Normative reference values for the 20-meter shuttle-run test in a population-based sample of schoolchildren in Bogota, Colombia: The FUPRECOL Study

Running title: 20-meter shuttle-run test in schoolchildren in Bogota, Colombia

By
Adalberto Palacios-López
A thesis submitted to the School of Medicine and Heatlh Science of Rosario University
in partial fulfillment of the requirements for the degree of Master of Physical Activity
2016

Robinson Ramírez-Vélez, Ph.D (MsC advisor)
Jorge Enrique Correa-Bautista, Ph.D (MsC co-advisor)

Master in Physical Health Program
Center of Studies in Physical Activity Measurements (CEMA)
School of Medicine and Heatlh Science
Rosario University
Bogotá, D.C
Colombia

ABSTRACT

Objectives: Our aim was to determine the normative reference values of cardiorespiratory fitness (CRF) and to establish the proportion of subjects with low CRF suggestive of future cardio-metabolic risk.

Methods: A total of 7244 children and adolescents attending public schools in Bogota, Colombia (55.7% girls; age range of 9–17.9 years). We expressed CRF performance as the number of shuttle-runs completed and the estimated peak oxygen consumption (VO_{2peak}) and smoothed percentile curves were calculated. In addition, we also present the prevalence of low CRF after applying a previously suggested correction factor, to account for the impact of Bogota’s altitude (2,625 meters over sea level) on CRF assessment and we calculated the number of participants who fell below health-related FITNESSGRAM cut-points for low CRF.

Results: Shuttles and VO_{2peak} were higher in boys than in girls in all age groups. In boys there were higher levels of performance with increasing age, with most gains between the ages of 13 and 17. The proportion of subjects with a low CRF, suggestive of future cardio-metabolic risk (health risk FITNESSGRAM category) was 31.5% (28.2% for boys and 34.1% for girls; χ^2 p = 0.001). After applying a 1.11 altitude correction factor, the overall prevalence of low CRF was 11.5% (9.6% for boys and 13.1% for girls; χ^2 p = 0.001).

Conclusions: Our results provide sex- and age-specific normative reference standards for the 20-meter shuttle-run test and estimated VO_{2peak} values in a large, population-based sample of schoolchildren from an Latin-American city at high altitude.

Keywords: Cardiorespiratory fitness, children, adolescent, percentiles, normative data.

INTRODUCTION

Cardiorespiratory fitness (CRF) is a direct indicator of an individual’s physiological status and reflects the overall capacity of the cardiovascular and respiratory systems (Castro-Piñeiro et al., 2011). There are a number of cross-sectional studies showing that low CRF in youth is independently associated with a higher cardio-metabolic risk (Andersen et al., 2006; Lobelo et al., 2010; Ruiz et al., 2006). In addition, longitudinal studies have shown that a healthy CRF in childhood and adolescence is associated with a healthier cardio-metabolic profile later in life (Ortega et al., 2008). These findings have been replicated in clinical adult populations with diabetes mellitus, hypertension, metabolic syndrome, and several types of cancer (LaMonte and Blair, 2006). In light of this evidence, it is of great concern that in recent decades, CRF appears to have declined in children and adolescents worldwide (Catley and Tomkinson, 2013; Garber et al., 2014). These trends have been observed against a background of increased, decreased or stable body mass index (BMI) within the same populations (Olds et al., 2006).

Sex- and age-specific normative values for CRF in youth have been published (Eisenmann et al., 2002; Pate et al., 2006; Tomkinson and Olds, 2007; Barnett et al., 1995; Twisk et al., 2002; Ortega et al., 2011). However, the majority of the published aerobic fitness reference values are for schoolchildren from high income countries in North America (Pate et al., 2006; Carrel et al., 2012; Tremblay et al., 2010), Asia/Oceania (Tomkinson et al., 2007; Gürsel et al., 2004) and Europe (Roriz De Oliveira et al., 2014; Gulías-González et al., 2014; Haugen et al., 2014; Sandercock et al., 2012). There is a scarcity of reference values for children using harmonized measures of physical fitness in Latin America (Aguilar et al., 2011; González et al., 2014) and other low-middle income countries (LMICs) undergoing rapid epidemiologic and nutrition transitions

(Wachira et al., 2014), making it impossible to evaluate secular trends within these regions and identify high risk groups for which risk reduction interventions should be prioritized. In particular, no population-based studies have been conducted to assess CRF for youth living at high altitude (over 2,000 meter over sea level). This is important because it is estimated that more than 16.5 million youth between the ages of 10 and 20 years old live at such altitudes in the Andes in Latin America and in mountain ranges in Central America, Europe, Asia and Africa, for which CRF normative values may need to be created or adjusted.

Therefore, the objectives of this study are 1) to present normative reference values for CRF in a population-based sample of 9 to 17 year old schoolchildren in Bogota, Colombia as estimated via the 20-m Shuttle-run test; 2) to establish the proportion of subjects whose aerobic capacity is indicative of future cardiovascular risk based on previously validated health-related standards to define low CRF and 3) to present the prevalence of low CRF after applying a correction factor previously suggested in the literature to account for the impact of Bogota's altitude (2,625 meters over sea level) on CRF assessment.

METHODS

Study population

In Colombia, measures of weight and physical activity have been added to youth health monitoring systems by the government (ICBF 2010) and research institutions. Recently (2015), physical fitness assessment was added to the FUPRECOL study (*in Spanish* ASOCIACIÓN DE LA **FU**ERZA **PRE**NSIL CON MANIFESTACIONES DE RIESGO CARDIOVASCULAR TEMPRANAS EN NIÑOS Y ADOLESCENTES

COLOMBIANOS). The FUPRECOL study seeks to establish the general prevalence of cardiovascular risk factors (anthropometric, metabolic and genetic markers) in the study population (children and adolescents aged 9 to 17.9 years living in Bogota, Colombia) (Ramírez-Vélez et al., 2015; Rodríguez-Bautista et al., 2015; Prieto-Benavides et al., 2015) and examine the relationships between physical fitness levels and cardio-metabolic risk factors.

The FUPRECOL study assessments were conducted during the 2014–2015 school year. The sample consisted of children and adolescents (boys n = 3211 and girls n = 4033) ages 9–17.9 years. All schoolchildren were of low-middle socioeconomic status (SES, 1–3 in a scale 1-6 defined by the Colombian government) and enrolled in public elementary and high schools (grades 5 through 11) in the capital district of Bogota, 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 meters (min: 2,500; max: 3,250) above sea level. Bogota is considered an urban area, with approximately 7,862,277 inhabitants (DANE, 2007). A convenience sample of volunteers was recruited and grouped by sex and age based on 1-year intervals (9 groups total). Power calculations were based on the mean CRF values from the first 200 participants recruited (range: 35-45 ml•kg^{-1}•min^{-1}), with a group SD of approximately 5.2 ml•kg^{-1}•min^{-1}. 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 approximately 200 to 400 participants per age and sex groups. Exclusion factors included clinical diagnosis of cardiovascular disease, diabetes mellitus 1 and 2, pregnancy, use of alcohol or drugs, not having lived in Bogota for at least 1 school year.

Exclusion from the study was made effective *a posteriori*, without the students being aware of their exclusion to avoid any undesired situations.

Data collection

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 (Marfell-Jones et al. 2006). Variables were collected at the same time in the morning, between 7:00-10:00 a.m., following an overnight fast. Body weight of the subjects was measured when the subjects were in underwear and did not have shoes on, using electronic scales (Tanita® BC544, Tokyo, Japan) with a low technical error of measurement (TEM = 0.510%). Height was measured using a mechanical stadiometer platform (Seca® 274, Hamburg, Germany; TEM = 0.019%). BMI was calculated as the body weight in kilograms divided by the square of the height in meters. Waist circumference was measured at the midpoint between the last rib and the iliac crest using a tape measure (Ohaus® 8004-MA, New Jersey, USA; TEM = 0.086%). Sexual maturation was classified based on Tanner staging (Tanner and Whitehouse, 1976), which uses self-reported puberty status to classify participants into stages I to V (Matsudo S and Matsudo V, 1994). Each volunteer entered an isolated room where they categorized the development of their own genitalia (for boys), breasts (for girls), armpits (for boys) and pubic hair (for both genders) using a set of images exemplifying the various stages of sexual maturation. The data were recorded on paper by the FUPRECOL evaluators.

Cardiorespiratory fitness

Testing procedures were consistent with international guidelines for school-based fitness assessment (Universidad de Granada, 2007). At each school, a team of trained FUPRECOL evaluators administered the tests in partnership with the school´s physical education instructor. Testing was conducted in the school gymnasium or in areas where a hard surface was available. The CRF was assessed via the 20 m shuttle–run test (ml•kg^{-1}•min^{-1}) (Leger et al., 1988). Participants jogged or ran in a straight line between two lines 20 m apart while keeping pace with pre-recorded audio signals. The initial speed was 8.5 km/hour and increased by 0.5 km/hour each minute. The test was terminated if the participant failed to reach the end lines in time with the audio signals on two consecutive occasions or when the subject stopped because of self-reported fatigue. The results were recorded to the nearest stage (minute) completed. The equation of Leger et al. (Leger et al., 1988) was used to estimate the VO_{2peak}. To calculate the VO_{2peak} from the result of the 20 m shuttle-run test score, age (A; in years) and the final speed (S; corresponding to the stage speed = 8 + 0.5 per stage number, in km/h) were entered into the following formula (r = 0.7; for children and adolescents, from 8–19 years) VO_{2peak} (ml•kg^{-1}•min^{-1}) = 31.025 + 3.238 x S - 3.248 x A + 0.1536 x S x A. The reliability and validity of this test has been widely documented (Liu et al., 1992; Leger et al., 1984) and is considered a test of choice for population-based CRF assessments for schoolchildren (Ramírez-Vélez et al., 2015). All tests were conducted by a trained research team that provided standardized encouragement for participants during all test phases. The systematic error when the CRF assessments were performed twice (n=229) was 0.217 SD of bias 0.811 [95% CI= -1.808% to 1.373%; n = 207] (Ramírez-Vélez et al., 2015).

CRF and future cardio-metabolic risk

In the 1990s, FITNESSGRAM® established sex- and age-specific CRF cutoff values for adolescents that were known as the Healthy Fitness Zones (Cureton and Warren, 1990). The Healthy Fitness Zones were designed to represent the lowest levels of CRF that were linked to adequate functional and/or health-related outcomes in adolescents (Garber et al., 2014; Sandercock et al., 2012). We calculated the number of participants in each age-sex group who might be considered to have low CRF levels according to recently-updated FITNESSGRAM® health-related standards (Welk et al., 2011). Low CRF was defined by using either the cut-off values for age- and sex-specific test performance (shuttle-runs or estimated VO_{2peak}) listed in the healthy fitness zone (needs improvement and health risk). The FITNESSGRAM® (Welk et al., 2011) has been shown to have cardio-metabolic health predictive value (Welk et al., 2011), and VO_{2peak} cut-off points were validated against the presence of metabolic syndrome using nationally representative U.S. data (Lobelo et al., 2009).

All measures were performed twice, except for the 20 m shuttle-run tests, which were performed only once for the study sample. All standard operating procedures and protocols for CRF testing are available in the manual and videos on the ALPHA project website (https://sites.google.com/site/alphaprojectphysicalactivity/). Direct and simple language was used for the communication process and the explanation of tests. Additionally, the evaluators provided visual models and examples before performing the test when necessary. Participants did not receive previous training on these tests.

Altitude Correction Factor

Previous studies have reported VO_{2max} values to be reduced by about 10% for each 1000 m above 1500 m, point where arterial oxygen desaturation is evident despite adequate erithropoietic adaptations (Fulco et al., 1998; Squires et al., 1982) in altitude-adjusted individuals. In our analysis we present both raw VO_{2peak} values as well as values adjusted by a correction factor of 1.11 to account for the impact of Bogota's altitude (2,625 meters over sea level) on CRF assessment.

Ethics Statement

The Review Committee for Research on Human Subjects at the University of Rosario [Code Nº CEI-ABN026-000262] approved all of the study procedures. A comprehensive verbal description of the nature and purpose of the study and its experimental risks was given to the participants and their parents/guardians. This information was also sent to parents/guardians by mail. Written informed consent was obtained from parents and subjects before participation in the study. The protocol was in accordance with the latest revision of the Declaration of Helsinki and current Colombian laws governing clinical research on human subjects (Resolution 008430/1993 Ministry of health).

Statistical analysis

Anthropometric and CRF characteristics of the study sample are presented as means and standard deviations (SD). Normality of selected variables was verified using histograms and Q-Q plots. Differences were analyzed by one-way analysis of variance (ANOVA) or Chi-square test (χ^2) to explore sex and age differences. Smoothed and specific curves for each age were obtained via a penalized maximum likelihood with the following abbreviations: (1) L (Box-Cox transformation), (2) M (median), and (3) S (coefficient of variation) (Cole and Green, 1992). 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 the LMSChartMaker Pro Version 2.54, (Medical Research Council, London, UK, http://www.healthforallchildren.com/shop-base/software/lmschartmaker-light/). The appropriate number of degrees of freedom was selected on the basis of deviance, Q-tests and worm plots, following the suggestions of Royston & Wright (Royston and Wright, 2000). The 3rd, 10th, 25th, 50th, 75th, 90th and 97th smoothing percentiles were chosen as age- and gender-specific reference values. We used SPSS V. 21.0 software for Windows (SPSS, Chicago, Illinois, USA) for all but the LMS method calculations. Statistical significance was set at $p<0.05$

RESULTS

Descriptive characteristics

Descriptive statistics by sex are shown in Table 1. All anthropometric variables, except BMI, were higher in boys than in girls ($p<0.001$). The prevalence of overweight and obesity differed by sex ($p<0.001$). One-way ANOVA tests showed that VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$) and shuttles (count) were higher in boys than in girls ($p<0.001$). The proportion of subjects with a low CRF suggestive of future cardio-metabolic risk (health risk FITNESSGRAM standard) was 31.5% (28.2% for boys and 34.1% for girls; χ^2 p = 0.001). After applying an 11% altitude correction factor, the overall prevalence of low CRF was 11.5% (9.6% for boys and 13.1% for girls; χ^2 p = 0.001).

**** Table 1 here ****

20 m shuttle-run performance and FITNESSGRAM health-related standards

The age-sex distribution of 20 m shuttle-run performance for the study sample is presented in Table 2. Performance is expressed as number of shuttles completed, running speed for the final shuttle completed and predicted VO_{2peak} (ml•kg^{-1}•min^{-1}). The prevalence of low CRF (health risk FITNESSGRAM category) was 0% in 9 to 11.9 year olds but ranged from 15.4% to 79.2% in other age groups, being particularly high among 15 to 17 year-old girls and 17 year-old boys. The altitude-adjusted prevalence of low CRF ranged from 0% to 60%, following a similar patter by age and sex groups.

**** Table 2 here ****

Normative 20 m shuttle-run values

Smoothed LMS curves (3rd, 10th, 25th, 50th, 75th, 90th and 97th percentile) for boys' and girls' performance (shuttles completed and VO_{2peak} in ml•kg^{-1}•min^{-1}) are shown in Figures 1 and 2. The equivalent numerical values are available in Tables 3 and 4. Together, these data show that boys performed better on the test at all ages compared with girls. In boys, the 50th percentile of shuttles completed, VO_{2peak} and altitude-adjusted VO_{2peak} adjusted ranged from 17.5 to 52.0 shuttles, 40.3 to 43.9 ml•kg^{-1}•min^{-1}, and 44.7 to 48.7 ml•kg^{-1}•min^{-1} respectively. In girls, the 50th percentile ranged from 15.0 to 25.0 shuttles, 31.5 to 43.4 ml•kg^{-1}•min^{-1}, and 35.0 to 48.2 ml•kg^{-1}•min^{-1} respectively. In boys there were higher levels of performance across all age groups, with most apparent gains between the ages of 14 and 17. In girls, performance was also higher between the ages of 12 and 14, but this difference was more modest. From the ages of 15 to 15.9, test performance was slightly lower in girls (Tables 3 and 4).

**** Table 3 and Table 4 here ****

**** Figure 1 and Figure 2 here ****

Table S1 and Figure S1 (Supporting Information) presents altitude-adjusted VO_{2peak} normative values following a similar described pattern according to age and gender. Figure S2 (Supporting Information) presents a comparison of VO_{2peak} centile values (3rd, 50th and 97th percentiles) for raw and altitude-adjusted values among boys and girls. The effect of the altitude adjustment can be observed in the graphic.

Finally, comparisons of the mean (±SD) for the VO_{2peak} ($ml \bullet kg^{-1} \bullet min^{-1}$) from this study are presented in Table S2 y Table S3 (Supporting Information). Based on the raw non-adjusted data, we found that Bogota boys had lower VO_{2peak} values than their counterparts from England, Canada, Argentina, Spain, Portugal and Australia. Bogota schoolchildren girls had lower VO_{2peak} values than counterparts from England, Canada, and Australia. After performing the altitude adjustment, only youth from Canada had higher VO_{2peak} values than youth in Colombia.

DISCUSSION

This study presented for the first time smoothed reference values for the 20-meter shuttle-run performance and predicted VO_{2peak} ($ml \bullet kg^{-1} \bullet min^{-1}$) among a large, population-based sample of schoolchildren from Bogota, Colombia. These results can be used as a baseline for long-term physical fitness surveillance in the city, the country and the Latin American region. The 20 m shuttle-run performance curves can also be useful for cross-country comparisons as efforts to include CRF testing in national health and nutrition studies and surveillance efforts gain more traction, in particular in LMICs (Catley and Tomkinson, 2013; Tomkinson and Olds, 2007; Barnett et al., 1995; Sandercock et al., 2012; Matsudo

S and Matsudo V, 1994; Cole and Green, 1992; Royston and Wright, 1992; Secchi et al., 2014; Ortega et al., 2005; Slinger et al., 2009; Ortega et al., 2008; LaMonte and Blair, 2006).

The age- and gender-related developmental patterns of aerobic fitness have been well studied in non-representative samples (Ortega et al., 2011; Liu et al., 1992; Ortega et al., 2008; LaMonte and Blair, 2006; Catley and Tomkinson, 2013). Data from this study show the well-documented differences between sexes and the typical changes in aerobic test performance associated with growth and maturation in youth (Malina et al., 1997). For example, boys' test performance was higher than that of girls at all ages and their CRF levels remained relatively stable. In girls, it is generally thought that VO_{2peak} decreases during adolescence.

We found six studies, published within the last 10-years, using similar CRF field-tests in population-based samples of children and adolescents and presenting age and gender-specific normative values. Compared to their counterpart and based on our non-adjusted VO_{2peak} values, Colombian boys had the lowest CRF levels found in any country with available data. Among Colombian girls, CRF levels were lower than those reported for England, Canada, and Australia but on par or higher than for Argentina, Spain and Portugal girls. (Tomkinson and Olds, 2007; Sandercock et al., 2012; Matsudo S and Matsudo V, 1994; Cole and Green, 1992; Secchi et al., 2014) (Supporting Information File S4). Given the prevalence of physical inactivity and overweight/obesity are generally lower in Colombia than in the mentioned countries (Rivera et al., 2014; González et al.

2014), such finding seemed counter-intuitive. However, after performing the altitude adjustment, only youth from Canada had higher VO_{2peak} values than youth in Colombia.

At sea level, the standard barometric pressure is 760 mmHg, the oxygen partial pressure in the athmosphere is 160 mmHg and in the arteries drops to 100 mmHg. Comparatively, values at 2660 level are 559 mmHg, 100 mm Hg and 60 mmHg for standard barometric pressure, athmospheric and arterial blood oxygen partial pressure, respectively. A 40% lower arterial oxygen partial pressure leads to arterial oxygen desaturation ($Sa0_2$=89%) despite adequate erithropoietic adaptations among individuals regularly living at such altitudes (Fulco et al., 1998; Squires et al., 1982). We believe that the correction factor we applied is warranted and altitude-adjusted CRF normative values should be presented. There are no published estimates regarding the number of 10-20 year olds living at high altitude (above 2,000 meter sea level). A previously published report estimated that 130 million people lived above 2,000 meters sea level based on global population estimates for 1994 (Cohen et al., 1998). According to World Bank figures, global population has grown 30% from 1994 (5.6 Billion) to 2015 (7.3 Billions) (World Bank 2015). Assuming a steady 30% population growth for the global population living above 2,000 meters sea level and given that on average 9.8% of the population in LMICs are in the 10-20 year old range, we conservatively estimated that 16,562,000 million youth between 10 and 20 years old live at high altitude (World Bank 2015). Therefore, normative CRF values such as the ones developed for this study may need to be created or adjusted for youth living at high altitudes in the Andes in Latin America and in mountain ranges in Central America, Europe, Asia and Africa.

Even after adjusting for altitude, a significant proportion of Colombian youth (17.9 boys; 27.3% girls) showed unhealthy CRF levels according to the combined prevalence of needs improvement and health risk FITNESSGRAM categories. This proportion is similar to that reported in a representative sample of 13-17 year olds in Chile (Garber et al., 2014) and similar population-based samples of schoolchildren in Argentina, the UK, Sweden and Spain, but lower than those reported in the USA, Australia and a Pan-European sample (Supporting Information Files S4). The prevalence of physical inactivity and sedentary behavior among children and adolescents has increased in several countries in recent decades (Rey-López et al., 2008; Sandercock and Ogunleye, 2013), and consequently it is possible that physical fitness values may also have changed (Craig et al., 2012). Historical declines in fitness may indeed have been partly due to concomitant increases in body mass (Stratton et al., 2007; Olds et al., 2007). Sandercock et al. (2010) indicated that increases in BMI may explain some of the decrease in fitness; however, Sandercock et al. (2015) reported an 8% decrease in fitness between 1998 and 2008 that was largely independent of changes in BMI. Support for this hypothesis was elegantly provided in the Fitlinx project, which reported declines in shuttle-run performance concurrent with increases in BMI (Sandercock et al., 2015). In Latin America, for example, populations have disparities in health along with disparities in modifiable risk factors, including low participation in physical activity. LMICs, such as Colombia, are experiencing rapid urbanization and integration with global markets. This has led to changes in diet and physical activity, which in turn have had large effects on body composition and other health-related fitness components (Ramírez-Vélez et al., 2015; Malina et al., 1997; Parra et al., 2015; González et al., 2014; López et al., 2006). It is well known that CRF and muscular fitness (Buchan et al., 2015; Melo et al., 2015) are better predictors of cardiovascular disease risk factors in children than BMI, and prospective and case–control studies have shown that even with a normal BMI, those with lower physical fitness are at increased risk of cardiovascular disease risk and premature death (Ortega et al., 2012; Ekelund et al., 2007). These changes are contributing to a global increase in the prevalence of non-communicable diseases (Malina et al., 1997). Therefore, the inclusion of CRF within health surveillance systems is justifiable and has been recommended (Kaminsky et al., 2013). Schools may be an ideal setting to monitor youth fitness (De Miguel-Etayo et al., 2014) and could help to formulate specific strategies to promote the future health of youth.

Low CRF is a strong and independent predictor cardio-metabolic disease in adults (Kodama et al., 2009). Mesa et al. (2006) tested CRF using the 20 m shuttle-run and used ROC analyses to determine the cut- off point for aerobic fitness and an adverse blood lipid profile in adolescents (ages from 13–18 years). Lobelo et al. (2009) reported that the CRF thresholds that best discriminated between low and high cardio-metabolic risk in a representative sample of US adolescents were very similar to those established in 2004 by the FITNESSGRAM® expert panel. A similar method was then used by the FITNESSGRAM group to develop their current health-related standards (Welk et al., 2011). These data can be useful to guide existing noncommunicable disease prevention efforts in Colombia (Aguilar et al., 2011; González et al., 2014). The fact that almost 1 in 5 Colombian boys and 1 in 4 girls had a low aerobic capacity, suggestive of an increased future cardio-metabolic risk is noteworthy. However, these values should be interpreted with caution, as the data have been converted to predicted VO_{2peak} based on one of a number of available reference equations, which has limitations (Sandercock et al., 2012;

Aguilar et al., 2011). We adopted the 20 m shuttle-run test to estimate CRF because it has been extensively used in situations when it is unfeasible to use direct measurements (Machado-Rodrigues et al., 2014; Moreira et al., 2011; Prieto-Benavides et al., 2015), and because its results are highly correlated with laboratory measurements (Batista et al., 2013).

This study had some limitations. First, we did not measure important variables in relation to CRF and altitude such as levels of physical activity, sex hormone levels, family background birthplace and time living in Bogota. Second, the estimation of VO_{2peak} from the 20 m shuttle-run is known to vary according to the equation used. A previous study (Boiarskaia et al., 2011) has tested the degree of agreement between various equations used to estimate VO_{2peak} and the actual VO_{2peak}. The equation used to estimate VO_{2peak} in this study may have underestimated cardiorespiratory fitness by up to 12% relative to other methods and therefore may have, in isolation, inflated the prevalence of unhealthy aerobic capacity (Sandercock et al., 2012; Leger et al., 1988). Therefore, we considered our low CRF estimates to be conservative.

On the other hand, our decision to categorize CRF according to its health predictive value instead of using continuous variables can be considered strength of the study, as it allowed for greater public health interpretability. Taking advantage of a newly compiled and large population-based sample, this study develops centile references for Colombian schoolchildren using the popular LMS method (Cole and Green, 1992) and smoothed and specific CRF curves for each age and gender are further generated from LMS model parameters to facilitate direct comparison of Colombian data with international references. The results contribute to the recent application of the LMS statistical procedure for the construction of growth percentiles for a variety of outcomes (e.g., BMI, waist circumference, blood pressure) (Eisenmann and Malina, 2002; Pate et al., 2006; Carrel et al., 2012; Tomkinson et al., 2007; Roriz et al., 2014; Haugen et al., 2014; Sandercock et al., 2012). Another potential strength of the study was the use of a, valid, and reliable field tests recommended for Latin American youth school-based fitness assessment.

In conclusion, our results provide sex- and age-specific normative reference standards for the 20-meter shuttle-run test and estimated VO_{2peak} values in a large, population-based sample of schoolchildren from Bogota, a city situated at high altitude. These curves can be used as a reference with which to compare the performance of individuals of a corresponding age in the city, country and region. Establishing these reference percentiles allows for comparison of CRF in schoolchildren, who vary geographically and demographically, with others in similar settings. The reference percentiles also enable year-by-year tracking of the fitness profiles of large numbers of students now participating in statewide school-based initiatives to improve fitness. We also introduce a method to adjust VO_{2peak} levels to account for the impact of high altitude on CRF assessment that can be replicated in future studies. Future research aimed at establishing the CRF cut-off value associated with high cardio-metabolic risk in this population is warranted.

ACKNOWLEDGEMENTS

The authors are grateful to the Bogota District Education Department for supporting the data collection for this study. The authors also thank the participating Bogota District students, teachers, schools, and staff. The “FUPRECOL Study” was possible given the financial support provided by the Instituto Colombiano para el Desarrollo de la Ciencia y la Tecnología “Francisco José de Caldas” COLCIENCIAS (Contract Nº 671-2014 Code 122265743978). The authors declare no conflict of interest with this work.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

LITERATURE CITED

Aguilar AC, Pradilla A, Mosquera M, Gracia AB, Ortega JG, Leiva JH, et al. (2011). Percentile values for physical condition for Cali, Colombian children and adolescents. Biomedica, 31, 242-248.

Andersen LB, Harro M, Sardinha LB, Froberg K, Ekelund U, Brage S, et al. (2006). Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). Lancet, 368, 299–304.

Barnett A, Bacon-Shone J, Tam KH, Leung M, Armstrong N. (1995). Peak oxygen uptake of 12-18-year-old boys living in a densely populated urban environment. Ann Hum Biol., 22(6), 525-532.

Batista MB, Cyrino ES, Arruda M, Dourado AC, Coelho ESMJ, Ohara D, Romanzini M, Ronque ER. 2013. Validity of equations for estimating V[combining dot above]O2peak from the 20-m shuttle run test in adolescents aged 11-13 years. J Strength Cond Res 27(10):2774-2781.

Boiarskaia EA, Boscolo MS, Zhu W, Mahar MT. (2011). Cross-validation of an equating method linking aerobic FITNESSGRAM(R) field tests. Am J Prev Med, 41: S124-30.

Buchan DS, Boddy LM, Young JD, Cooper SM, Noakes TD, Mahoney C et al. (2015). Relationships between Cardiorespiratory and Muscular Fitness with Cardiometabolic Risk in Adolescents. Res Sports Med, 23(3): 227-39.

Carrel AL, Bowser J, White D, Moberg DP, Weaver B, Hisgen J, et al. (2012). Standardized childhood fitness percentiles derived from school-based testing. J Pediatr, 161, 120-4.

Castro-Piñeiro J, Ortega FB, Keating XD, González-Montesinos JL, Sjöstrom M, Ruiz JR. (2011). Percentile values for aerobic performance running/walking field tests in children aged 6 to 17 years; influence of weight status. Nutr Hosp, 26, 572-578.

Catley MJ, Tomkinson GR. (2013). Normative health-related fitness values for children: analysis of 85347 test results on 9-17-year-old Australians since 1985. Br J Sports Med, 47, 98-108.

Cole TJ, Green PJ. (1992).Smoothing reference centile curves: the LMS method and penalized likelihood. Stat Med 11:1305-19.

Cohen JE1, Small C. (1998). Hypsographic demography: the distribution of human population by altitude. Proc Natl Acad Sci U S A, 95(24):14009-14.

Craig CL, Shields M, Leblanc AG, Tremblay MS. (2012). Trends in aerobic fitness among Canadians, 1981 to 2007-2009. Appl Physiol Nutr Metab, 37(3): 511-9.

Cureton KJ, Warren GL. (1990). Criterion-referenced standards for youth health-related fitness tests: a tutorial. Res Q Exerc Sport, 16: 7–19.

De Miguel-Etayo P, Gracia-Marco L, Ortega FB, Intemann T, Foraita R, Lissner L, et al. (2014). Physical fitness reference standards in European children: the IDEFICS study. Int J Obes (Lond), 38 Suppl 2: S57-66.

Departamento Administrativo Nacional de Estadística (DANE). (2007). Los grupos étnicos de Colombia en el censo de 2005. Análisis de Resultados, Bogotá, Colombia, 25-26.

Eisenmann JC, Malina RM. (2002). Secular trend in peak oxygen consumption among United States youth in the 20th century. Am J Hum Biol, 14, 699–706.

Ekelund U, Anderssen SA, Froberg K, Sardinha LB, Andersen LB, Brage S. (2007). Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European youth heart study. Diabetologia, 50: 1832-40.

España-Romero V, Artero EG, Jimenez-Pavón D, Cuenca-Garcia M, Ortega FB, Castro-Piñero J, et al. (2010). Assessing health-related fitness tests in the school setting: reliability, feasibility and safety; the ALPHA Study. Int J Sports Med, 31(7): 490-7.

Fulco CS, Rock PB, Cymerman A. (1998). Maximal and submaximal exercise performance at altitude. Aviat Space Environ Med, 69(8):793-801.

Garber MD, Sajuria M, Lobelo F. (2014). Geographical variation in health-related physical fitness and body composition among Chilean 8th graders: a nationally representative cross-sectional study. Plos One, 9, e108053.

González SA, Sarmiento OL, Cohen DD, Camargo DM, Correa JE, Páez DC, et al. (2014). Results from Colombia's 2014 Report Card on Physical Activity for Children and Youth. J Phys Act Health 11(Suppl 1):S33-S44.

Gulías-González R, Sánchez-López M, Olivas-Bravo Á, Solera-Martínez M, Martínez-Vizcaíno V. (2014). Physical fitness in Spanish schoolchildren aged 6-12 years: reference values of the battery EUROFIT and associated cardiovascular risk. J Sch Health, 84(10), 625-35.

Gürsel Y, Sonel B, Gök H, Yalçin P. (2004). The peak oxygen uptake of healthy Turkish children with reference to age and sex: a pilot study. Turk J Pediatr, 46(1), 38-43.

Haugen T, Høigaard R, Seiler S. (2014). Normative data of BMI and physical fitness in a Norwegian sample of early adolescents. Scand J Public Health, 42(1), 67-73.

Instituto Colombiano de Bienestar Familiar. (2010). Encuesta Nacional de la Situación Nutricional en Colombia. Julio 1, 2015, de ICBF Sitio web: http://www.icbf.gov.co/portal/page/portal/PortalICBF/NormatividadC/ENSIN1/

Kaminsky LA, Arena R, Beckie TM, Brubaker PH, Church TS, Forman D, et al, (2013). The importance of cardiorespiratory fitness in the United States: the need for a national registry: a policy statement from the American Heart Association. Circulation, 127(5): 652-662.

Kodama S, Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, et al. (2009). Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthymen and women: a meta-analysis. JAMA, 301(19): 2024-35.

LaMonte MJ, Blair SN. (2006). Physical activity, cardiorespiratory fitness, and adiposity: contributions to disease risk. Curr Opin Clin Nutr Metab Care, 9, 540-546.

Leger L, Lambert J, Goulet A, Rowan C, Dinelle Y. (1984). Aerobic capacity of 6 to 17-year-old Quebecois–20 meter shuttle run test with 1 minute stages. Can J Appl Sport Sci, 9: 64–69.

Leger LA, Mercier D, Gadoury C, Lambert J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. J Sports Sci, 6: 93-101.

Liu NY, Plowman SA, Looney MA. (1992). The reliability and validity of the 20-meter shuttle test in American students 12 to 15 years old. Res Q Exerc Sport, 63: 360–365.

Lobelo F, Pate RR, Dowda M, Liese AD, Daniels SR. (2010). Cardiorespiratory fitness and clustered cardiovascular disease risk in U.S. adolescents. J Adolesc Health, 47(4): 352-359.

Lobelo F, Pate RR, Dowda M, Liese AD, Ruiz JR. (2009). Validity of cardiorespiratory fitness criterion-referenced standards for adolescents. Med Sci Sports Exerc, 41: 1222-1229.

(2013) 2012-2013 California Physical Fitness Report. Sacramento, CA: California Department of Education. Available: http://data1.cde.ca.gov/dataquest/PhysFitness/PFTDN/Summary2011.aspx?r=0&t=4&y=2012-13&c=00000000000000&n=0000 Accessed 1 Dec 2015.

Lopez AD, Mathers CD, Ezzati M, Jamison DT, Murray CJ editors (2006). Global burden of disease and risk factors. Washington, DC: World Bank.

Machado-Rodrigues AM, Leite N, Coelho-e-Silva MJ, Martins RA, Valente-dos-Santos J, Mascarenhas LPG, Boguszewski MCS, Padez C, Malina RM. 2014. Independent association of clustered metabolic risk factors with cardiorespiratory fitness in youth aged 11-17 years. Ann Hum Biol 41(3):271-276.

Malina RM, Beunen G, Lefevre J, Woynarowska B. (1997). Maturity-associated variation in peak oxygen uptake in active adolescent boys and girls. Ann Hum Biol, 24(1): 19-31.

Matsudo SMM, Matsudo VKR. (1994). Self-assessment and physician assessment of sexualmaturation in Brazilian boys and girls – concordance and reproducibility. Am J Hum Biol, 6: 451-455.

Marfell-Jones, M, Olds, T, Stewart A. International standards for anthropometric assessment. Potchefstroom, South Africa: ISAK, 2006.

Melo X, Santa-Clara H, Santos DA, Pimenta NM, Minderico CS, Fernhall B, et al, (2015). Independent Association of Muscular Strength and Carotid Intima-Media Thickness in Children. Int J Sports Med, 36(8): 624-30.

Mesa JL, Ruiz JR, Ortega FB, Wärnberg J, González-Lamuño D, Moreno LA, et al. (2006). Aerobic physical fitness in relation to blood lipids and fasting glycaemia in adolescents: influence of weight status. Nutr Metab Cardiovasc Dis, 16(4): 285-93.

Moreira C, Santos R, Ruiz JR, Vale S, Soares-Miranda L, Marques A, et al. (2011). Comparison of different VO(2max) equations in the ability to discriminate the metabolic risk in Portuguese adolescents. J Sci Med Sport, 14(1): 79-84.

Olds T, Tomkinson G, Leger L, Cazorla G. (2006). Worldwide variation in the performance of children and adolescents: An analysis of 109 studies of the 20-m shuttle run test in 37 countries. J Sports Sci, 24(10), 1025–1038.

Olds TS, Ridley K, Tomkinson GR. (2007). Declines in aerobic fitness: are they only due to 184 increasing fatness? Med Sport Sci, 50: 226-40.

Ortega FB, Artero EG, Ruiz JR, España-Romero V, Jiménez-Pavón D, Vicente-Rodriguez G., et al., (2011). Physical fitness levels among European adolescents: the HELENA study. Br J Sports Med, 45, 20-29.

Ortega FB, Ruiz JR, Castillo MJ, Moreno LA, González-Gross M, Wärnberg J, et al. (2005). Low level of physical fitness in Spanish adolescents. Relevance for future cardiovascular health (AVENAstudy. Rev Esp Cardiol, 58(8): 898-909.

Ortega FB, Ruiz JR, Castillo MJ, Sjostrom M. (2008). Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes (Lond), 32, 1-11.

Ortega FB, Silventoinen K, Tynelius P, Rasmussen F. (2012). Muscular strength in male adolescents and premature death: cohort study of one million participants. BMJ, 345: e7279.

Parra DC, Iannotti L, Gomez LF, Pachón H, Haire-Joshu D, Sarmiento OL, et al. (2015). The nutrition transition in Colombia over a decade: a novel household classification system of anthropometric measures. Arch Public Health 73(1):12.

Pate RR, Wang CY, Dowda M, Farrell, SW, O'Neill J. (2006). Cardiorespiratory fitness levels among US youth 12 to 19 years of age: findings from the 1999-2002 National Health and Nutrition Examination Survey. Arch Pediatr Adolesc Med, 160, 1005–12.

Pate RR, Wang CY, Dowda M, Farrell SW, O'Neill JR. (2006). Cardiorespiratory fitness levels among US youth 12 to 19 years of age: findings from the 1999-2002 National Health and Nutrition Examination Survey. Arch Pediatr Adolesc Med, 160, 1005-12.

Prieto-Benavides DH, Correa-Bautista JE, Ramírez-Vélez R. (2015). Physical activity levels, physical fitness and scree time among children and adolescents from Bogotá, Colombia: The FUPRECOL Study. Nut Hosp, 32(5):2184-92.

Ramírez-Vélez R, Rodrigues-Bezerra D, Correa-Bautista JE, Izquierdo M, Lobelo F. (2015). Reliability of Health-Related Physical Fitness Tests among Colombian Children and Adolescents: The FUPRECOL Study. PLoS One, 10(10):e0140875.

Rey-López JP, Vicente-Rodríguez G, Biosca M, Moreno LA. (2008). Sedentary behaviour and obesity development in children and adolescents. Nutr Metab Cardiovasc Dis, 18(3): 242-51.

Rivera JÁ, de Cossío TG, Pedraza LS, Aburto TC, Sánchez TG, Martorell R (2014). Childhood and adolescent overweight and obesity in Latin America: a systematic review. Lancet Diabetes Endocrinol, 2:321-32.

Rodríguez-Bautista YP, Correa-Bautista JE, González-Jiménez E, Schmidt-RioValle J, Ramírez-Vélez R. (2015). Values of waist/hip ratio among children and adolescents from Bogotá, Colombia: The FUPRECOL Study. Nut Hosp, 32(5):2054-61.

Roriz De Oliveira MS, Seabra A, Freitas D, Eisenmann JC, Maia J. (2014). Physical fitness percentile charts for children aged 6-10 from Portugal. J Sports Med Phys Fitness, 54(6), 780-92.

Royston P, Wright EM. (2000). Goodness-of-fit statistics for age-specific reference intervals. Stat Med 19:2943-2962.

Ruiz JR, Ortega FB, Meusel D, Harro M, Oja P, Sjöström, M. (2006). Cardiorespiratory fitness is associated with features of metabolic risk factors in children. Should cardiorespiratory fitness be assessed in a European health monitoring system? The European Youth Heart Study. J Public Health, 14, 94-102.

Sandercock G, Voss C, Cohen D, Taylor M, Stasinopoulos DM. (2012). Centile curves and normative values for the twenty metre shuttle-run test in English schoolchildren. J Sports Sci, 30(7), 679-87.

Sandercock G, Voss C, McConnell D, Rayner P. (2010). Ten year secular declines in the cardiorespiratory fitness of affluent English children are largely independent of changes in body mass index. Arch Dis Child, 95(1): 46-7.

Sandercock GR, Ogunleye A, Voss C. (2015). Six-year changes in body mass index and cardiorespiratory fitness of English schoolchildren from an affluentarea. Int J Obes (Lond), doi: 10.1038/ijo.2015.105, [Epub ahead of print].

Sandercock GR, Ogunleye AA. (2013). Independence of physical activity and screen time as predictors of cardiorespiratory fitness in youth. Pediatr Res, 73(5): 692-7.

Santos R, Mota J, Santos DA, Silva AM, Baptista F, Sardinha LB. (2014). Physical fitness precentiles for portuguese children and adolescents aged 10-18 years. J Sports Sci, 32(16): 1510-1518.

Secchi D, García C, España-Romero V, Castro-Piñero J. (2014). Condición Física y riesgo cardiovascular futuro en niños y adolescentes argentinos:una introducción de la bateria ALPHA. Arch Argent Pediatr, 112(2): 132-140.

Silva G, Aires L, Mota J, Oliveira J, Ribeiro JC. (2012). Normative and criterion-related standards for shuttle run performance in youth. Pediatr Exerc Sci, 24(2): 157-69.

Slinger J, Breda E, Kupiers H. (2009). Aerobic fitness data for Dutch adolescents (2002-2005). Pediatr Exerc Sci, 21: 10-18.

Stratton G, Canoy D, Boddy LM, Taylor SR, Hackett AF, Buchan IE. (2007). Cardiorespiratory fitness and body mass index of 9-11-year-old English children: a serial cross-sectional study from 1998 to 2004. Int J Obes (Lond), 31(7): 1172-8.

Squires RW, Buskirk ER. (1982). Aerobic capacity during acute exposure to simulated altitude, 914 to 2286 meters. Med Sci Sports Exerc, 14(1):36-40.

Tanner JM, Whitehouse RH. (1976). Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. Arch Dis Child, 51: 170–179.

Tomkinson GR, Olds TS, Kang SJ, Kim DY. (2007). Secular trends in the aerobic fitness test performance and body mass index of Korean children and adolescents(1968-2000). Int J Sports Med, 28(4), 314-20.

Tomkinson GR, Olds TS. (2007). Secular changes in aerobic fitness test performance of Australasian children and adolescents. Med Sport Sci, 50, 168–82.

Tovar G, Poveda JG, Pinilla MI, Lobelo F. (2008). Sobrepeso, inactividad física y baja condición física en un colegio de Bogotá, Colombia [Relationship between overweight, physical activity and physical fitness in school-aged boys in Bogota Colombia]. Arch Latinoam Nutr, 58: 265-273.

Tremblay MS, Shields M, Laviolette M, Craig CL, Janssen I, Connor Gorber S. (2010). Fitness of Canadian children and youth: results from the 2007-2009 Canadian Health Measures Survey. Health Rep, 21, 7-20.

Twisk JW, Kemper HC, van Mechelen W. (2002). The relationship between physical fitness and physical activity during adolescence and cardiovascular disease risk factors at adult age. The Amsterdam Growth and Health Longitudinal Study. Int J Sports Med, 23, S8–14.

Universidad de Granada; Universidad de Cédiz: Karolinska Institutet; UKK Institute. (2007). The ALPHA Health-Related Fitness Test Battery for Children and Adolescents: Test Manual. Granada, Spain. Diciembre 1, 2013, de Universidad de Granada Sitio web: https://sites.google.com/site/alphaprojectphysicalactivity/

Wachira L JM, Muthuri SK, Tremblay MS, Onywera VO. (2014). Results from Kenya's 2014 Report Card on the Physical Activity and Body Weight of Children and Youth. J Phys Act Health, (Suppl 1): S69-73.

Welk GJ, Laurson KR, Eisenmann JC, Cureton KJ. (2011). Development of Youth Aerobic-Capacity Standards Using Receiver Operating Characteristic Curves. Am J Prev Med, 41: S111-116.

World Development Indicators database, World Bank (2015).

Table 1. Characteristics of among a population-based sample of Schoolchildren in Bogota, Colombia [mean (SD) or frequencies (%)]

Characteristics	Boys (n=*3211*)	Girls (n=*4033*)	Total (n=*7244*)
Age (years)	12.9 (2.3)	12.8 (2.4)*	12.8 (2.3)
Body weight (kg)	45.0 (13.0)	44.8 (11.4)**	44.6 (12.3)
Height (m)	1.50 (0.13)	1.47 (0.10)*	1.49 (0.12)
BMI (kg/m^2)	19.3 (3.3)	20.3 (3.5)*	19.7 (3.4)
Weight status n,(%)			
Underweight	930 (29)	1209 (31)*	2139 (29)
Normal weight	1697 (53)	1828(45)*	3525 (49)
Overweight	405 (13)	658 (16)*	1063 (15)
Obese	179 (6)	338 (8)*	517 (7)
Waist circumference (cm)	66.3 (8.2)	65.0 (8.1)*	65.6 (8.1)
Sexual maturation status n,(%)			
I	244 (8)	710 (18)*	954 (13)
II	988 (31)	960 (24)*	1948 (27)
III	922 (29)	981 (24)*	1903 (26)
IV	833 (26)	1189 (29)*	2022 (28)
V	224 (7)	193 (5)*	417 (6)
VO_{2peak} (ml•kg^{-1}•min^{-1})[a]	42.4 (5.2)*	38.5 (4.8)*	40.2 (5.3)
VO_{2peak} altitude-adjusted (ml•kg^{-1}•min^{-1})[c]	47.1 (5.8)*	42.7 (5.3)*	44.6 (5.9)
Shuttles (total count)	36.6 (20.0)*	22.3 (11.3)*	28.7 (17.3)
Running speed at last completed shuttle (km•h^{-1})	4.4 (2.2)*	2.8 (1.3)*	3.5 (2.0)
FITNESSGRAM (fitness zones) n,(%)[b]			
Needs improvement	538 (16.8)*	1039 (25.8)*	1577 (21.8)
Health risk	904 (28.2)*	1373 (34.1)*	2277 (31.5)
FITNESSGRAM (fitness zones) n,(%)[c]			
Needs improvement	268 (8.3)*	573 (14.2)*	841 (11.6)
Health risk	308 (9.6)*	530 (13.1)*	838 (11.5)

Note: Frequencies in brackets represent the proportion of the total sample with data for each variable
Significant between-sex differences (ANOVA one way test or Chi-square; *p<0.001; **p<0.01)

[a] VO_{2peak} (ml•kg^{-1}•min^{-1}) predicted using the Leger et al equation (1988)

[b] To classify VO_{2peak}, we used the 2011 FITNESSGRAM® standards and Healthy Fitness Zones (Welk et al., 2011)

[c] VO_{2peak} (ml•kg^{-1}•min^{-1}) predicted using the Leger et al. equation (1988) and adjusted by an altitude correction factor (1.11)

Table 2. Descriptive statistics for 20 m-shuttle run performance and FITNESSGRAM Health-related standards among a population-based sample of Schoolchildren in Bogota, Colombia

Sex	n	Shuttles (total count)	Running speed at last completed shuttle (km•h)	$\text{VO}_{2\text{peak}}$ (ml•kg^{-1}•min^{-1})[a]	$\text{VO}_{2\text{peak}}$ Altitude-adjusted (ml•kg^{-1}•min^{-1})[c]	FITNESSGRAM (fitness zones)[b]		FITNESSGRAM Altitude-Adjusted (fitness zones)[c]	
						Needs improvement	Health risk	Needs improvement	Health risk
Boys									
9 to 9.9	215	20.0 (11.8)	8.6 (2.4)	44.6 (3.2)	49.5 (3.5)	0.0%	0.0%	0.0%	0.0%
10 to 10.9	399	24.2 (13.3)	9.2 (1.2)	43.6 (3.7)	48.4 (4.1)	22.6%	0.0%	0.0%	0.0%
11 to 11.9	408	26.1 (13.5)	9.3 (1.4)	42.4 (4.0)	47.1 (4.4)	23.5%	18.1%	0.0%	0.0%
12 to 12.9	381	29.7 (15.2)	9.6 (1.6)	41.8 (4.6)	46.4 (5.1)	21.0%	26.8%	13.1%	0.0%
13 to 13.9	391	35.8 (16.9)	10.0 (1.9)	42.0 (5.0)	46.6 (5.6)	11.5%	23.0%	13.3%	6.9%
14 to 14.9	434	42.2 (18.9)	10.2 (2.0)	42.4 (5.9)	47.0 (6.5)	17.7%	41.0%	10.4%	14.4%
15 to 15.9	403	47.3 (19.1)	10.4 (2.2)	42.2 (6.2)	46.8 (6.8)	48.1%	15.4%	11.9%	19.6%
16 to 16.9	340	51.4 (19.7)	10.6 (2.4)	41.9 (6.3)	46.5 (6.9)	15.6%	39.4%	11.8%	27.4%
17 to 17.9	238	54.0 (19.9)	10.7 (2.4)	40.9 (6.4)	45.4 (7.1)	14.7%	55.5%	13.9%	20.2%
Total	*3211*	*36.6 (20.1)*	*9.9 (2.1)*	*42.4 (5.2)*	*47.1 (5.8)*	*16,8%*	*28,2%*	*8,3%*	*9,6%*
Girls									
9 to 9.9	293	15.8 (8.6)	8.5 (1.9)	43.3 (2.4)	48.0 (2.6)	0.0%	0.0%	0.0%	0.0%
10 to 10.9	628	18.5 (10.0)	8.9 (1.5)	42.0 (2.9)	46.6 (3.2)	36.3%	0.0%	0.0%	0.0%
11 to 11.9	585	19.9 (9.5)	9.1 (1.0)	40.5 (2.9)	45.0 (3.2)	39.1%	25.8%	0.0%	0.0%
12 to 12.9	464	21.4 (9.5)	9.1 (1.5)	39.4 (3.1)	43.7 (3.4)	29.1%	20.7%	20.7%	0.0%
13 to 13.9	429	23.7 (11.6)	9.2 (1.9)	38.5 (4.0)	42.8 (4.4)	28.4%	43.1%	15.4%	0.0%
14 to 14.9	555	25.2 (11.2)	9.3 (1.6)	37.2 (4.0)	41.3 (4.4)	29.0%	36.4%	25.4%	11.0%
15 to 15.9	434	25.0 (11.9)	9.0 (2.3)	35.2 (4.2)	39.1 (4.7)	16.4%	68.2%	26.7%	41.5%

16 to 16.9	383	26.5 (12.0)	9.2 (2.2)	34.1 (4.5)	37.9 (5.0)	18.5%	61.9%	27.2%	34.7%
17 to 17.9	260	28.1 (13.1)	9.0 (2.6)	32.7 (4.8)	36.3 (5.3)	8.5%	79.2%	19.2%	60.0%
Total	*4033*	*22.4 (11.3)*	*9.0 (1.8)*	*38.5 (4.8)*	*42.7 (5.3)*	*25.8%*	*34,1%*	*14,2%*	*13,1%*

Note: Data are mean (SD) for continuous variables or (%)

[a] VO_{2peak} (ml•kg^{-1}•min^{-1}) predicted using the Leger et al. equation (1988)

[b] To classify VO_{2peak}, we used the 2011 FITNESSGRAM® standards and Healthy Fitness Zones (Welk et al., 2011)

[c] VO_{2peak} (ml•kg^{-1}•min^{-1}) predicted using the Leger et al. equation (1988) and adjusted by an altitude correction factor (1.11)

Table 3. Smoothed age- and sex-specific percentile values for the 20-m Shuttle run test (Total Shuttles Completed) among a population-based sample of Schoolchildren in Bogota, Colombia

	n	M	SD	P_{3}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{97}
Boys										
9 to 9.9	215	20.0	11.8	5.0	8.0	11.0	16.0	27.0	36.0	43.5
10 to 10.9	399	24.2	13.3	7.0	9.0	14.0	22.0	32.0	42.0	54.0
11 to 11.9	408	26.1	13.5	7.0	10.0	15.0	23.5	34.0	47.0	55.5
12 to 12.9	381	29.7	15.2	8.0	12.0	18.0	27.0	39.0	50.0	63.5
13 to 13.9	391	35.8	16.9	8.9	14.0	24.0	34.0	46.0	59.0	76.0
14 to 14.9	434	42.2	18.9	10.1	18.5	28.0	40.0	56.0	66.0	79.9
15 to 15.9	403	47.3	19.1	12.0	22.0	34.0	48.0	60.0	71.0	81.9
16 to 16.9	340	51.4	19.7	16.0	25.1	35.3	52.0	66.0	78.0	87.0
17 to 17.9	238	54.0	19.9	14.0	27.0	40.0	54.0	68.0	80.2	91.3
Total	*3211*	*36.6*	*20.1*	*8.0*	*12.0*	*20.0*	*34.0*	*50.0*	*65.0*	*78.6*
Girls										
9 to 9.9	293	15.8	8.6	6.0	8.0	10.0	14.0	19.0	27.0	37.2
10 to 10.9	628	18.5	10.0	7.0	9.0	12.0	16.0	22.0	32.0	43.0
11 to 11.9	585	19.9	9.5	8.0	10.0	13.0	18.0	24.0	33.0	44.0
12 to 12.9	464	21.4	9.5	7.0	10.5	14.0	20.0	27.0	35.0	42.0
13 to 13.9	429	23.7	11.6	7.9	11.0	15.0	21.0	30.0	41.0	51.0
14 to 14.9	555	25.2	11.2	10.0	12.0	16.0	23.0	32.0	41.0	51.0
15 to 15.9	434	25.0	11.9	10.0	12.0	16.0	22.0	30.0	40.0	52.0
16 to 16.9	383	26.5	12.0	10.0	13.4	17.0	25.0	34.0	43.0	52.0
17 to 17.9	260	28.1	13.1	12.0	14.0	18.0	25.0	35.0	47.0	60.0
Total	*4033*	*22.4*	*11.3*	*8.0*	*10.0*	*14.0*	*20.0*	*28.0*	*37.0*	*49.0*

M, mean; SD, standard deviation; P, percentile

Table 4. Smoothed age- and sex-specific percentile values for VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$) among a population-based sample of Schoolchildren in Bogota, Colombia

	n	M	SD	P_3	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{97}
Boys										
9 to 9.9	215	44.6	3.2	41.1	41.2	41.2	43.5	45.8	48.2	51.6
10 to 10.9	399	43.6	3.7	39.3	39.3	41.5	43.9	46.4	48.8	51.2
11 to 11.9	408	42.4	4.0	37.3	37.3	39.8	42.3	44.7	47.4	49.7
12 to 12.9	381	41.8	4.6	35.4	35.4	37.9	40.5	45.4	48.1	50.6
13 to 13.9	391	42.0	5.0	33.4	35.9	38.7	41.3	43.9	49.2	51.8
14 to 14.9	434	42.4	5.9	31.5	34.2	39.4	42.3	47.5	50.2	53.1
15 to 15.9	403	42.2	6.2	29.6	35.0	37.9	43.3	46.2	49.0	51.7
16 to 16.9	340	41.9	6.3	30.5	33.3	36.2	41.9	44.7	50.3	53.1
17 to 17.9	238	40.9	6.4	25.7	31.5	37.4	40.3	46.0	49.1	52.0
Total	*3211*	*42.4*	*5.2*	*32.3*	*35.9*	*39.3*	*42.3*	*46.0*	*49.0*	*52.0*
Girls										
9 to 9.9	293	43.3	2.4	41.1	41.2	41.2	43.4	43.5	45.8	48.2
10 to 10.9	628	42.0	2.9	39.3	39.3	39.3	41.7	43.9	46.4	48.8
11 to 11.9	585	40.5	2.9	37.3	37.3	37.3	39.8	42.3	44.7	47.2
12 to 12.9	464	39.4	3.1	35.4	35.4	37.8	40.3	40.5	43.0	45.6
13 to 13.9	429	38.5	4.0	33.4	33.4	36.1	38.5	41.2	43.9	46.5
14 to 14.9	555	37.2	4.0	31.5	31.5	34.2	36.9	39.6	42.3	45.0
15 to 15.9	434	35.2	4.2	29.6	29.6	32.3	35.0	37.7	40.6	46.0
16 to 16.9	383	34.1	4.5	27.6	30.3	30.5	33.3	36.2	39.0	44.6
17 to 17.9	260	32.7	4.8	25.7	28.5	28.6	31.5	34.5	40.2	43.2
Total	*4033*	*38.5*	*4.8*	*28.6*	*31.5*	*35.2*	*39.3*	*41.7*	*44.1*	*46.5*

M, mean; SD, standard deviation; P, percentile

Supplemental File Table S1. Smoothed age- and sex-specific percentile values for VO_{2peak} (ml•kg^{-1}•min^{-1}) (altitude-adjusted) among a population-based sample of Schoolchildren in Bogota, Colombia

	n	M	SD	P_3	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{97}
Boys										
9 to 9.9	215	49.5	3.5	45.6	45.7	45.7	48.3	50.8	53.5	57.3
10 to 10.9	399	48.4	4.1	43.6	43.6	46.1	48.7	51.5	54.2	56.8
11 to 11.9	408	47.1	4.4	41.4	41.4	44.2	47.0	49.6	52.6	55.2
12 to 12.9	381	46.4	5.1	39.3	39.3	42.1	45.0	50.4	53.4	56.2
13 to 13.9	391	46.6	5.6	37.1	39.9	43.0	45.8	48.7	54.6	57.5
14 to 14.9	434	47.0	6.5	35.0	38.0	43.8	47.0	52.7	55.7	58.9
15 to 15.9	403	46.8	6.8	32.9	38.8	42.1	48.0	51.3	54.4	57.4
16 to 16.9	340	46.5	6.9	33.9	37.0	40.2	46.5	49.6	55.8	58.9
17 to 17.9	238	45.4	7.1	28.5	35.0	41.5	44.7	51.1	54.5	57.7
Total	*3211*	*47.1*	*5.8*	*35.9*	*39.9*	*43.6*	*47.0*	*51.1*	*54.4*	*57.7*
Girls										
9 to 9.9	293	48.0	2.6	45.6	45.7	45.7	48.2	48.3	50.8	53.5
10 to 10.9	628	46.6	3.2	43.6	43.6	43.6	46.3	48.7	51.5	54.2
11 to 11.9	585	45.0	3.2	41.4	41.4	41.4	44.2	47.0	49.6	52.4
12 to 12.9	464	43.7	3.4	39.3	39.3	41.9	44.8	45.0	47.7	50.6
13 to 13.9	429	42.8	4.4	37.1	37.1	40.1	42.8	45.7	48.7	51.6
14 to 14.9	555	41.3	4.4	35.0	35.0	38.0	41.0	44.0	47.0	50.0
15 to 15.9	434	39.1	4.7	32.9	32.9	35.9	38.8	41.9	45.1	51.1
16 to 16.9	383	37.9	5.0	30.6	33.7	33.9	37.0	40.2	43.3	49.5
17 to 17.9	260	36.3	5.3	28.5	31.6	31.7	35.0	38.3	44.6	48.0
Total	*4033*	42.7	5.3	31.7	35.0	39.1	43.6	46.3	49.0	51.6

M, mean; SD, standard deviation; P, percentile

Supplemental File Table S2. Reference values for VO$_{2peak}$ (ml•kg^{-1}•min^{-1}) mean (± SD) from selected studies

Study	FUPRECOL Study (2015) n = 7244	Altitude-adjusted FUPRECOL Study (2015) n = 7244	England (Sandercock et al., 2012) n = 7366	Canada (Tremblay et al., 2010) n = 7000	Argentina (Secchi et al., 2014) n = 1867	Spain (Ortega et al., 2005) n = 3528	Portugal (Santos et al., 2014) n = 22048	Australia (Tomkinson et al 2007) n = 85347
Boys								
9 to 9.9	44.6 (3.2)	49.5 (3.5)	-	51.5 (4.3)	-	-	-	43.4 (4.6)
10 to 10.9	43.6 (3.7)	48.4 (4.1)	47.1 (5.6)	51.6 (4.2)	-	-	43.9 (2.4)	43.9 (4.8)
11 to 11.9	42.4 (4.0)	47.1 (4.4)	45.9 (5.4)	51.1 (4.5)	44.6 (5.2)	-	44.6 (4.9)	44.6 (4.9)
12 to 12.9	41.8 (4.6)	46.4 (5.1)	45.3 (5.8)	51.9 (5.1)	45.4 (5.1)	-	42.9 (5.1)	42.9 (5.1)
13 to 13.9	42.0 (5.0)	46.6 (5.6)	45.2 (6.2)	50.0 (5.2)	45.4 (5.1)	43.8 (5.4)	43.8 (5.3)	41.1 (5.3)
14 to 14.9	42.4 (5.9)	47.0 (6.5)	46.3 (6.9)	50.1 (5.2)	42.1 (5.4)	44.8 (5.4)	44.8 (5.4)	42.1 (5.4)
15 to 15.9	42.2 (6.2)	46.8 (6.8)	45.7 (7.1)	50.2 (6.0)	43.3 (5.5)	43.3 (5.5)	43.3 (5.5)	43.3 (5.5)
16 to 16.9	41.9 (6.3)	46.5 (6.9)	46.4 (5.7)	49.9 (5.8)	44.6 (5.7)	41.7 (5.4)	44.6 (5.7)	44.6 (6.7)
17 to 17.9	40.9 (6.4)	45.4 (7.1)	-	49.6 (5.9)	40.2 (5.9)	43.1 (5.8)	43.1 (5.8)	44.5 (5.8)
Total	*42.4 (5.2)*	*47.1 (5.8)*	*45.8 (6.2)*		*43.7 (5.4)*	*43.3 (5.5)*	*43.9 (5.0)*	*43.4 (5.3)*
Girls								
9 to 9.9	43.3 (2.4)	48.0 (2.6)	-	49.9 (3.2)	-		-	41.1 (4.6)
10 to 10.9	42.0 (2.9)	46.6 (3.2)	44.7 (4.6)	46.8 (2.7)	-		41.5 (4.8)	41.5 (4.8)

11 to 11.9	40.5 (2.9)	45.0 (3.2)	43.0 (4.3)	47.5 (4.0)	42.1 (5.1)		42.1 (5.0)	39.6 (4.9)
12 to 12.9	39.4 (3.1)	43.7 (3.4)	41.9 (4.4)	46.6 (4.1)	40.3 (5.1)		40.3 (5.1)	40.3 (5.1)
13 to 13.9	38.5 (4.0)	42.8 (4.4)	40.7 (4.7)	44.4 (4.7)	38.5 (5.2)	38.5 (5.2)	38.5 (6.0)	38.5 (5.2)
14 to 14.9	37.2 (4.0)	41.3 (4.4)	39.2 (5.0)	41.6 (4.7)	36.7 (5.4)	36.7 (5.4)	36.7 (5.4)	37.8 (5.2)
15 to 15.9	35.2 (4.2)	39.1 (4.7)	37.2 (4.7)	41.1 (5.0)	35.0 (5.5)	35.0 (5.5)	35.0 (5.2)	37.5 (4.8)
16 to 16.9	34.1 (4.5)	37.9 (5.0)	37.8 (5.8)	39.5 (4.9)	33.2 (5.7)	33.2 (6.3)	36.0 (5.7)	38.2 (5.1)
17 to 17.9	32.7 (4.8)	36.3 (5.3)	-	38.6 (5.1)	32.4 (5.8)	32.4 (5.8)	34.3 (5.8)	34.3 (5.8)
Total	*38.5 (4.8)*	*42.7 (5.3)*	*41.2 (5.0)*		*36.5 (5.4)*	*35.2 (5.6)*	*38.5 (5.4)*	*38.8 (5.1)*

Supplemental File Table S3. Prevalence of unhealthy CRF among Colombian schoolchildren and selected comparable population-based studies in other countries.

Location	Sample year	n	Age sample	Health-related CRF Standard	Percent unhealthy[c]	
					Boys	Girls
South America						
Fuprecol Study[a]	2015	7,244	9 to 17	FITNESSGRAM 2011	45%	59%
Altitude-adjusted Fuprecol Study[b]	2015	7,244	9 to 17	FITNESSGRAM 2011	17%	27%
Argentina	2014	1,867	6 to 19	FITNESSGRAM 2011	11%	49%
Chile (R)	2014	19,904	13 to 17	FITNESSGRAM 2011	15%	30%
Colombia (Bogotá)	2008	665	7 to 18	FITNESSGRAM 2004	37%	-
Colombia (Cali)	2011	1,773	10 to 16	FITNESSGRAM 2004	52%	60%
USA						
California	2013	1,666	11 to 18	FITNESSGRAM 2011	28%	44%
Midwest	2011	447,619	8 to 17	FITNESSGRAM 2011	26%	23%
USA – NHANES (R)	1999-2002	1,247	12 to 19	FITNESSGRAM 2004	35%	35%
Europe						
UK (East)	2013	7,366	10 to 16	FITNESSGRAM 2011	12%	25%
Sweden (R)	2008	472	14 to 16	FITNESSGRAM 2004	9%	20%
Spain (R)	2005	1,867	14 to 16	FITNESSGRAM 2004	19%	17%
Pan-European (R)	2008	3,428	12 to 17	FITNESSGRAM 2004	39%	43%
Australia	1985-2009	18,075	9 to 17	FITNESSGRAM 2004	29%	23%

[a] VO_{2peak} ($ml•kg^{-1}•min^{-1}$) predicted using the equation of Leger et al. (1988)

[b] VO_{2peak} ($ml•kg^{-1}•min^{-1}$) predicted using the equation of Leger et al. (1988) and adjusted by correction factor (1.11) and 2011 FITNESSGRAM® standards and Healthy Fitness Zones (Welk et al., 2011)

[a] VO_{2peak} ($ml•kg^{-1}•min^{-1}$) predicted using the Leger et al. equation (1988) and adjusted by correction factor (1.11)

[b] To classify VO_{2peak}, we used the 2011 FITNESSGRAM® standards and Healthy Fitness Zones (Welk et al., 2011)

[c] If three categories reported, unhealthy combines the two higher-risk categories. (R) Sample is nationally representative.

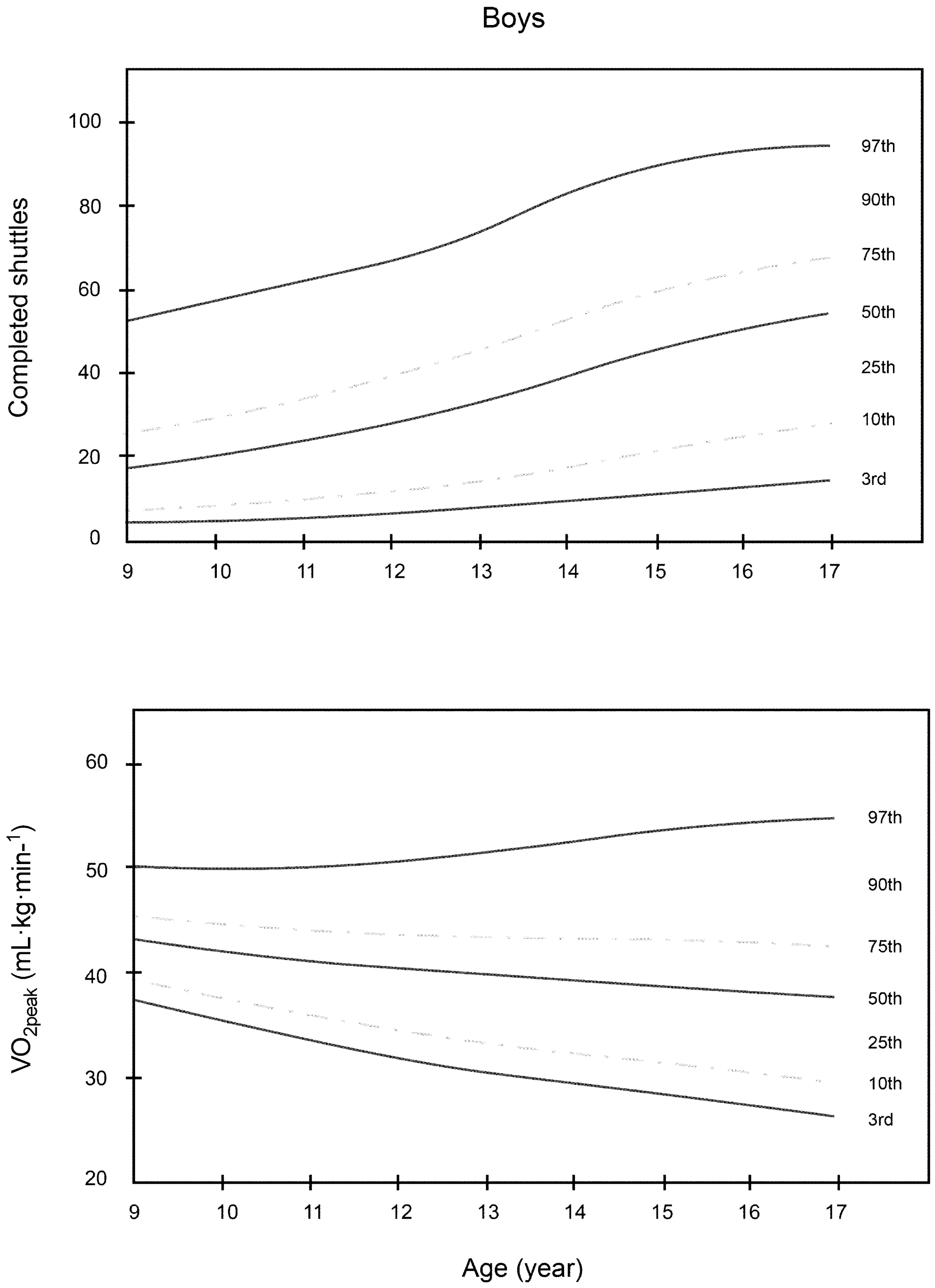

Figure 1. Centile curves for 20-m Shuttle run test (Total Shuttles Completed) and VO2peak (ml•kg^{-1}•min^{-1}) among among a population-based sample of Schoolboys in Bogota, Colombia

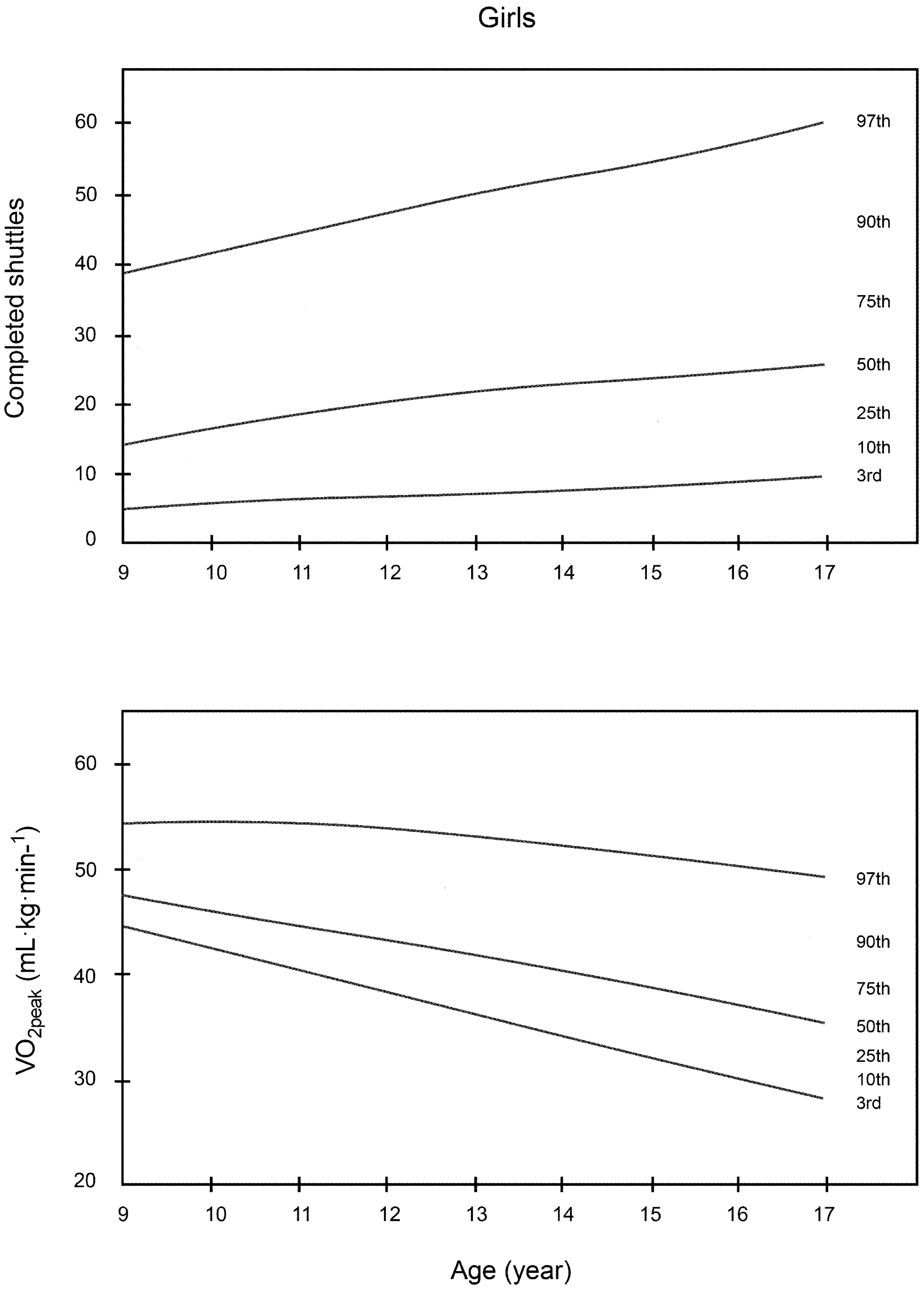

Figure 2. Centile curves for 20-m Shuttle run test (Total Shuttles Completed) and VO2peak (ml•kg^{-1}•min^{-1}) among a population-based sample of Schoolgirls in Bogota, Colombia

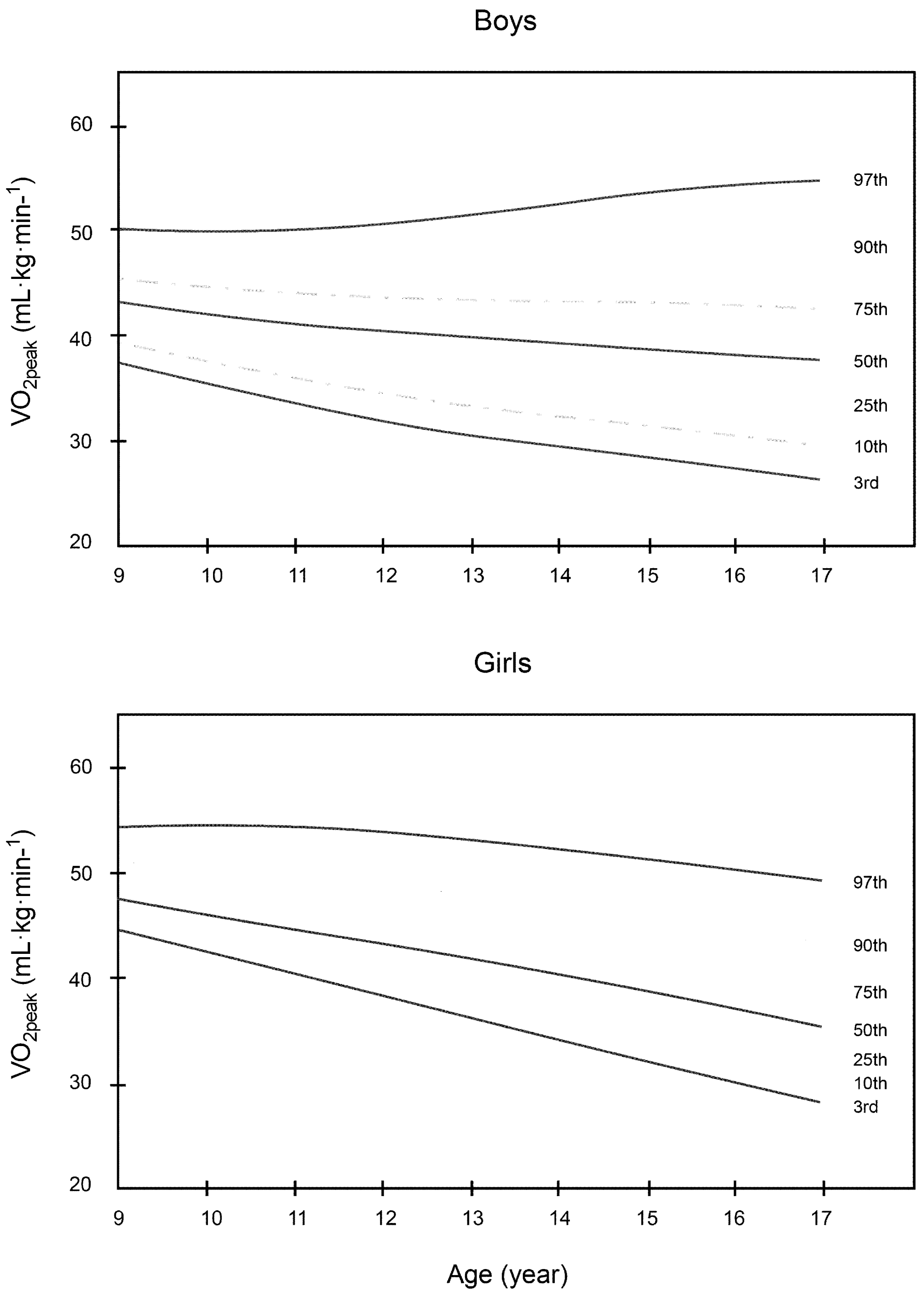

Figure S1. Centile curves for 20-m VO_{2peak} (ml•kg^{-1}•min^{-1}) altitude-adjusted among among a population-based sample of Schoolchildren in Bogota, Colombia

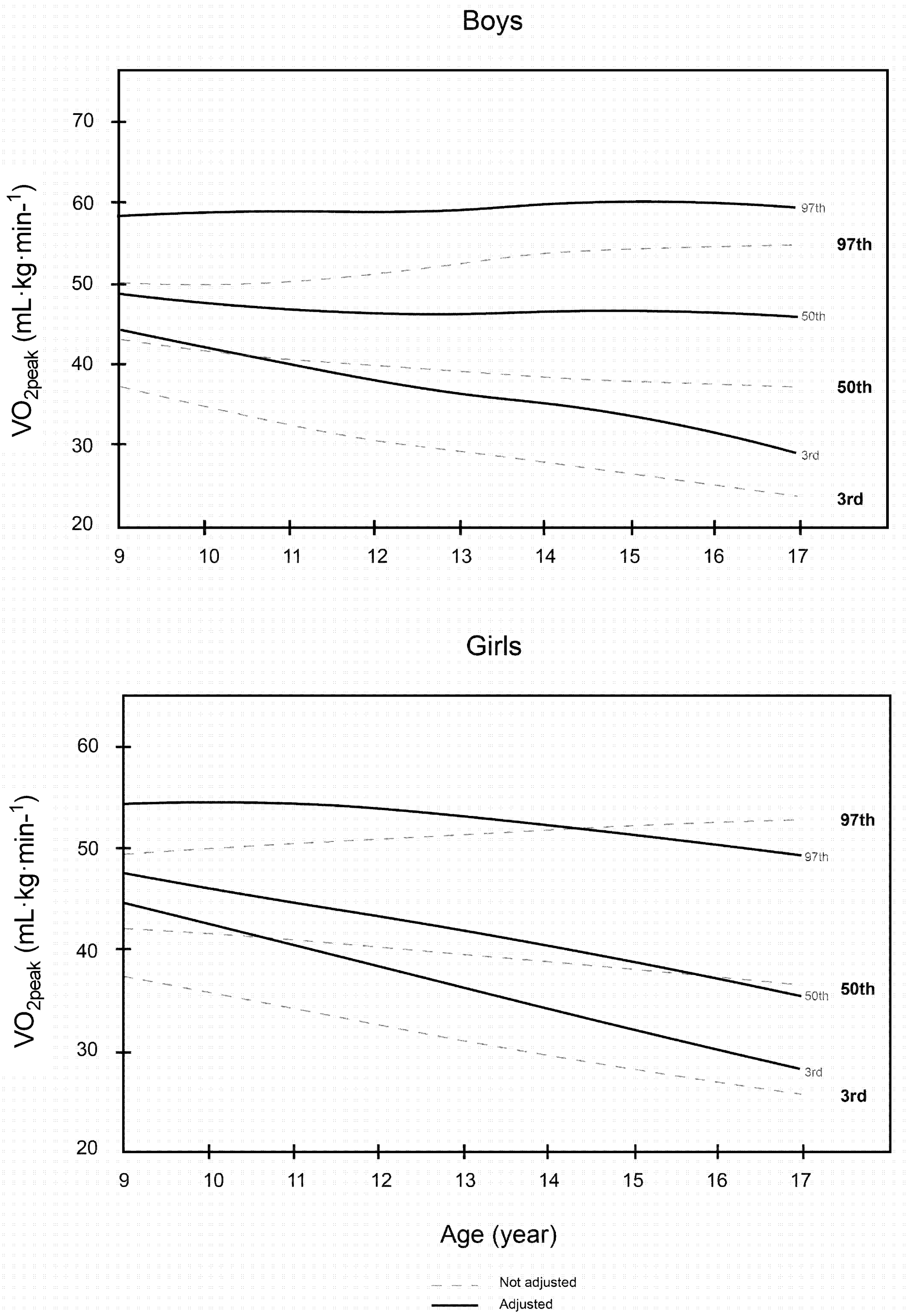

Figure S2. Centile curves for 20-m VO_{2peak} and altitude- VO_{2peak} (ml•kg^{-1}•min^{-1}) among a population-based sample of Schoolchildren in Bogota, Colombia