009.
12. Harman, EA, Rosenstein, MT, Frykman, PN, Rosenstein, RM, and Kramer, WJ. Estimates of human power output from vertical jump. *J Appl Sport Sci Res* 5: 116–120, 1991.
13. Leard, JS, Cirillo, MA, Katsnelson, E, Kimiatek, DA, Miller, TW, Trebincevic, K, and Garbalosa, JC. Validity of two alternative systems for measuring vertical jump height. *J Strength Cond Res* 21: 1296–1299, 2007.
14. Malina, RM, Beunen, GP, Classens, AL, Lefevre, J, Vanden Eynde, BV, Renson, R, Vanreusel, B, and Simons, J. Fatness and physical fitness of girls 7 to 17 years. *Obes Res* 3: 221–231, 1995.
15. Marfell-Jones, M, Olds, T, and Stewart, A. *International standards for anthropometric assessment.* Potchefstroom, South Africa: ISAK, 2006, pp 44–109.
16. Markovic, G, Dizdar, D, Jukic, I, and Cardinale, M. Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res* 18: 551–555, 2004.
17. Parra, DC, Iannotti, L, Gomez, LF, Pachón, H, Haire-Joshu, D, Sarmiento, OL, Kuhlmann, AS, and Brownson, RC. The nutrition transition in Colombia over a decade: A novel household classification system of anthropometric measures. *Arch Public Health* 73: 12, 2015.
18. Patterson, DD and Peterson, DF. Vertical jump and leg power norms for young adults. *Meas Phys Educ Exerc Sci* 81: 33–41, 2004.
19. Payne, N, Gledhill, N, Katzmarzyk, PT, Jamnik, VK, and Keir, PJ. Canadian Musculoskeletal fitness norms. *Can J Appl Physiol* 25: 430–442, 2000.
20. Prieto-Benavides, DH, Correa-Bautista, JE, and Ramírez-Vélez, R. Physical activity levels, physical fitness and screen time among children and adolescents from Bogotá, Colombia [in Spanish]: Estudio FUPRECOL. *Nutr Hosp* 32: 2184–2192, 2015.
21. Ramírez-Vélez, R, López-Albán, CA, La Rotta-Villamizar, DR, Romero-García, JA, and Izquierdo, M. Wingate anaerobic test percentile norms in colombian healthy adults. *J Strength Cond Res* 30: 217–225, 2016.
22. Ramírez-Vélez, R, Rodrigues-Bezerra, D, Correa-Bautista, JE, Izquierdo, M, and Lobelo, F. Reliability of Health-Related Physical Fitness Tests among Colombian Children and Adolescents: The FUPRECOL Study. *PLoS One* 10: e0140875, 2015.
23. Reiser, RF, Rocheford, EC, and Armstrong, CJ. Building a better understanding of basic mechanical principles through analysis of the vertical jump. *J Strength Cond Res* 28: 70–80, 2006.
24. Rodriguez-Bautista, YP, Correa-Bautista, JE, Gonzalez-Jimenez, E, Schmidt RioValle, J, and Ramirez Velez, R. Values of waist/hip ratio among children and adolescents from Bogotá, Colombia: The FUPRECOL study [in Spanish]. *Nutr Hosp* 32: 2054–2061, 2015.
25. Royston, P and Wright, EM. Goodness-of-fit statistics for age-specific reference intervals. *Stat Med* 19: 2943–2962, 2000.
26. Ruiz, JR, Castro-Piñero, J, España-Romero, V, Artero, EG, Ortega, FB, Cuenca, MM, Jimenez-Pavón, D, Chillón, P, Girela-Rejón, MJ, Gutiérrez, A, Suni, J, Sjöström, M, and Castillo, MJ. Field-based fitness assessment in young people: The ALPHA health-related fitness test battery for children and adolescents. *Br J Sports Med* 45: 518–524, 2011.
27. Saint-Maurice, PF, Laurson, KR, Kaj, M, and Csányi, T. Establishing normative reference values for standing broad jump among Hungarian youth. *Res Q Exerc Sport* 86: S37–S44, 2015.

28. Sayers, SP, Harackiewicz, DV, Harman, EA, Frykman, PN, and Rosenstein, MT. Cross-validation of three jump power equations. *Med Sci Sports Exerc* 31: 572–577, 1999.
29. Taylor, MJ, Cohen, D, Voss, C, and Sandercock, GR. Vertical jumping and leg power normative data for English school children aged 10–15 years. *J Sports Sci* 28: 867–872, 2010.
30. Yan-Chung, LM, Yu-Chow, LP, and Yee-Chung, JW. Normative reference of standing long jump indicates gender difference in lower muscular strength of pubertal growth. *Health* 5: 6–11, 2013.
31. Zainal-Abidin, N and Bakri-Adam, M. Prediction of vertical jump height from anthropometric factors in male and female martial arts athletes. *Malays J Med Sci* 20: 39–45, 2013.