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Original Research Article

Profile of thoracic expansion in Congolese school children in Brazzaville: an exploratory study

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ABSTRACT

Background: To determine the values of chest expansion in Congolese children aged 7 to 12 years, and to investigate the link between chest expansion and anthropometric variables (age, height, BMI), hemodynamic variables (heart rate, blood pressure) and maximum oxygen consumption.

Methods: A total of 3745 children (2023 boys and 1722 girls) enrolled in public primary schools in seven districts of Brazzaville were assessed. Anthropometric, hemodynamic and aerobic capacity (VO_{2max}) data were collected; thoracic circumference who has been measured at the axillary and xiphoid levels, was used to assess thoracic expansion. Significance of differences between experimental variables was analysed using a paired t test, Sokal's to compare thoracic expansion to the axillary and xiphoid levels, between the two sexes, as well as its variations from 7 to 12 years and during the transition from the 7-10 years age group to the 11-12 years age group. Pearson correlation coefficients were used to test the relationship between a few independent variables and thoracic expansion.

Results: The mean values of thoracic expansion at the axillary and xiphoid levels were 2.23±0.13 cm (2.45±0.15 cm in boys *versus* 2.00±0.12 cm in girls; p<0.01) and 2.04±0.11 cm (2.25±0.13 cm in boys *versus* 1.83±0.10 cm in girls; p<0.01). Chest expansion increased with age, regardless of the level of measurement. Significant differences were found between the 7-10 year and 11-12-year age groups for axillary and xiphoidal chest expansion, regardless of sex. Thoracic expansion was positively correlated with age, height, BMI and absolute VO_{2max} in boys at any measurement level, but only at the axillary level in girls. A negative and close relationship between thoracic expansion determined at the axillary level and heart rate was highlighted.

Conclusions: This work revealed age- and sex-related differences in chest expansion, as well as the influence of a few parameters of interest. However, the data obtained deserve verification and validation by larger studies at the national level before possible popularization.

Keywords: Thoracic expansion, Congo-Brazzaville, School child, Assessment methods, Respiratory muscles, Thorax

INTRODUCTION

The measurement of thoracic expansion is used throughout the world on the one hand as a clinical sign in pulmonology and rheumatology, in the diagnosis and monitoring of the progression of the disease; and on the other hand as a measure of response to treatment in rehabilitation medicine.[1-5] It can also provide important information about the lung capacity and respiratory efficiency of adolescents, which are essential for their overall well-being and physical performance.[6] Recent research indicates that growing adolescents exhibit substantial variations in respiratory mechanics, which may influence baseline values for chest expansion.[7] This variability highlights the importance of having accurate and age-specific data to properly assess respiratory health and detect potential abnormalities.[8]

The development of the thorax in children follows a normal distribution. However, studies on the determination of reference values in children are inconclusive. For this reason, the lack of established standards for chest expansion in adolescents aged 7 to 12 years complicates the assessment of respiratory function and the monitoring of thoracic growth. In addition, while reference values have been established for adult populations and some pediatric populations, there is a lack of specific data for adolescents aged 10 to 12 years, a period of development marked by rapid changes in the size and shape of the rib cage.[9] Inadequate reference values can lead to errors in the assessment of respiratory health and physical development, thus affecting medical management and preventive interventions. Hence the need to establish reliable reference values for chest expansion in Congolese children aged 7 to 12 years, based on local experimentation, integrating the various factors associated with thoracic expansion.

In addition, ventilation affects cardiovascular function. This is because the pulmonary system and the heart are in the same chest cavity and become subject to intrathoracic pressure changes. Chest expansion is generated when the lungs inflate and compress the heart where they are in a closed chest cavity. The expansion of the thorax thus affects cardiac output, diastolic and systolic pressures. While studies objectifying these correlations are found in the literature, there is a lack of African data, particularly Congolese data.[10-13] Hence the initiation of the present study, which attempts to answer the following questions: What are the reference values for chest expansion in Congolese children aged 7 to 12 years? What is the impact of chest expansion on aerobic capacity, heart rate, and blood pressure?

To answer these questions, we hypothesize: 1) an increase in chest expansion values is observed in girls and boys aged 7 to 12 years; 2) boys have a more marked thoracic expansion than girls; 3) the increase in thoracic expansion with age improves heart rate, blood pressure and aerobic capacity.

The general objective of the study is to determine the profile of chest expansion values in Congolese children aged 7 to 12 years. In carrying out this work, we have set ourselves the following specific objectives: 1) to describe the profile of thoracic expansion of boys and girls aged 7 to 12 years in school as a function of age; 2) to investigate the link between thoracic expansion and anthropometric variables (height, weight, BMI) in these children; 3) to determine the link between chest expansion thoracic and heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP); 5) to determine the relationship between thoracic expansion and maximum oxygen consumption (VO_{2max}).

METHODS

Type, time period and setting of the study

The observational and cross-sectional study was carried out from November 7, 2024 to June 12, 2025 in Brazzaville, the capital of the Republic of Congo, which has nine boroughs. However, only seven boroughs were selected by random draw without discount due to the lack of funding for our research.

Population and sample

Population

The target population was made up of public elementary school school children in the seven school inspection facilities associated with the seven selected boroughs. During the study period, these districts had 162 public sector elementary schools with a total enrolment of 91384 school children. After discussions with the authorities of each inspectorate in the school district, the number of 94 primary schools with an enrolment of 68053 school children was decided taking into account their location and security conditions.

Sample

The theoretical sample size was set at 3500 school children (500 per school district) for convenience. This choice was adopted in order to include a large number of subjects, in order to minimize the effect of confounding factors and to avoid biases in the interpretation of certain values in the study groups. The study sample size by school district was determined using a 2-stage cluster survey, stratified by gender and educational attainment. To do this, a selection of classes was made by drawing 1/3 per level of study. In practice, in the 94 primary schools selected, 34271 pupils were selected: 15684 (45.8%) boys and 18587 (54.2%) girls. However, the inclusion criteria for the study were: being free of chest or spinal deformity; have parental consent; be regular in classes. The age of the student was calculated as the difference between the subject's age on the day of the survey and the date of birth, so it was determined as a decimal number. The non-inclusion criteria were:

showing symptoms of respiratory pathologies; have a history of cardiorespiratory pathologies; have had a respiratory tract infection (upper or lower) or malaria less than 3 weeks ago; have a major respiratory disease (birth defects, destructive type of pneumonia); be asthmatic or have recurrent asthma (3 or more episodes); have a history of thoracic surgery; have a systemic disease that is thought to directly or indirectly influence the respiratory system; be on medication for a respiratory pathology. Exclusion criteria were: low birth weight for 11-year-olds; be a resident of the other two school districts of Brazzaville not included in this work; be Congolese of non-Bantu origin; be of unknown ethnic origin or of a different ethnic origin from the parents. Finally, 3745 school children (2023 boys and 1722 girls; sex ratio: 1.2) participated in the study.

Experimental procedure

Classes at the primary school in Brazzaville are taking place in two periods of study in accordance with official guidelines: the first wave of school children attends between 7:00 and 12:00 in the morning (Period A) and the second period B between 12:00 and 17:00. Four types of measurement have been retained: anthropometric measurements (height, weight); measurements of thoracic expansion, based on those of the thoracic perimeter; hemodynamic measurements (resting heart rate and blood pressure); measurements of maximum oxygen consumption. The height was measured using a STANLEY measuring rod (precision: 1cm by default), with wall mounting and equipped with a movable square slider. Body mass (or body weight, P) was measured on subjects wearing light clothing, using a Tanita BC-545N-Japan brand medical impedance meter scale, for intensive use, (accuracy: ±0.5kg by default), calibrated regularly and verified annually by an approved certifying body. Subsequently, the body mass index was calculated from the relationship:

$$BMI\ (kg/m^2) = Weight\ (kg) / [Height\ (m)]^2$$

The thoracic circumference was measured using a tape measure, in two anatomical markers during maximum inhalation and exhalation in accordance with the recommendations noted in the literature.[14,15] Marker 1 (measurement site 1) was the line from the underside of the armpits, passing over the level of the nipples. The perimeter measured is the axillary perimeter. Marker 2 (site 2 of measurement) was the process (or xiphoid appendage) of the sternum. The perimeter measured is the xyphoid perimeter. Measurements were taken for each subject, in a standing position, with the arms at the sides of the body, the trunk and chest uncovered (torso not inflated).

Instructions: Participants were asked to exhale completely, empty the lungs completely, then participants were asked to exhale completely, empty the lungs completely, then inhale deeply to the vital capacity, and finally exhale completely. If subjects did not comply with the breathing instructions, they were to be excluded. The experimenter performed a measurement of upper chest expansion (axillary perimeter) and then a measurement of lower thoracic expansion (xiphoid perimeter) consecutively, holding the tape measure at both ends with the thumb and index finger around the subject's body. The tape measure was tight, but not very tight. Thoracic expansion (in centimeters) was obtained by subtracting the inspiratory perimeter from the expiratory perimeter, according to each of the anatomical markers mentioned above:

$$\text{Thoracic Expansion (in cm)} = \text{Inspiratory Thoracic Perimeter} - \text{Expiratory Thoracic Perimeter}$$

Instructions were given to the subjects and the procedure was demonstrated to ensure that the subjects had an adequate understanding and reproducibility of the measurement process. Measurements were performed by a single investigator. The data were classified by sex, age and then into two age groups: 7-10 years and 11-12 years. Three tests were carried out at each measurement site, and the best performance of the three measurements was selected. As far as the measurement of the child's heart rate is concerned, the auscultation of the heartbeat was carried out with a stethoscope by a paediatrician. Blood pressure was measured using a blood pressure monitor. The size of the paediatric cuff has been adapted to the child's upper arm. Its width must have covered 75% of the upper arm. The children were invited to sit down and relax their arms. The cuff was positioned about 3 fingers, or 2.5 cm from the antecubital fold. The examiner's index and middle fingers were placed on the radial artery, and then the bulb was operated until the pulse disappeared on palpation. After the pulse disappeared, the cuff was slowly emptied. A stethoscope was placed on the brachial artery and the bulb was pumped until the pulse disappeared. Measurements were taken 3 times on each arm at the radial artery plus 30 mmHg. The measurements were carried out by the same paediatrician. As for the maximum oxygen consumption of the children, it was determined indirectly from the half-Cooper test (6-minute race), an event carried out around an athletics track traced by the organizers of the study. In the playground of the selected primary school. Maximum aerobic speed (MAS) is calculated by dividing the distance traveled by 100. From this value, the maximum oxygen consumption is determined using the formula:

$$VO_{2max}\ (ml/kg/min) = (3.5 \times MAS) + 13.8$$

The VO_{2max} in relation to the subject's weight P is obtained by the relationship:

$$VO_{2max}\ (l/min) = \frac{VO_{2max}\ (ml/kg/min) \times P\ (in\ kg)}{1000}$$

where P is the subject's body mass.

An explanatory letter and a written consent form were given to the schoolchildren and were completed by the parents/guardians. The anthropometric measurements of the study participants were carried out in the selected institution in the following order: height, weight and thoracic circumference. These measurements were carried out in one morning for each subject. As for the half-Cooper test, it was carried out after the anthropometric measurements, in the morning between 8 and 10 a.m. regardless of the wave of studies (A and B).

Statistical analysis

Statistical analyses were performed using SPSS software version 25.0 (IBM, Armouk, New York). The data are presented as means with standard deviations and their ranges. The dependent variable (to be explained) studied was thoracic expansion. The independent variables (= explanatory) were gender (boy/girl), age, height, BMI, heart rate, blood pressure and maximal oxygen consumption. Student's t-test was used to compare two means while the analysis of variance (ANOVA) was used to compare six means. HR and blood pressure data, which do not follow the normal distribution, were statistically compared between boys and girls, 7-10 years old and 11-12 years old using the nonparametric Mann-Whitney U test. Pearson r-coefficients were calculated to assess correlations between chest expansion measurements (lower and upper, separately) and some anthropometric parameters (age, height, BMI), heart rate and blood pressure (systolic blood pressure, diastolic blood pressure), and maximal oxygen consumption (absolute and weight-related). The relationship was considered as follows: very strong if $r>0.80$; strong if r is between 0.41 and 0.60; low if r is between 0.21 and 0.40 and very low if $r<0.21$. The significance level of all tests was set at $p<0.05$.

Ethical considerations

The study was approved by the Institutional Ethics Committee of the Higher Institute of Physical Education and Sports. Written informed consent was obtained from parents based on the Good Clinical guidelines of the Declaration of Helsinki.

RESULTS

Anthropometric characteristics

the mean values (±SD) of age, height, weight and body mass index for boys and girls by age are summatized in Table 1. The mean height of boys increased non-significantly with age, from 1.16 m at 7 years of age to 1.35 m at 12 years of age. The mean height of girls also increased with age, from 1.21 m at age 7 to 1.39 m at age 12. The boys' body mass increased steadily and significantly from 7 to 10 years of age, from 20.53 kg to 30.15 kg. Subsequently, there was a slight decrease of -1.10 kg (or 3.6%) between 10 and 11 years of age, then an increase of +4.2 kg (or 14.5%). The weight difference between 7 and 12 years is 12.67 kg (+12.7%).

Table 1: Means and standard deviations of height, weight and body mass index for boys and girls.

	Boys (n=2023)	Girls (n=1722)
Age (years)	10.21±2.33	10.32±2.17
Height (m)	1.26±0.54	1.30±0.39
Weight (kg)	27.41±3.10	29.42±4.54
BMI (kg/m2)	17.00±0.18	17.30±0.27

Abbreviation: BMI, Body Mass Index

The girls' body mass also increased significantly ($p<0.001$) with age. At 12 years of age, the weight differences were more marked than at 7 years of age: 41.8 kg versus 14.4 kg. As far as the body mass index is concerned, a regular increase was observed between 7 and 9 years, from 15.12 kg/m^2 at 7 years of age to 17.5 kg/m^2 at 9 years of age. Subsequently, a decrease was noted from 9 to 11 years and then an increase from 11 to 12 years. The BMI difference between 7 and 12 years was significant ($p<0.001$), equal to 2.91 kg/m^2 (+19.2%).

BMI increased steadily and significantly ($p<0.001$), from 13.93 kg/m^2 at 7 years to 19.42 kg/m^2 at 12 years. The differences between minimum and maximum BMI values from 7 to 12 years were variable: 15.17 kg/m^2 at 7 years, 14.49 kg/m^2 at 8 years, 20.11 kg/m^2 at 9 years, 15.47 kg/m^2 at 10 years, 18.11 kg/m^2 at 11 years, and 19.81 kg/m^2 at 12 years.

Rib cage perimeter data

On expiry

Table 2 compares the values between the axillary perimeter of the rib cage and the xiphoid perimeter at expiration in boys by age. No significant differences were observed between the values of the axillary and xiphoid perimeters of the rib cage. However, the values noted at the axillary level were higher than those recorded at the xiphoid level. The comparison of the values of the axillary and xiphoid perimeters of the rib cage at the expiration of the girls is the subject of Table 3. No significant differences were observed between the mean values of the axillary and xiphoid perimeters, regardless of age.

Inspiration

Table 4 compares the mean values of the axillary and xiphoid perimeters of the rib cage at inspiration in boys by age.

Table 2: Comparative results of the values of the axillary and xiphoid perimeters of the rib cage at expiration in boys of different ages.

Age (years)	N	Axillary	Xiphoid	P value
7	301	61.21±7.82	59.10±7.53	NS
8	336	61.42±7.83	58.21±7.59	<0.05
9	392	64.47±8.02	61.31±7.75	<0.05
10	308	66.15±8.13	63.05±7.94	NS
11	357	66.15±8.13	62.47±8.34	<0.05
12	329	69.36±8.32	65.89±8.11	<0.05

Abbreviation: NS, no significant difference

Table 3: Comparative results of the mean values of the axillary and xiphoid perimeters of the rib cage at expiration in girls of different ages.

Age (years)	N	Axillary	Xiphoid	P value
		X±S (cm)	**X±S (cm)**	
7	294	58.80±7.66	56.80±7.53	NS
8	273	59.50±7.71	57.70±7.59	NS
9	259	62.05±7.87	60.15±7.75	NS
10	308	65.85±8.11	63.10±7.94	NS
11	252	68.10±8.25	66.20±8.34	NS
12	336	68.50±8.27	69.65±8.13	NS

Abbreviation: NS, no significant difference

Table 4: Comparative results of rib cage perimeter values at inspiration versus measurement sites in boys of different ages.

Age (years)	N	Axillary	Xiphoid	P value
7	301	63.21±7.95	60.57±7.70	NS
8	336	63.73±7.98	60.36±7.76	<0.001
9	392	66.73±7.16	63.57±7.97	<0.001
10	308	68.68±8.28	65.52±8.09	NS
11	357	68.84±8.29	65.57±8.09	<0.001
12	329	72.15±8.49	68.52±8.13	<0.001

Abbreviation: NS, no significant difference

Table 5: Comparative results of the mean values of the axillary and xiphoid perimeters of the rib cage at inspiration in girls of different ages.

Age (years)	N	Axillary	Xiphoid	P value
7	294	60.25±7.76	58.40±7.64	NS
8	273	61.53±7.83	59.45±7.71	NS
9	259	63.75±7.98	61.25±7.82	NS
10	308	67.90±8.24	64.70±8.04	NS
11	252	70.55±8.39	67.85±8.23	NS
12	336	70.85±8.41	68.15±8.25	NS

Abbreviation: NS, no significant difference

The application of ANOVA has shown that the measurement site has no influence on the values of the rib cage perimeter in our boys, regardless of age. Comparison of the mean values of the axillary and the xiphoid perimeters of the rib cage at inspiration in girls is shown in Table 5. No statistical difference was observed between the mean values of the axillary and the xiphoid perimeters of the rib cage. However, the values of the axillary perimeter were higher than those of the xiphoid perimeter, regardless of age.

Chest expansion data

The mean, standard deviations and ranges of calculated chest expansion from axillary level in boys and girls aged 7 to 12 years are reported in Table 6. The application of ANOVA shows that the thoracic expansion determined at the axillary level increased significantly (p<0.001) from 7 to 12 years, the difference being 0.79 cm (or 28.3%). The evolution of thoracic expansion from 7 to 12 years of age fluctuated, with four phases: an increasing phase from 7 to 8 years, decreasing from 8 to 9 years, increasing from 9 to 10 years and then decreasing from 10 to 12 years. The peak of chest expansion was noted at 12 years of age, with mean values of 2.79 in boys and 2.45 cm in girls, a difference of 0.34 cm (12.2%). The analysis of the perceived differences between boys and girls according to age reveals significant differences (p<0.001) except at 9 years of age, with the higher values being found in boys regardless of age. The mean, standard deviation and range values of chest expansion calculated relative to xiphoid level in boys and girls aged 7 to 12 years are shown in Table 7.

Table 6: Mean values, standard deviations and ranges of chest expansion in relation to the axillary level in boys and girls of different ages.

Age (years)	Boys			Girls			P value
	N	X±S (cm)	Range	N	X±S (cm)	Range	
7	301	2.00±0.13	2-3	294	1.45±0.10	1-2	<0.001
8	336	2.26±0.14	2-3	273	1.70±0.11	1-2	<0.001
9	392	2.31±0.15	1-2	259	2.03±0.12	2-3	<NS
10	308	2.53±0.13	2-3	308	2.05±0.13	2-3	<0.001
11	357	2.69±0.16	2-3	252	2.35±0.14	2-3	<0.001
12	329	2.79±0.17***	4-5	336	2.45±0.14	2-3	<0.001
F(ANOVA);P		F=77.03;P<0.001			F=1.24;NS		

Abbreviation: NS, no significant difference, ***, p<0.001

Table 7: Mean values, standard deviations and ranges of chest expansion compared to xiphoid level in boys and girls of different ages.

Age (years)	Boys			Girls			P value
	N	X±S (cm)	Range	N	X±S (cm)	Range	
7	301	1.47±0.02	1-3	294	1.10±0.11	1-3	<0.001
8	336	2.15±0.14	2-3	273	1.60±0.12	1-1	<0.001
9	392	2.26±0.14	2-2	259	1.60±0.07	1-0	<0.001
10	308	2.47±0.15	1-2	308	1.75±0.10	1-2	<0.001
11	357	3.10±0.19	2-3	252	1.80±0.11	0-1	<0.001
12	329	3.26±0.14***	2-3	336	1.95±0.12	2-2	<0.001
F(ANOVA);P		F=995.43;P<0.1			F=0.011;NS		

Abbreviation: NS, no significant difference, ***, p<0.001

Table 8: Data on chest expansion at the axillary and xiphoid levels in children in each age group by sex.

	7-10 years		11-12 years		P value
	N	X±S	N	X±S	
Axillary					
Boys	1337	2.27±0.15	686	2.74±0.16	<0.001
Girls	1134	1.81±0.11	588	2.40±0.14	<0.001
Xiphoid					
Boys	1337	1.80±0.10	686	2.12±0.16	<0.001
Girls	1134	1.51±0.10	588	1.87±0.11	<0.001

The evolution of thoracic expansion compared to the xiphoid level also followed the same trend, with the difference between 7 and 12-year-old boys being 1.79 cm (or 54.9%). Thoracic expansion progressed irregularly, with two increasing phases (7 to 8 years, 9 to 12 years) and one decreasing phase (8 to 9 years). The deviation in chest expansion in 7 and 12-year-old girls was 0.35 cm. Comparison of the mean values of chest expansion of boys with respect to axillary and xiphoid levels, using the student's test, revealed significant differences between the values of thoracic expansion noted between the 2 measurement sites; the higher values were found at the 1 to 7-year-old site, 8 years, then 10 years; conversely, those noted on site 2 were greater than 10 and 11 years old. For girls, all values of thoracic expansion determined at the axillary level were significantly higher than those for the xiphoid level, regardless of age.

The differences were 31.8% at 7 years, 6.2% at 8 years, 26.9% at 9 years, 17.1% at 10 years, 30.5% at 11 years and 25.6% at 12 years, respectively. The mean values with standard deviations of chest expansion for children in each age group by sex are reported in Table 8. The chest expansion values noted in children in the 11-12-

year age group were significantly (p<0.001) higher than those in 7-10 years old, regardless of sex and measurement level.

Hemodynamic and maximum oxygen consumption data

The mean values of heart rate, systolic blood pressure, diastolic blood pressure, and maximum oxygen consumption are shown in Table 9.

Analysis of the association between thoracic expansion and some parameters of interest

The results of the correlation analysis between chest expansion and some anthropometric parameters, hemodynamics and maximal oxygen consumption in boys and girls are presented in Table 10.

Age was positively and significantly (p<0.001) correlated with chest expansion determined in relation to the axillary level in children of both sexes, and in relation to the xiphoid level in boys. Regarding anthropometric parameters, height was positively associated with thoracic expansion at the axillary and xiphoid levels in boys, and at the axillary level in girls. The AT-BMI association was significant only compared to the data for the axillary and xiphoid levels in boys and the xiphoid level in girls. In addition, there was a negative and close association between heart rate and chest expansion determined in relation to the axillary level, regardless of sex. Finally, a positive and strong association between AT and VO_{2max}, both absolute and weight-related, was demonstrated in boys and girls regardless of the level of thoracic circumference measurement.

Table 9: Means and standard deviations of resting heart rate, systolic and diastolic blood pressures, and maximal oxygen consumption in boys and girls.

	Boys	Girls	P value
HR (bpm)	130±7	134±5	>0.05
SBP (mmhg)	124±8	130±4	<0.05
DBP (mmhg)	114±6	126±7	<0.05
VO_{2max} (ml/kg/min)	96±7	94±6	>0.05
VO_{2max} (l/min)	81±8	76±8	>0.05

Table 10: Correlation coefficients (r) between chest expansion and selected parameters of interest in boys and girls.

	Boys (n=2923)		Girls (n=1822)	
	Axillary	Xiphoid	Axillary	Xiphoid
Age (years)	0.482**	0.437**	0.412**	0.388
Height	0.474**	0.398*	0.495*	0.372
BMI	0.421**	0.405**	0.422*	0.353
HR (bpm)	-0.132**	-0.312	-0.434**	-0.231
SBP (mmhg)	-0.031	-0.018	-0.037	-0.014
DBP (mmhg)	+0.17	0.135	0.022	-0.147
VO_{2max} (ml/kg/min)	0.658***	0.503***	0.535***	0.296**
VO_{2max} (l/min)	0.102	0.094	0.071	0.083

Abbreviations: BMI, body mass index; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; VO_{2max}, maximum oxygen consumption; **, strong bond at p<0.01; *, strong bond at p<0.05.

DISCUSSION

Whole data

The present study, which aims to determine a specific profile of chest expansion in the school population aged 7 to 12 years in Brazzaville, included 3745 schoolchildren (2023 boys and 1722 girls). The main results obtained have highlighted: an increase in the axillary and xiphoid perimeters of the rib cage with age, both at the exhalation and at the maximum inspiration; at maximum expiration, a superiority of the values of the axillary perimeter of the rib cage compared to those of the xiphoid perimeter in boys, regardless of age. However, significant differences (p<0.05) were only noted at the 8, 9, 11 and 12 years. As far as girls are concerned, while this superiority remained (except at 12 years of age), the differences were not significant; at maximum inhalation, a superiority of the values of the axillary perimeter of the rib cage compared to that of the xiphoid perimeter, found in boys regardless of age. However, significant differences were only noted at 8, 9, 11 and 12 years. As for girls, the superiority of the values of the axillary perimeter of the rib cage was noted at all ages, with non-significant differences between the axillary perimeter and the xiphoid perimeter; an increase in thoracic expansion determined at the axillary and xiphoid levels with age in boys. On the other hand, in girls, three phases of evolution of thoracic expansion were observed: an increase between 7 and 8 years of age, a decrease from 8 to 9 years of age, then an increase beyond 9 years of age; a superiority of thoracic expansion determined at the axillary level from 7 to 10 years of age in boys, the difference being significant at 7 years. On the other hand, the thoracic expansion determined at the xiphoid level was significantly higher ($p<0.001$) at 11 and 12 years of age. In girls, the superiority of the values of thoracic expansion determined at the axillary level was not found until the age of 8; a significant superiority ($p<0.001$) of chest expansion values in subjects aged 11-12 years compared to those noted in those aged 7-10 years, regardless of the site of measurement of the perimeters; a positive and significant correlation ($p<0.001$) between age and thoracic expansion determined at the axillary level in both sexes, but only in boys at the xiphoid level; a positive and significant link ($p<0.001$) between BMI and chest expansion in boys; a strong negative association ($p<0.001$) between heart rate and chest expansion determined at the axillary level in both sexes; a positive and close link ($p<0.001$) between absolute VO_{2max} and thoracic expansion determined at the axillary level in both sexes; at the xiphoid level, it remained positive and close in boys, strong in girls.

However, the interpretation of chest expansion values varies; values from other populations, as reported in the literature, cannot be extrapolated, as the lungs are known to be different depending on the ethnic, racial, and geographic origin of the subjects. Also, if the mean thoracic expansion determined at the axillary level is 2.48±0.14 cm in boys and 2.00±0.12 cm in girls in our series. Tonguino-Rosero et al (2025) in Colombia report higher values: 3.82±1.2 cm in boys and 2.53±1.1 cm in girls. However, even though the measurements were made at the axillary level, the authors used cirtometry as a measurement technique. Soman et al (2022), in 600 Indian children aged 5 to 12 years, report chest expansion values ranging from 2.50±0.1 cm to 4.25±0.28 cm using the same measurement technique as us. Finally, Derasse et al (2021), in their study on the correlation between chest expansion and lung function, note an mean value of 3.82±1.14 cm in Belgian children aged 8 to 12 years in boys and 2.99±1.05 cm in girls.

Regarding the impact of the measurement site on the value of the TA, the mean value of thoracic expansion at the axillary level is higher than that found at the xiphoid level, regardless of sex. This difference may be explained by the fact that the major respiratory muscles, the external and internal intercostal muscles, and the diaphragm in the chest wall, construct the rib cage.[16] Indeed, the expansion of the thorax at the axillary level is limited by the costal bone, with the exception of the lower thorax where no bone is placed.

Chest expansion and age

In the present study, thoracic circumference and thoracic expansion increase steadily with age. This evolution could be explained by the predominance of the apical respiratory pattern generally observed at these ages.[17] This is likely due to better control of the external intercostal muscles compared to the diaphragmatic muscles. During this period of maturation of the respiratory system, total control of these muscles is not achieved during maximum inhalation.[17] According to De Cordoba Lanza et al, this phase leads to changes in size, shape, physiology and growth rate, indicating that our children should benefit from a different approach to determining thoracic expansion than that used in adults.[18] In addition, our results show that thoracic expansion at the axillary level is higher than that of the xiphoid level in both sexes regardless of age. Apical breathing is essential in the 7-12 age group: the respiratory system, diaphragm and breathing mode are not fully developed in this age group. The orientation of the coasts changes with age in this population. The ossification of the ribs is completed with age in parallel with the elongation of the ribs and the development of costal cartilage. Finally, the thoracic expansion of children in the 11-12 age group is significantly higher than that of 7-10 years old in the workplace. An explanatory factor is related to the bodily changes marking the beginning of the pubertal maturation process. During the period of 11-12 years, hormonal changes can directly influence lung function: first, through growth spurts followed by an increase in trunk length and rib cage diameter, which influence the increase in thoracic expansion.

Chest expansion and gender

Our observations report significant differences between boys and girls with regard to chest expansion values, with higher values noted in boys. These gender differences have already been described. Indeed, Mehan et al showed differences in their study on the relationship between respiratory function and rib cage morphology.[19] The lean mass, which is reputed to be greater in boys, influences thoracic mechanics and the participation of the diaphragm in breathing, and therefore in the increase of thoracic expansion. Finally, total fat with its various compartments, in particular visceral fat and subcutaneous adipose tissue, contribute to the restriction of thoracic expansion, by the mechanical stress exerted on the thorax and which limits its compliance during exhalation and inhalation.[17]

Thoracic expansion and anthropometric variables

Among the anthropometric variables (height, BMI), height, in our study, is the one that most influences thoracic expansion in children. These observations corroborate those of Kale et al, who analyzed the thoracic mobility of 91 healthy Indian school-going children, aged 7-11 years.[20] However, Malegaonkar et al, in 229 boys and 226 girls aged 6 to 15 years and living in India, also found a negative correlation between thoracic circumference and height in women.[21] According to these authors, in adolescence, the relationship between lung function and height is no longer linear, as the increase in height is mainly due to the lengthening of the legs and less to the increase in the length of the chest. A positive correlation between chest expansion and BMI was observed in this work. This can be explained by an increase in lean body mass in this age group, even if this was not objectified in our study. Indeed, the growth of children is accompanied by an increase in lean mass, which translates into an increase in thoracic circumference.[22] In addition, lean mass, represented in particular by muscles, exerts a strengthening action on the respiratory muscles, as described by Intolo et al Mikael and Levitzky, showed that with age, muscle mass developed at the expense of body fat would have a beneficial effect on the compliance of the thorax during breathing.[23,24]

Thoracic expansion and hemodynamic variables

Examination of the relationship between chest expansion and heart rate shows a significant negative correlation between axillary chest expansion and heart rate in children of both sexes ($r = -0.532$; $p<0.01$ in boys; $r = -0.434$; $p<0.01$ in girls). Interpretation of the negative correlation coefficient between chest expansion and HR means that significant chest expansion leads to a slowing of heart rate. This is because the heart is located in the upper thorax, at the fifth spinous process of the thoracic vertebrae and the third intercostal space in the midclavicular line.[25]

In addition, an earlier study showed that an increase in pleural pressure affects both diastolic and systolic pressure.[26] It is known that pleural pressure increases during breathing and can be measured by chest expansion. Nevertheless, our study reveals that blood pressure is not correlated with diastolic and systolic pressures. However, the literature suggests that increases in blood pressure, as well as increases in HR, stroke volume, blood viscosity, and peripheral resistance, are among the many factors influencing pleural pressure.[25] If any of these factors change, blood pressure will also change and remain as normal as possible. Blood pressure usually varies in response to variations in cardiac output. An increase in cardiac output leads to an increase in blood pressure in accordance with the relationship below.[25]

$$\text{Cardiac output} = \text{Stroke volume} \times \text{HR}$$

Finally, blood pressure in children is influenced by physical activity, body mass, gender, and energy consumption.[27,28]

Relationship between chest expansion and maximum oxygen consumption

A positive and strong correlation was noted between chest expansion and absolute VO_{2max} in children regardless of sex and measurement site. This observation, which corroborates the data in the literature, shows that thoracic expansion is an essential but indirectly limiting element of VO_{2max}.[18-29] This is because VO_{2max} is primarily determined by the overall ability of the cardiorespiratory system to transport and use oxygen. However, good chest expansion is essential for the effectiveness of the first step in this process: the supply of air to the lungs. Thoracic expansion, made possible by the contraction of the inspiratory muscles (especially the diaphragm and intercostal muscles), increases the volume of the lungs, creating a negative pressure that draws in outside air. Thus, an efficient chest movement maximizes the volume of air inhaled (vital capacity). The greater the volume of air inhaled, the greater the amount of oxygen available for gas exchange in the pulmonary alveoli. Thus, limited chest expansion reduces the amount of oxygen that can enter the system, which can become a limiting factor in the maximum oxygen consumption.

Limitations and strengths of the study

However, the interpretation of our results must take into account certain limitations. First, although several authors have proposed different methods for measuring thoracic circumference, but there is still no consensus on its use.[30] In 2005, Basso et al proposed to determine thoracic mobility solely by indices of expansion and reduction of the chest wall in the axillary and xiphoid regions.[31] Later, Malaguti et al, recommended the use of the Thoracic Mobility Index, calculated as the difference between maximum inhalation and total lung capacity and maximum exhalation to residual volume.[30] In addition, Bockenhauer et al, proposed the use of the amplitude index (AI), which takes into account the highest value of 3 measurements and is integrated into a specific equation in order to account for individual anthropometric differences.[32] These authors considered that the normal AI values are between 2 and 3.5 in children and adolescents. Despite these discrepancies, thoracic circumference is commonly used in physiotherapy to quantify thoraco-abdominal mobility and is considered an accurate measure, with good intra- and inter-observer reliability.[11-33] However, it is necessary to take into account the possibility of intra- and inter-observer variability, a problem that can be observed when measuring thoracic circumference.

Second, the other limitation of our study concerns the relatively small size of our sample (N=3745). Elsewhere, da Silva et al, in Brazil report a height of 166 healthy children of comparable age, Wandini et al (2016) in Indonesia 96 children aged 6 to 15 years.[11-13] Third, the study was conducted in a single city in Congo and in a single district. This may compromise its external validity and the interpretation of the results. Fourth, the cross-sectional nature of the study allows only for a temporal snapshot. Conducting a longitudinal survey would have been better suited to determining the baseline profile of thoracic expansion. Fifth, the interpretation of the results is hampered by the scarcity of studies in Africa, particularly their absence in the Bantu environment, but also by the lack of standardization in the literature of the thoracic cirtometry technique, as well as disagreements on how to interpret the values obtained in the assessment of thoracic expansion. However, these limitations do not totally affect the power of our observations. This study, which is part of one of the research themes in health and sports sciences in Congo, is in any case, the first of its kind in our field, by looking for the usual factors that influence chest expansion such as age, sex, height, BMI and heart rate. The measurement protocols respected a certain regularity. Finally, the present study provides a database that can be used in the monitoring of school children in sports activities, even if the inclusion of a larger number of subjects is essential. Validation of these data by surveys across the country could allow them to be used in schools and medical settings.

CONCLUSION

The aim of this study was to determine the profile of chest expansion values in Congolese children aged 7 to 12 years. In the light of the data obtained which confirm our working hypotheses, it can be concluded that our data confirm those reported elsewhere in the literature, while highlighting differences with European, American and Asian studies on the determining factors of thoracic expansion, in particular the ethnic and/or racial origin of the subjects, the geographical location. However, from a methodological point of view, it would be wise to undertake broader studies on a national scale with a view to a reliable and valid exploitation of our data. This is why other studies will need to be carried out in order to deepen our knowledge of thoracic expansion in our environment.

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