



Maximum oxygen uptake in adolescents as measured by cardiopulmonary exercise testing: a classification proposal

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Abstract

Objective: The identification of populational levels of maximum oxygen uptake (VO_{2max}) is an aid to studies that propose to relate physical fitness to cardiovascular risk, and also for prescribing exercise and analyzing the effects of training. To date, there is no information with which this parameter can be classified in samples of adolescents from the Brazilian population. This study is, therefore, the first to propose the determination of mean VO_{2max} levels in a sample of the Brazilian population.

Methods: A sample of 380 schoolchildren (177 boys and 203 girls, aged 10 to 14 years) was selected at random from public schools in Vitória, ES. After anthropometric assessment they underwent cardiopulmonary exercise testing, VO_{2max} was measured directly and results were classified according to quintiles calculated from the study sample.

Results: The mean VO_{2max} values observed ranged from 42.95 to 49.55 $mL \cdot kg^{-1} \cdot min^{-1}$ for boys and from 36.76 to 38.29 $mL \cdot kg^{-1} \cdot min^{-1}$ for girls.

Conclusions: This paper proposes mean VO_{2max} ranges as a classification parameter for cardiorespiratory fitness, in addition to contributing to a definition of normal values for the Brazilian population. This classification will also be of use for establishing cutoff points in future studies.

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Introduction

Inactivity is a growing problem that is affecting an ever growing number of children and adolescents. Authors report that there is a tendency among adolescents to involve themselves less in physical education at school and in vigorous activity, and to increase the time they spend watching television.¹ These behavioral changes can have future repercussions in the form of health problems. In contrast, increased physical fitness has been related to a profile of lower cardiovascular risk in children and

adolescents,² and also with lower blood pressure levels, in both boys and girls.³⁻⁷ Despite the important correlation between maximum oxygen consumption (VO_{2max}) and cardiovascular risk, Brazilian literature does not provide reference values for the classification of VO_{2max} in children and adolescents.

The identification of populational maximum oxygen uptake levels (VO_{2max}) is an aid to studies that propose to relate physical fitness to cardiovascular risk. It is also important to point out that VO_{2max} measurements are also used for prescribing exercise and analyzing the effects of training programs.^{8,9}

Aerobic capacity as measured by VO_{2max} depends on cardiovascular, respiratory, and hematological components in addition to oxidative mechanisms of muscles being exercised. It is determined by means of the cardiopulmonary exercise testing, which allows for the simultaneous evaluation of the capacities of the cardiovascular and respiratory systems to perform their principal functions, such as gaseous exchange.⁹ The

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gaseous exchange measurements are of fundamental importance to understanding the mechanisms that limit exercise, since it requires an integrated cardiopulmonary response to meet the increased metabolic requirements of the muscles.

Maximum oxygen uptake is the best indicator of cardiovascular status, which makes it an important predictive factor for associated morbidity.¹⁰ One way of analyzing the clinical value of VO_{2max} is to relate it to the dimensions of the body or of a range of organ measurements, such as the size of the heart, muscular mass and pulmonary volume.¹¹

During the period of transition from adolescence to adulthood, many structural, hormonal and biochemical changes to physiology take place which interfere with VO_{2max} .¹² This being so, it is necessary to establish specific VO_{2max} values for this population. The international literature offers reference values for healthy children and adolescents.⁹ Nevertheless, data for classifying this parameter, sourced from the Brazilian population, are still lacking.

In consideration of the importance of VO_{2max} measurement for the classification of physical fitness, and also for prescribing exercise, this study aims to establish mean VO_{2max} values from a regional sample of the Brazilian population, in addition to performing a comparative analysis by sex.

Methods

Sample

This cross-sectional study was carried out during the period between March 2003 and August 2005, with schoolchildren enrolled at public schools in the municipality of Vitória, ES, within the age range of 10 to 14 years, of both sexes. The minimum sample size was determined using the general sample size calculation for all populations¹³ – large and small – with a 95% confidence level and a 5% confidence interval; attributing that value to p that would result in the largest sample, and thereby arriving at $n = 380$. Sampling was performed using a random sample selection method, taking into account the proportionality within the population of this age group (a total 27,491 adolescents within the age range being studied, 59.7% of whom are enrolled on the public school system) in the seven administrative districts of the municipality. Schools were selected by lots from each of the seven administrative districts and their principals invited to take part in the study. They in turn provided lists of their students which were used to select 380 schoolchildren at random; 177 males and 203 females. Just two of the first-choice children refused to take part and were replaced by others, also chosen by lots.

The chosen adolescents were invited, through their parents or guardians, to take part in the study. All of them signed free and informed consent forms detailing the benefits risks and procedures involved. The study protocol was approved by the Research Ethics Committee at the Faculdade Salesiana de Vitória. None of the subjects reported smoking, prior knowledge of metabolic disease or use of oral contraceptives, which were exclusion criteria. The adolescents' chronological ages were determined centesimally, with date of data collection and date of birth as references.

Anthropometric measurements

Body mass was measured using an anthropometric balance, accurate to 100 g and with a maximum capacity of 150 kg, while height was measured with a stadiometer with 0.1 cm divisions, in accordance with accepted standards. These two variables were then used to calculate body mass index (BMI). Overweight and obesity were defined using average BMI for age and sex, with cutoffs at the 85th and 95th percentiles for overweight and obesity, respectively.¹⁴⁻¹⁷

Cardiopulmonary exercise testing protocol

Prior to undertaking the test all subjects were informed of the precautions that had to be taken. Cardiopulmonary monitoring was performed by a MedGraphics Corporation (MGC) spirometer, which provides data on oxygen consumption (VO_2), carbon dioxide production (VCO_2), pulmonary ventilation (VE), ventilatory equivalents for oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2) and respiratory exchange ratio ($RER = VCO_2/VO_2$). First, all subjects were subjected to a resting electrocardiogram (ECG), using the conventional 12 leads. Children and adolescents remained in decubitus dorsal for around 5 minutes, in a calm environment with temperature maintained at around 22 °C and the electrical activity of their hearts was measured. The testing location was equipped with equipment and drugs to deal with emergencies. Subjects were then taken to the treadmill (Inbrasport Super ATL) where the way the test would progress was explained to them as were criteria for stopping the test. A neoprene mask was then fitted, medium or small as appropriate. The mask allows breathing via both the nose and mouth and was connected to a pneumotach (to measure airflow and for expired gas analysis), and constant care was taken to ensure that there was no leakage from this connection.

After around 2 minutes' rest standing up, making electrocardiographic and ventilatory recordings (pre-exercise phase), the test was begun. Subjects were monitored during the test with 12-lead ECG to keep track of cardiac response and heart rate (HR) during exercise.

For this study we employed a progressive ramping protocol, increasing inclination in accordance with predicted VO_2 , in metabolic equivalents (MET), compared with the observed VO_2 . Therefore, when subjects exhibited a slower response in terms of increased VO_2 or when estimated VO_2 was very high, maximum speed was attained early on. According to the American College of Sports Medicine, the ramp test, applying progressive force on a treadmill, is a relatively new procedure, different from traditional protocols with incremental loads, and requiring modern equipment.¹⁰ As a result, when defining predicted maximum velocity, it was necessary to rely on experience acquired in previous research carried out at our laboratory.^{18,19} Thus, taking account of the age and physical condition of each adolescent, tests were followed closely, allowing the predicted conditions to be monitored. When maximum velocity had been attained without tiring the subject, the protocol automatically adjusted load by means of increasing the treadmill angle. The use of personalized protocols, like the ramping system used here, has been described as the most appropriate method for attaining maximum VO_2 in children.²⁰ Testing was stopped if the subject indicated (by means of predefined gestures) fatigue or any type of discomfort that impeded continuation of the test. In order to define the VO_2 attained as maximum, at least three of the following criteria had to be met:²⁰ a) exhaustion or inability to maintain the required velocity; b) $\text{RER} \geq 1.0$; c) maximum HR attained $\geq 90\%$ of estimated HR; d) maximum VO_2 describes a plateau or attains values $\geq 85\%$ of predicted.

Gas analysis

Gas analysis during exercise was performed with the aid of an MGC Cardio2 spirometer, which consists of an open-circuit calorimetry system, i.e. the calibration gas was adjusted using a mixture of gasses with constant concentrations of carbon-dioxide (CO_2) and oxygen (O_2). Breeze Suite software was used to determine the concentrations of VO_2 and VCO_2 by measuring, in VE (minute volume or expired volume per minute), the difference between gas pressures in inspired air and expired air, measured breath by breath. A transducer quantified CO_2 concentration by means of non-dispersive infrared analysis (NDIR), and another transducer was used to quantify O_2 with a zirconium cell. Respiratory exchange ratios were calculated from the ratio between VCO_2 and VO_2 for each respiratory incursion ($\text{RER} = \text{VCO}_2/\text{VO}_2$). The spirometry equipment was calibrated as follows: first the equipment was left on for 30 minutes to warm up the circuits. Next, airflow was adjusted using a calibration syringe with a volume generation capacity of 3 L. The syringe was operated manually so as to produce a flow of 0.4 to 12 L/s, in order to test the system's calibration for low and high flow rates. The O_2 and CO_2 sensors were

calibrated using a reference gas comprising 22% O_2 and 0% CO_2 and then with a reference gas containing 12% O_2 and 5% CO_2 .

Statistics

Statistical analysis of data employed descriptive statistics (means, standard deviations) for anthropometric measurements and $\text{VO}_{2\text{max}}$ for age and sex. In order to adhere to the cardiorespiratory fitness characteristics proposed by the American Heart Association (AHA),²¹ maximum VO_2 quintiles were calculated by sex. Means by sex were compared using Student's *t* test for independent samples. The cutoff for statistical significance was set at $p < 0.05$.

Results

This study was designed to provide mean values for maximum VO_2 from a sample of adolescents drawn from the Brazilian population. The anthropometric characteristics and ages of the sample are given in Table 1. Mean BMI values were within the range of normality, according to published literature,¹⁴⁻¹⁷ characterizing the sample as well-nourished.

Table 2 contains maximum VO_2 values by body mass ($\text{mL.kg}^{-1}.\text{min}^{-1}$). It will be observed that boys exhibit higher $\text{VO}_{2\text{max}}$ values than girls in all age groups ($p < 0.01$), and also that the sexes behave differently as they age. While the girls exhibited a variation of 38.29 ± 6.28 (10 years old) to 36.76 ± 5.98 $\text{mL.kg}^{-1}.\text{min}^{-1}$ (at 14 years), among boys the increment was from 43.53 ± 6.65 (10 years) to 49.55 ± 7.29 $\text{mL.kg}^{-1}.\text{min}^{-1}$ (at 14 years).

Maximum VO_2 values by sex and distributed by quintiles are given in Table 3. This table represents a proposal for classification of the 10 to 14 year age group into five categories. It will also be observed that the highest observed values were 52.3 $\text{mL.kg}^{-1}.\text{min}^{-1}$ for boys and 42.5 $\text{mL.kg}^{-1}.\text{min}^{-1}$ for girls.

Around 93% of the girls and 87% of the boys met the criteria for the VO_2 attained to be defined as maximum, according to the criteria adopted by this study.²⁰

Discussion

The results of this study indicate that the cardiopulmonary exercise testing employed demonstrates considerable quality, with around 90% of those tested attaining criteria for maximum VO_2 , according to the literature proposed.²⁰

There were 71 to 82 subjects of each age ($n = 380$, 10-14 years), selected at random from among the schoolchildren enrolled at public schools in Vitória, ES, which guaranteed the quality of the data collected.

Table 1 - Anthropometric characteristics by age and sex

| | Girls | | | Boys | | |
|-------------------|-------------|-------------|--------------------------|-------------|-------------|--------------------------|
| | Weight (kg) | Stature (m) | BMI (kg/m ²) | Weight (kg) | Stature (m) | BMI (kg/m ²) |
| 10 years (n = 73) | 34.05±6.27 | 1.41±0.06 | 17.01±2.51 | 33.08±6.58 | 1.40±0.06 | 16.79±2.47 |
| 11 years (n = 77) | 42.57±11.87 | 1.47±0.08 | 19.39±3.91 | 37.41±9.16 | 1.45±0.08 | 17.61±3.01 |
| 12 years (n = 71) | 43.07±8.59 | 1.52±0.07 | 18.43±2.73 | 38.98±9.71 | 1.48±0.07 | 17.50±3.06 |
| 13 years (n = 77) | 46.16±8.57 | 1.56±0.07 | 18.89±2.72 | 51.75±11.50 | 1.62±0.09 | 19.61±3.48 |
| 14 years (n = 82) | 50.78±11.50 | 1.59±0.06 | 20.06±4.04 | 50.22±12.83 | 1.61±0.09 | 19.18±3.77 |

BMI = body mass index.
Mean ± standard deviation.

While the sample studied here is representative of the age group investigated, our data should not be extrapolated to all populations. This is because subjects were only chosen from the public education system, where, as a rule, individuals from lower socioeconomic strata are concentrated. Therefore, future studies should investigate a wider range of maximum VO₂, covering other population strata.

In general, international research suggests that adolescents have similar or greater VO_{2max} values than adults.¹⁵ This is because, instead of a reduced capacity to

increase maximum cardiac output, in conjunction with lower systolic volume, adolescents exhibit increased maximum chronotropic capacity and greater efficiency in the use of the oxidative, rather than the glycolytic, ATP resynthesis.^{12,22} Nevertheless, the capacity of these youngest subjects to perform work is greatly reduced as due to structural limitations to the cardiorespiratory system resulting from the smaller size of these organs and from biochemical limitations to anaerobic ATP production.^{9,22,23}

Another significant difference between adults and adolescents is the difficulty involved in achieving a VO₂ plateau, in order to identify maximum aerobic fitness.^{9,20,24} Studies^{23,25,26} suggest that peak VO₂ is a good indicator of aerobic fitness in children, even when a VO₂ plateau is not attained.^{20,25}

It was observed that boys' maximum VO₂ values were greater than girls'. This was to be expected,¹² bearing in mind that for boys cultural factors are more favorable to physical activity and muscular development.²⁷ It is worth pointing out that none of the adolescents we studied were athletes, and that any differences in daily physical activity levels, if present, were predominantly due to cultural factors.

Although international standards cannot be adopted for the Brazilian population, it is of interest to note that the behavior of maximum VO₂ over the adolescent period observed here was similar to descriptions in the international literature, i.e. progressively increasing for boys and decreasing for girls.²⁵

The maximum observed VO₂ values in our sample were 42.5 mL.kg⁻¹.min⁻¹ among the girls and 52.3 mL.kg⁻¹.min⁻¹ for the boys; and these were defined as the cutoff points for excellent cardiorespiratory fitness. However, mean values, by age and sex, ranged from 42.95 to 49.55 mL.kg⁻¹.min⁻¹ for boys and from 36.76 to 38.29 mL.kg⁻¹.min⁻¹ for girls. Armstrong et al.²⁵ offer typical values for boys of 48 to 50 mL.kg⁻¹.min⁻¹ during

Table 2 - Observed maximum oxygen uptake values by age and sex

| | VO _{2max} (mL.kg ⁻¹ .min ⁻¹) | | |
|----------|--|---------------|-------------------------|
| | Girls | Boys | p |
| 10 years | 38.29±6.28 | 43.53±6.65 * | 0.00096 |
| 11 years | 38.58±7.10 | 42.95±6.93 * | 0.0084 |
| 12 years | 37.63±5.67 | 44.77±8.90 * | 0.0001 |
| 13 years | 38.27±4.43 | 45.49±10.41 * | 0.0001 |
| 14 years | 36.76±5.98 | 49.55±7.29 * | 5.8 x 10 ⁻¹³ |

VO_{2max} = maximum oxygen uptake.
Mean ± standard deviation. Student's *t* test for independent samples.
* p < 0.01 (comparing boys vs. girls).

Table 3 - Classification of cardiorespiratory fitness by directly-measured maximum oxygen uptake (mL.kg⁻¹.min⁻¹) for ages 10 to 14

| | Girls | Boys |
|-----------|-----------|-----------|
| Very weak | < 33.0 | < 38.7 |
| Weak | 33.0-36.4 | 38.7-43.3 |
| Regular | 36.5-38.7 | 43.4-47.9 |
| Good | 38.8-42.4 | 48.0-52.2 |
| Excellent | ≥ 42.5 | ≥ 52.3 |

adolescence, while for girls, their figures are 39 to 45 mL.kg⁻¹.min⁻¹.

Other studies²⁴ have indicated expected values of between 44.2 and 58 mL.kg⁻¹.min⁻¹ for boys and girls aged 6 to 12 years,^{27,28} 47.7 mL.kg⁻¹.min⁻¹ for girls aged 12 to 14 years and from 49 to 52.1 mL.kg⁻¹.min⁻¹ for boys aged 13 and 14 years.²⁹⁻³²

Therefore, data accumulated to date, based on the sample studied here, point to lower aerobic fitness levels among the Brazilian adolescent population, as expressed through VO_{2max} in mL.kg⁻¹.min⁻¹, when compared with international data.

This study has been the first to provide mean maximum VO₂ values to be used as parameter for the classification of cardiorespiratory fitness in Brazilian adolescents. This classification is a contribution to the definition of values to define normality. Furthermore, our data will also be helpful when defining cutoff points for future studies that aim to investigate the occurrence of physiological limitations to organic systems and possible cardiovascular risk factors among adolescents with lower cardiorespiratory fitness levels.

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