

Full length Research paper

# Growth of the limbs and their segments during childhood and adolescence: a photogrammetric study

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Accepted 29 October, 2019

A clear picture of patterns of growth for the limbs and their segments is not abundant and difficult to obtain from the literature due to different techniques used, this have confused an overall realistic composite picture for these important parameters. This study used cross-sectional and longitudinal data to establish normal variation for growth of the limbs during childhood and adolescence in both sexes, and to locate the adolescent growth spurt by calculating velocities of growth cm/year , its timing, intensity, and its relationship to that for height and sitting height. The extent to which the length of upper and lower limbs may vary in relation to each other, and to the trunk irrespective of age was presented (Bivariate analysis). All limb segments share in the adolescent growth spurt with some variations in its timing and intensity, lower limb is the first to peak, then stature and upper limb, sitting height is the latest, a difference of 1.2 years in boys and 0.9 years in girls. Upper limbs stop growing 0.25 years after lower limbs. There was no significant differences in timing of peak velocity between proximal and distal segments within the same limb. Girls stop growing in their lower limbs earlier than boys by two years, but they continue to grow in their trunk length, so that adult women have larger trunks than men for a given height . 65% of subjects have their right upper limbs longer, variability and magnitude of limb asymmetry is greater in children with low and high birth weight. Our data provided a clear realistic composite picture for growth of the limbs than the schematic illustrations found in the literature. Results are useful in clinical pediatrics, bivariate standards can be used in conjunction with univariate standards by age to define the exact nature of any abnormality and help in the differential diagnosis of growth disorders where body proportions are disturbed e.g. achondrplasia , growth hormone deficiency. Data can be used to improve garment industry and in ergonomics , also in sports to help coaches to select children for training in specific athletic skills which suits best their trunk / limb proportions, certain body proportions are optimal for certain athletic skills, however favorable training may be.

**Key words:** Growth of limbs at adolescence

## INTRODUCTION

During the last fifty years, the accurate assessment of physical growth of children has found increasing interests in many fields, such as pediatrics, public health, sports, physical education, ergonomics, and garment industry. The general growth curve of man has been known, Boas (1932), Tanner (1962). No two children, except identical twins grow in the same way, yet all children follow a similar course, so that the form of the curve is the same

for all, the numerical values of the measurements differ for each. At puberty, the adolescent growth spurt, occurs in all normal children triggered by the maturation of the hypothalamic – pituitary – gonadal axis and the secretion of sex hormone, Attallah (1987,2013), Dennis, Styne, Melvin, and Grunbach (2016).

Height and weight are the most common parameters studied. On the other hand, information regarding other important body segments, such as the limbs and their segments is not so abundant, Attallah (1980). The measurements of height and weight alone, by no means represent a full assessment of a Childs physical status. In pediatrics particularly endocrinology where body proporti-

ons are disturbed, measurements of the limbs and their segments, and their relation to trunk length are considered very important and help in the differential diagnosis in some growth disorders, e.g in achondroplasia, the child is dwarfed with short limbs but an almost normal trunk length, there is also little shortening of the proximal to the distal segment within the same limb. On the other hand, in growth hormone deficient children, the child is dwarfed, but trunk – limb proportions are not disturbed from those of normal children of the same size, Tanner, Whitehouse (1971).

Also there is great variation in trunk – limb proportions between individuals belonging to different ethnic groups, e.g the differences between Europeans, Africans and Japanese. Even individuals of the same height, vary widely in their limb proportions. Environmental factors such as nutrition, exercises, can only change final size, muscles increase in size by 30% as we see in body builders, but not body proportions which are genetically determined, Tanner (1964).

Accordingly, in order to make a satisfactory description of the growth status of a child, we must know not only his height and weight, but also how the length of the limbs and their segments relate to the normal range of variation. We also need to know the extent to which the length of the limbs may vary in relation to trunk length.

Paula, Alain Dimeglio (2008), calculated percentage of length reached by the lower limb relative to its final length at different ages from birth up to maturity, at birth it constitute 20 % of its final length, at puberty it is 90 %. His aim was to help in predicting final deficit whether congenital or post traumatic using multiplying factor, he also reported an increase in growth velocity for the lower limbs with onset of puberty which occur 6 months earlier than that for the trunk. Anderson, Green and Messner (1963) reported that from 6 years the lower limb increase by 3.5 cm / year, 2cm for the femur and 1.5 cm for the tibia. Cameron, Tanner, and Whitehouse (2009), reported a peak growth velocity at adolescence for all upper and lower limb segments between 1- 2.5 cm/year which is more than that obtained using cross sectional data, distal segments preceded more proximal segments at age of peak velocity. Wolport (2010) studied symmetrical growth of arms in man, he attributed limb asymmetry to different cartilage cell behavior at the growth plate of long bones before it is replaced by bone after adolescence. Garney B (2002), studied leg discrepancy and how it affects gait and posture of the individual.

A clear composite picture of the growth pattern of the limbs and their segments is difficult to obtain from the literature, due to variations in measuring techniques, datum points used, and the use of cross sectional data to estimate velocities of growth, all have confused an overall composite picture for growth patterns of these important body components.

Our main objectives were: Investigate patterns of growth for upper and lower limbs and their segments in 2

boys and girls, and to establish normal range of variation during childhood and adolescence. Study the velocity of growth for the limbs and their segments to locate the adolescent growth spurt, its timing, intensity, and its relationship to that of height and sitting height (trunk length), to have a clear realistic composite picture for these important body parameters.

Study the extent to which the length of the upper and lower limb may vary in relation to each other and to trunk length, by constructing bivariate standards for one body segment given the value of another, irrespective of age.

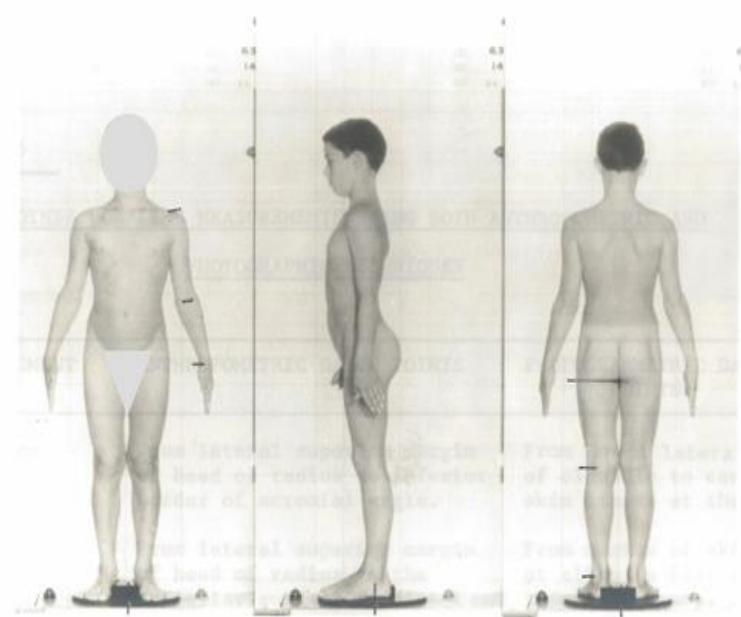
Study asymmetry in limbs.

## SUBJECTS AND METHODS

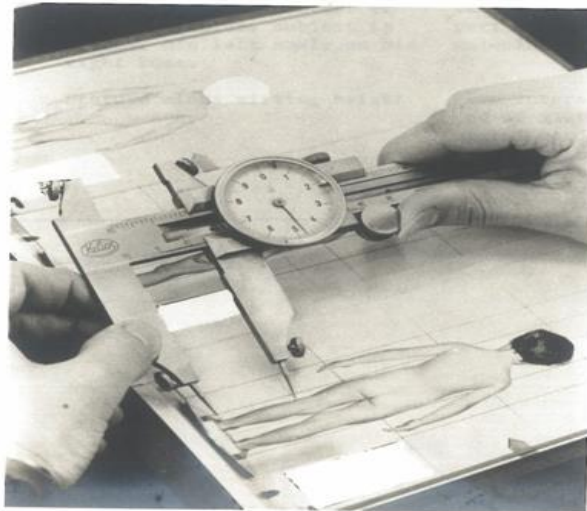
Subjects were 214 boys and 130 girls aged 3-19 years, all were healthy white British children participating in 3 longitudinal studies at the Department of Growth and Development, Institute of Child Health, London (Harpenden; International children centre; and London Family growth study), Attallah (1980). Each child was photographed under standardized condition every 6 months within 2 weeks of his / her birth day using an aerial mapping camera, Dupertuis, Tanner (1950), Marshall, Harrison(1971), figure (1A). All photographs were processed and enlarged to an exact scale at the British Royal Air Force laboratories, Tanner, weiner (1949). All limb measurement were taken on the photographs by the author using Helios Caliber, the dial of which registered in 0.05 mm, using the techniques and datum points as follows, figure 1B.

For upper limb measurement, the front view was used. Upper limb length: from lower margin of lateral end of clavicle to base of the eminence at the level of the distal skin crease of the wrist. Upper arm length: from the lower margin of lateral end of the clavicle to the centre of skin crease at the elbow. Forearm length: from the centre of skin crease at elbow to base of Tanner eminence as above. For the lower limb parameters, the rear view was used. Lower limb length: from a horizontal line through the intersection of the medial end of the gluteal fold with the medial border of the thigh to the most prominent part of the outline of the lateral malleolus. Thigh length: from the gluteal fold intersection, as above, to the intersection of the skin crease at the knee with the lower end of the shadow associated with biceps femoris tendon. Lower leg length: from intersection of skin crease and shadow, as above, to the lateral malleolus.

To convert the photogrammetric measurements to real life size, were multiplied by a constant conversion factor of 8.333. A total of 36,820 limb measurements on boys and 15,820 in girls were taken and recorded from 3-19 years. Data were processed at the University of London computer Centre. Both sides of the body were measured to study asymmetry in limbs, readings were recorded to the nearest 0.1 cm. Height and sitting height (trunk length)



**Figure 1A:** The standardized Photographic Poses, with Datum Points used to Measure Limb Segments



**Figure 1B:** Measuring the Photographs using the Helios Caliper

were recorded for each child, 212 children have their birth weight recorded.

### **Data Collection and editing**

To scrutinize our raw data, mean values for each age were examined for skewness and kurtosis, where  $p < 0.05$  non normal value, the listing for that age was checked to see whether the minimum and maximum values were correct, or were due to mismeasuring or misrecording, this resulted in the elimination of about 2% of the measurements.

## **STATISTICAL METHODS**

### **Cross – sectional analysis**

Assuming a Gaussian distribution of the data, means and standard deviations were computed for all limb measurements in boys and girls at yearly intervals from 3-19.

Since examination dates did not always fall near the children birth days, a limit of  $\pm 0.25$  years has been applied to the ages (a child aged 6 years may be any where between 5.75 and 6.24), any child outside these limits was not included.

Standard deviations were used to describe the normal range of variation for all parameters at each age.

### **Longitudinal analysis, velocity of growth**

We calculated the increments in growth from two occasions a year apart from 3-19 years in both sexes using the longitudinal data, means and standard deviations were computed at each age and plotted at the mid – interval (age centre), e.g the increment from 3-4 years was plotted at 3.5 years etc, curves were smoothed graphically.

These velocity curves gives a more realistic picture of the velocity of growth, cm/year, and locate the adolescent growth sport, its timing and intensity in all limbs.

### **Bivariate analysis**

Mean values with its standard deviations was

computed for one variable for a given interval of another irrespective of age for the following pairs of measurements in boys aged 4-19 years. Upper limb / Lower limb; upper limb / sitting height; lower limb / sitting height.

### **Limb asymmetry**

Absolute asymmetry was computed by subtracting the shorter limb from the longer, its relationship to age and birth weight was studied.

## **RESULTS**

Tables listing the data on which the curves are based are given and labeled as A.

### **Cross – sectional results, distance standards**

Figures (2A-2B), show that all limb segments displayed the general pattern of sex differences as stature, i.e the usual double crossing over at a adolescence.

In case of stature and trunk, boys are taller by about less than 1 cm till age 10.5 when the girls earlier adolescent spurt makes them taller at age 12-13.

The cross – over by boys to surpass the girls at adolescence occurred in our data at age 13 for lower limbs, and at 15 for trunk length.

This reflects the earlier spurt for the lower limbs than the trunk, as a consequence the cross-over for stature occurred at age 14.

Tables (A1-A6) lists means, standard deviations for all parameters from 3-19 years in boys and girls with numbers of subjects at each age.

Percentage of lower limb and trunk length to stature was calculated at each age in both sexes fig (3), it is clear that during childhood, lower limbs grew faster than sitting height till early teens (12-13 years), there after, sitting height increases more than lower limbs and more in girls than in boys, while lower limbs constitute more of stature in boys than in girls.

At age 16 sitting height constitutes about 54.1% in girls, and 52.7% in boys in agreement with Krogman (1970), Tanner (1962).

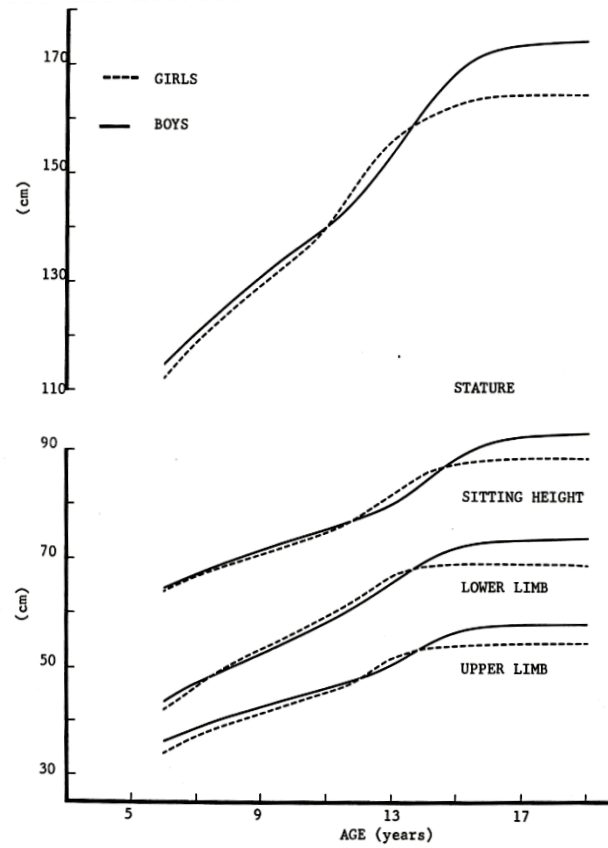


Figure 2A: Mean Distance Curves For Stature, Sitting Height, Lower Limb and Upper Limb in Boys and Girls (Longitudinal Data)

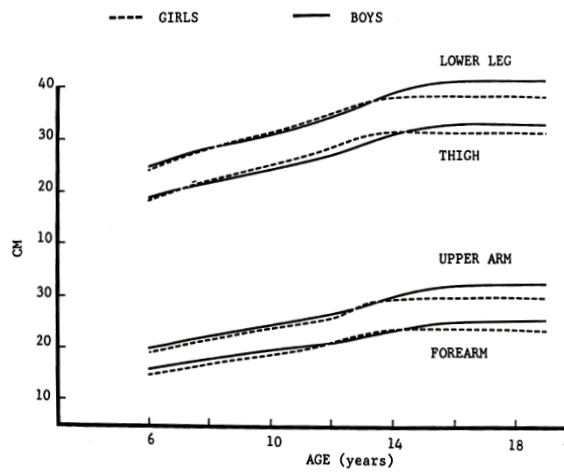


Figure 2B Mean Distance Curves for Thigh Length, Lower Leg, Upper Arm and forearm in Both Sexes

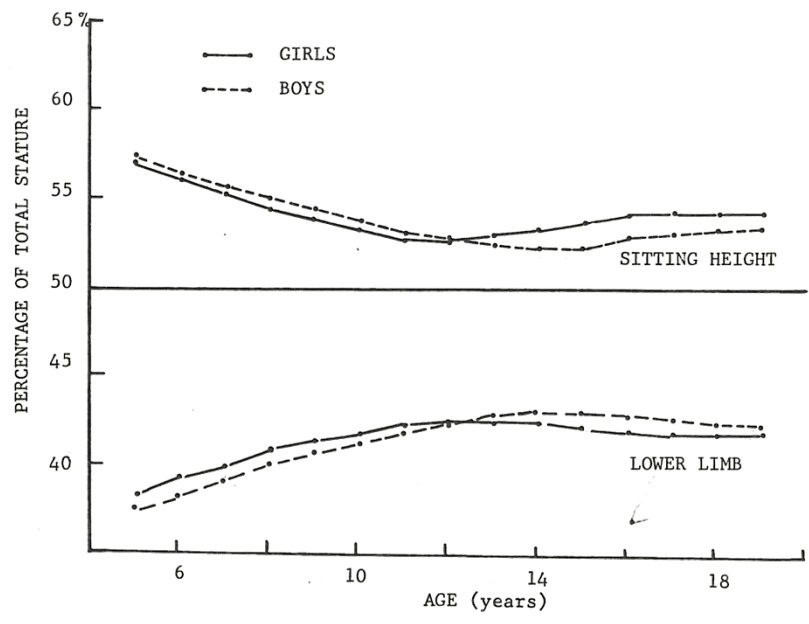


Figure 3: Percentage of Total Stature For Sitting Height and Lower Limb at yearly Intervals in both sexes

**Table A1:** Measurements in cm at each year of age – boys\_

Parameters	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
<b>Stature:</b>																	
<b>N</b>	52	91	103	113	115	125	132	137	130	132	156	153	139	111	100	73	42
<b>X</b>	95.39	102.52	109.52	115.61	121.77	127.26	132.36	137.47	141.81	146.81	153.05	159.13	165.97	169.26	172.93	173.89	174.91
<b>S.D.</b>	3.47	4.2	4.4	4.76	4.86	5.44	6.0	6.49	6.67	7.22	7.65	8.3	8.43	8.13	7.74	7.53	8.59
<b>Sitting Height:</b>																	
<b>N</b>	52	91	103	113	115	125	132	137	130	132	156	153	139	111	100	73	42
<b>X</b>	56.24	59.37	62.45	65.26	67.72	69.86	71.94	73.92	75.52	77.45	80.19	83.08	86.79	89.19	91.59	92.72	93.21
<b>S.D.</b>	2.24	2.37	2.49	2.31	2.29	2.55	2.86	2.97	2.97	3.12	3.58	4.15	4.31	4.11	3.56	3.3	3.41

\*Each age is  $\pm 0.25$  of a year e.g. age 5 signifies 4.75 – 5.25 years

Table A2: Measurements in cm at each year of age – boys

Parameters	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
<b>Upper Limb:</b>																		
<b>N</b>	26	49	81	97	103	116	130	133	128	118	149	151	126	111	99	71	41	
<b>X</b>	28.73	31.62	34.58	36.88	38.79	40.81	42.81	44.57	46.35	48.11	50.28	52.60	55.02	56.32	57.67	57.90	58.12	
<b>SE</b>	.33	.25	.21	.20	.20	.21	.21	.22	.23	.27	.24	.26	.29	.30	.31	.35	.53	
<b>S.D.</b>	1.67	1.74	1.9	1.96	2.0	2.29	2.41	2.57	2.58	2.89	2.98	3.2	3.27	3.16	3.1	2.92	3.3	
 <b>Upper Arm:</b>																		
<b>N</b>	19	42	70	93	91	110	124	125	119	116	148	149	126	111	97	70	38	
<b>X</b>	16.28	17.84	19.03	20.50	21.52	22.68	23.72	24.65	25.66	26.59	27.74	29.12	30.49	31.21	32.03	32.13	32.14	
<b>SE</b>	.23	.15	.13	.11	.12	.13	.13	.14	.14	.15	.15	.16	.17	.18	.19	.22	.31	
<b>S.D.</b>	1.02	.97	1.12	1.10	1.12	1.33	1.41	1.55	1.55	1.66	1.76	1.89	1.92	1.91	1.85	1.84	1.93	
 <b>Upper Arm:</b>																		
<b>N</b>	20	45	72	96	93	111	126	126	120	117	148	149	126	111	97	70	38	
<b>X</b>	12.34	13.92	15.22	16.26	17.09	18.02	18.92	19.77	20.57	21.33	22.31	23.28	24.36	24.90	25.55	25.64	25.56	
<b>SE</b>	.21	.12	.12	.11	.11	.11	.12	.12	.12	.13	.11	.12	.14	.14	.15	.16	.26	
<b>S.D.</b>	.92	.79	1.0	1.07	1.06	1.19	1.66	1.29	1.28	1.39	1.36	1.47	1.52	1.47	1.44	1.36	1.59	

\*Each age is 0.25 of a year e.g. 5 signifies 4.75 – 5.25 years



Table A3: Measurements in cm at each year of age – boys

Parameters	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
<b>Lower Limb:</b>																	
<b>N</b>	35	46	78	101	102	121	123	131	124	116	143	144	117	96	77	46	23
<b>X</b>	33.46	37.06	41.02	44.39	47.55	50.77	53.74	56.83	59.46	62.22	65.34	68.45	71.42	72.47	74.32	73.70	73.71
<b>SE</b>	.27	.31	.26	.24	.27	.27	.30	.31	.33	.39	.35	.37	.43	.48	.52	.70	1.04
<b>S.D.</b>	1.60	2.08	2.28	2.38	2.68	3.0	3.32	3.53	3.65	4.15	4.13	4.40	4.65	4.67	4.54	4.77	4.99
<b>Thigh:</b>																	
<b>N</b>	31	42	71	90	90	108	117	118	117	112	139	142	113	92	69	42	18
<b>X</b>	13.64	15.55	17.38	19.07	20.44	22.02	23.42	25.0	26.34	27.84	29.33	30.73	32.06	32.58	33.38	32.83	32.37
<b>SE</b>	.16	.14	.14	.12	.13	.14	.15	.16	.18	.19	.18	.19	.22	.26	.28	.35	.58
<b>S.D.</b>	.90	.91	1.19	1.17	1.27	1.47	1.57	1.78	1.94	2.03	2.12	2.20	2.35	2.48	2.30	2.28	2.46
<b>Lower Leg:</b>																	
<b>N</b>	36	50	81	95	95	109	117	120	119	113	141	142	114	92	71	44	18
<b>X</b>	19.54	21.50	23.42	25.13	28.56	30.08	31.65	32.96	34.31	35.84	37.53	39.13	39.13	39.70	40.49	40.33	40.16
<b>SE</b>	.16	.20	.15	.15	.15	.17	.19	.19	.20	.23	.21	.21	.25	.26	.35	.39	.63
<b>S.D.</b>	.94	1.41	1.37	1.46	1.51	1.8	2.06	2.1	2.15	2.43	2.46	2.56	2.69	2.53	2.98	2.62	2.66

\*Each age is  $\pm 0.25$  of a year e.g. 5 signifies 4.75 – 5.25 years

Table A4: Measurements in cm at each year of age – girls

Parameters	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<b>Stature:</b>															
<u>N</u>	23	37	38	49	78	78	79	67	69	49	41	34	31	22	25
X	96.1	103.3	109.48	116.05	120.53	126.77	131.73	136.69	143.23	150.33	154.93	158.27	161.54	162.02	163.03
SE	0.66	0.56	0.63	0.58	0.60	0.58	0.58	0.70	0.70	0.97	1.02	0.81	0.99	1.08	0.90
S.D.	3.15	3.38	3.86	4.1	5.34	5.1	5.18	5.70	5.80	6.82	6.15	4.75	5.52	5.10	4.52
<b>Sitting Height:</b>															
<u>N</u>	23	37	38	49	78	78	79	67	69	49	41	34	31	22	25
X	57.04	60.1	62.37	64.67	66.60	69.0	70.94	72.99	75.99	79.71	82.2	84.36	86.52	87.51	88.32
SE	0.37	0.32	0.37	0.35	0.31	0.30	0.30	0.38	0.39	0.51	0.58	0.48	0.59	0.60	0.59
S.D.	1.78	1.96	2.30	2.46	2.72	2.67	6.65	3.10	3.20	3.57	3.72	2.82	3.31	2.83	2.93

Table A5: Measurements in cm at each year of age – girls – each age is +.25 years

Parameters	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<b>Upper Limb:</b>															
<u>N</u>	18	36	34	48	79	79	78	65	69	48	40	33	31	23	25
X	28.66	31.57	33.88	36.28	37.92	40.27	42.20	44.02	46.31	48.98	50.59	51.89	52.95	52.75	53.24
SE	0.30	0.25	0.32	0.24	0.25	0.25	0.25	0.28	0.29	0.40	0.46	0.38	0.48	0.53	0.36
S.D.	1.27	1.48	1.84	1.69	2.18	2.25	2.16	2.22	2.41	2.73	2.92	2.16	2.66	2.56	1.81
<b>Upper Arm:</b>															
<u>N</u>	18	35	34	48	77	76	75	65	66	43	34	28	27	21	20
X	16.04	17.51	19.02	20.33	21.31	22.61	23.68	25.68	25.94	27.43	28.36	28.98	29.62	29.61	29.91
SE	0.19	0.16	0.20	0.15	0.14	0.15	0.15	0.17	0.17	0.24	0.29	0.26	0.29	0.31	0.25
S.D.	0.79	0.95	1.15	1.02	1.27	1.32	1.31	1.39	1.41	1.59	1.72	1.39	1.52	1.44	1.13
<b>Forearm:</b>															
<u>N</u>	18	35	34	49	77	76	75	65	66	43	34	28	27	21	20
X	12.45	13.88	14.76	15.83	16.56	17.63	18.45	19.27	20.30	21.46	22.19	22.89	23.29	23.11	23.36
SE	0.18	0.12	0.16	0.13	0.12	0.12	0.13	0.13	0.14	0.20	0.22	0.20	0.26	0.27	0.17
S.D.	0.74	0.68	0.94	0.91	1.02	1.08	1.1	1.01	1.12	1.29	1.29	1.05	1.34	1.23	0.76

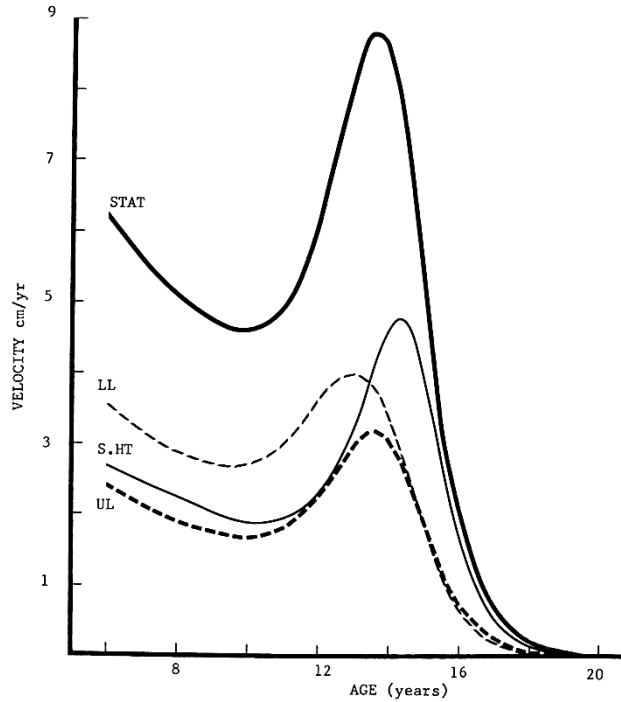
**Table A6:** Measurements in cm at each year of age – girls – each age is +.25 years

Parameters	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<b>Lower Limb:</b>															
<b>N</b>	13	32	29	47	73	75	77	62	63	42	35	28	20	20	19
<b>X</b>	34.2	38.0	42.09	45.73	47.73	51.43	54.21	57.07	60.35	63.59	65.79	66.89	68.53	67.56	68.29
<b>SE</b>	0.32	0.31	0.34	0.28	0.34	0.34	0.34	0.39	0.38	0.55	0.60	0.60	0.75	0.71	0.52
<b>S.D.</b>	1.17	1.73	1.83	1.93	2.92	2.92	2.95	3.06	2.98	3.59	3.55	3.17	3.34	3.16	2.28
<b>Thigh</b>															
<b>N</b>	13	32	29	47	72	74	77	62	59	37	29	19	18	17	15
<b>X</b>	14.36	16.22	18.35	19.99	20.94	22.62	23.89	25.14	26.74	28.38	29.66	30.42	30.90	30.71	30.76
<b>SE</b>	0.20	0.16	0.16	0.12	0.17	0.17	0.20	0.21	0.32	0.32	0.35	0.39	0.42	0.41	0.43
<b>S.D.</b>	0.73	0.91	0.86	0.81	1.44	1.48	1.51	1.59	1.62	1.94	1.88	1.72	1.76	1.71	1.65
<b>Lower Leg:</b>															
<b>N</b>	18	34	32	47	76	77	79	64	63	39	31	20	18	17	16
<b>X</b>	19.52	21.66	23.51	25.58	26.76	28.70	30.15	31.72	33.45	35.18	36.52	36.97	37.85	37.44	37.65
<b>SE</b>	0.19	0.18	0.21	0.20	0.18	0.19	0.18	0.23	0.21	0.33	0.32	0.29	0.45	0.38	0.26
<b>S.D.</b>	0.79	1.06	1.18	1.34	1.58	1.63	1.64	1.85	1.66	2.05	1.80	1.28	1.91	1.56	1.05

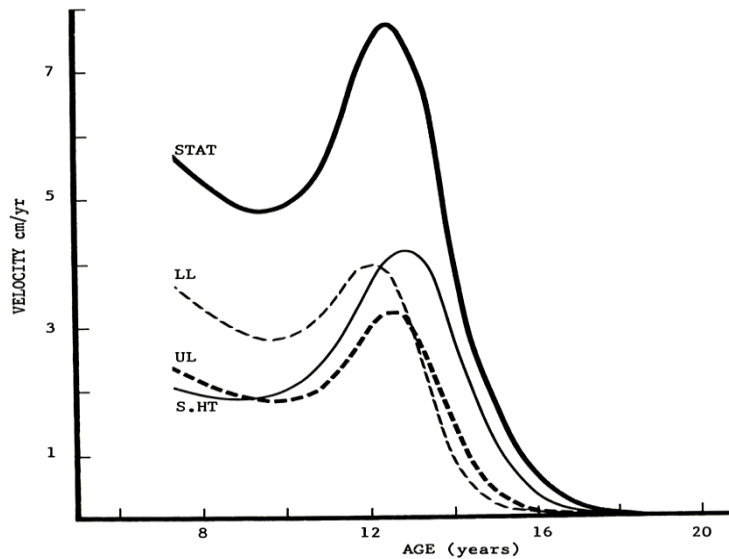
**Longitudinal analysis, velocity results**

Figures (4 A,B,C), show the mean velocity curves cm / year for stature, sitting height, upper limb and lower limb in boys and girls from age 4-19 demonstrating that all limbs and their segments share in the adolescent growth

spurt like stature with some variation in the timing and intensity , Initiation of puberty (take off point) occurred at about 11.0 years in boys and 9.0 in girls. The lower limbs and its segment are the first to peak, then stature, and upper limb segments, sitting height is the latest segment to have its adolescent growth spurt in both sexes. Tables (A7-A11) list the mean velocity values with its standard deviation.



**Figure 4A:** Mean Velocity Curves For Stature, Lower Limb, sitting Height and upper limb - boys



**Figure 4B:** Mean Velocity Curves for stature, Lower limb, sitting Height and upper limb Girls

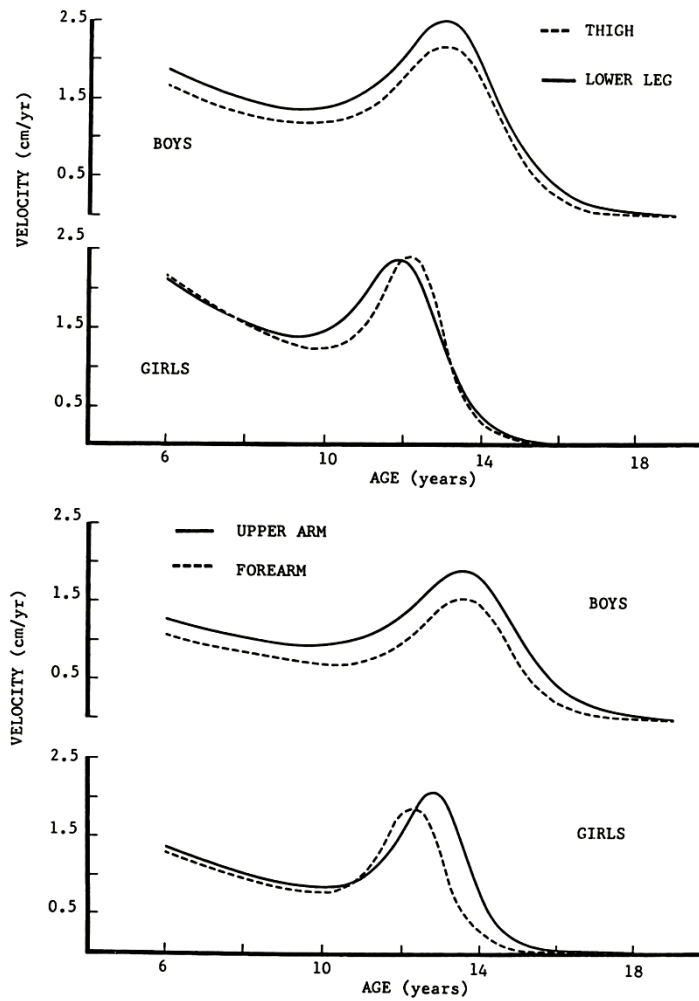


Figure 4C: Mean velocity curves for thigh length, lower Leg (UpperPanel), and upper arm, forearm (Lower Panel) in both sexes

**Table A7:** Whole year velocity – chronological age based – boys

Parameters	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
<b>Stature:</b>														
<u>N</u>	70	88	89	85	99	99	91	84	84	82	83	71	49	25
X	6.41	6.14	5.78	5.51	5.29	5.03	5.06	5.93	7.06	6.60	4.49	2.29	.90	.31
SE	.11	.08	.90	.08	.08	.07	.12	.20	.25	.25	.25	.21	.10	.09
S.D.	.89	.76	.88	.74	.79	.73	1.12	1.85	2.27	2.27	2.26	1.81	.78	.48
<b>Sitting Height:</b>														
<u>N</u>	70	88	89	85	99	99	91	84	84	82	83	71	49	25
X	2.83	2.5	2.32	2.27	2.03	1.99	1.92	2.65	3.46	3.56	2.82	1.79	.88	.25
SE	.11	.09	.08	.07	.06	.07	.09	.15	.16	.15	.15	.13	.11	.16
S.D.	.91	.88	.76	.64	.60	.66	.85	1.33	1.45	1.39	1.33	1.12	.74	.82
<b>Upper Limb:</b>														
<u>N</u>	44	71	77	81	95	95	83	76	75	73	77	71	48	24
X	2.39	1.96	2.2	1.97	1.82	1.94	1.93	2.03	2.56	2.48	1.82	.86	.37	.16
SE	.11	.07	.07	.06	.06	.06	.07	.09	.1	.11	.12	.09	.08	.09
S.D.	.72	.61	.64	.51	.54	.56	.60	.78	.85	.97	1.1	.79	.58	.46

**Table A8:** Whole year velocity – chronological age based – boys

Parameters	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
<b>Upper Arm:</b>														
<b>N</b>	37	60	69	76	89	91	78	75	75	73	77	69	47	21
<b>X</b>	1.38	1.14	1.27	1.04	.98	1.11	1.07	1.12	1.15	1.42	.96	.52	.28	.12
<b>SE</b>	.08	.07	.05	.05	.04	.05	.05	.07	.06	.07	.07	.06	.06	0.7
<b>S.D.</b>	.48	.53	.45	.41	.41	.43	.41	.57	.55	.63	.62	.51	.38	.30
<b>Fore Arm:</b>														
<b>N</b>	41	62	69	77	91	92	79	76	75	73	77	69	47	21
<b>X</b>	1.1	.90	.89	.96	.85	.86	.88	.88	1.08	1.05	.82	.40	.11	.02
<b>SE</b>	.1	.06	.05	.06	.04	.04	.05	.05	.06	.06	.07	.05	.05	.05
<b>S.D.</b>	.63	.50	.45	.48	.41	.38	.41	.43	.51	.52	.61	.38	.33	.24
<b>Lower Limb:</b>														
<b>N</b>	47	74	82	78	93	92	80	71	73	64	62	48	27	10
<b>X</b>	3.31	3.43	3.24	3.19	3.15	2.89	2.82	3.06	3.31	2.92	1.86	.77	.24	-.12
<b>SE</b>	.08	.07	.07	.05	.07	.06	.09	.11	.16	.16	.16	.1	.08	.11
<b>S.D.</b>	.54	.61	.64	.47	.53	.66	.55	.79	.98	1.25	1.28	.67	.44	.36



**Table A9:** Whole year velocity - chronological age based – boys

Parameter	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
<b>Thigh:</b>														
<b>N</b>	41	66	71	72	86	86	72	67	72	61	59	42	25	7
<b>X</b>	1.54	1.59	1.56	1.53	1.50	1.49	1.40	1.45	1.56	1.42	.87	.36	.1	-.15
<b>SE</b>	.07	.06	.06	.06	.06	.07	.07	.07	.07	.10	.09	.07	.05	.06
<b>S.D.</b>	.47	.52	.49	.52	.59	.60	.56	.53	.63	.80	.70	.42	.29	.15
<b>Lower Leg:</b>														
<b>N</b>	48	73	74	72	86	88	74	68	72	61	60	43	26	7
<b>X</b>	1.74	1.89	1.68	1.67	1.6	1.45	1.38	1.63	1.80	1.52	.98	.14	.07	-.12
<b>SE</b>	.09	.07	.06	.06	.05	.05	.06	.09	.08	.09	.1	.2	.05	.05
<b>S.D.</b>	1.61	.55	.47	.52	.48	.48	.51	.71	.66	.72	.75	1.31	.3	.14

Table A10: whole year velocity – chronological age based – girls

Parameters	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5
<b>Upper Limb:</b>												
<u>N</u>	19	16	44	51	40	34	28	24	22	16	13	12
X	2.28	2.22	2.11	2.04	1.78	1.98	2.64	2.15	1.92	.53	.26	.07
SE	.14	.16	.10	.1	.1	.12	.14	.17	.28	.16	.10	.07
S.D.	.62	.62	.63	.72	.65	.68	.72	.83	1.31	.6	.38	.24
<b>Upper Arm:</b>												
<u>N</u>	19	16	42	47	38	32	25	20	19	14	12	10
X	1.27	1.25	1.13	1.16	.93	1.09	1.43	1.25	1.06	.38	.21	.12
SE	.06	.11	.28	.07	.08	.08	.09	.13	.18	.1	.08	.04
S.D.	.24	.42	.53	.48	.49	.47	.47	.57	.78	.38	.27	.12
<b>Fore-Arm:</b>												
<u>N</u>	19	17	42	47	38	32	25	20	19	14	12	10
X	1.04	.96	1.0	.90	.84	.92	1.21	.86	.80	.15	.04	.07
SE	.09	.09	.06	.07	.07	.07	.12	.11	.17	.09	.10	.03
S.D.	.39	.38	.36	.47	.45	.42	.60	.50	.70	.33	.36	.1

Table A11: Whole year velocity – chronological age based – girls

Parameters	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5
<b>Upper Limb:</b>												
<b>N</b>	16	14	39	51	38	30	23	20	18	16	9	10
<b>X</b>	3.92	3.70	3.2	2.94	2.84	3.15	3.50	2.45	1.38	.74	.16	.1
<b>SE</b>	.14	.17	.13	.08	.09	.12	.12	.21	.24	.19	.13	.05
<b>S.D.</b>	.56	.65	.80	.58	.58	.67	.59	.92	1.0	.75	.38	.17
<b>Upper Arm:</b>												
<b>N</b>	16	14	38	50	38	26	20	16	16	14	6	7
<b>X</b>	1.63	1.84	1.44	1.36	1.27	1.52	1.65	1.28	.60	.51	.17	.07
<b>SE</b>	.10	.15	.11	.07	.09	.11	.14	.15	.15	.13	.07	.09
<b>S.D.</b>	.41	.58	.65	.48	.53	.56	.63	.60	.6	.50	.15	.24
<b>Fore-Arm:</b>												
<b>N</b>	17	16	42	51	39	29	22	18	16	14	6	8
<b>X</b>	2.22	1.82	1.72	1.59	1.58	1.67	1.86	1.30	.52	.44	.15	.12
<b>SE</b>	.16	.12	.09	.07	.08	.1	.12	.13	.12	.08	.08	.05
<b>S.D.</b>	.67	.22	.59	.52	.52	.56	.58	.56	.47	.31	.2	.14

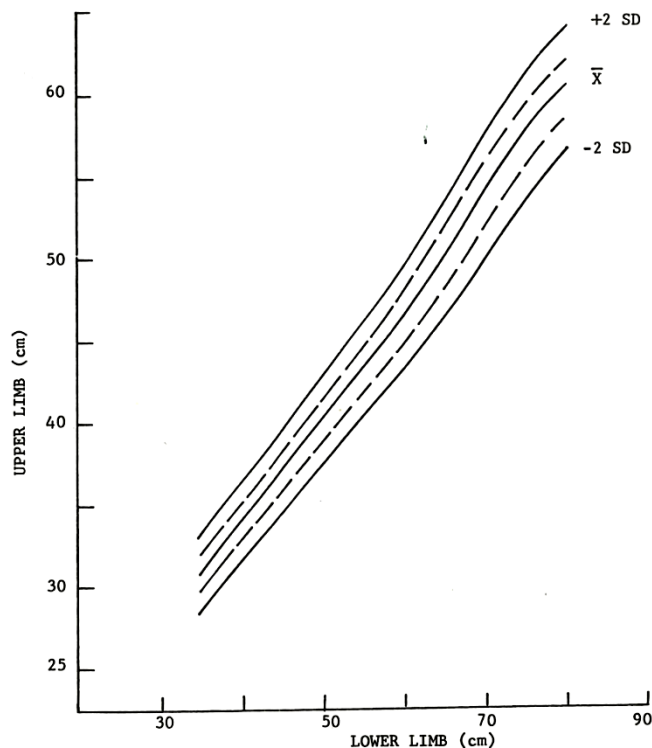
**Bivariate standards**

Figure (5A,B,C), show the plotted mean curves  $\pm 2$  S.D., for one variable for a given interval of another irrespective of age for boys between the following pairs of measurement; upper limb / lower limb; upper limb / trunk; lower limb / trunk. This bivariate standards answer the question; given the value of X, how normal is the value of Y, irrespective of age. Tables A12 – A14 lists the statistics on which these curves are based.

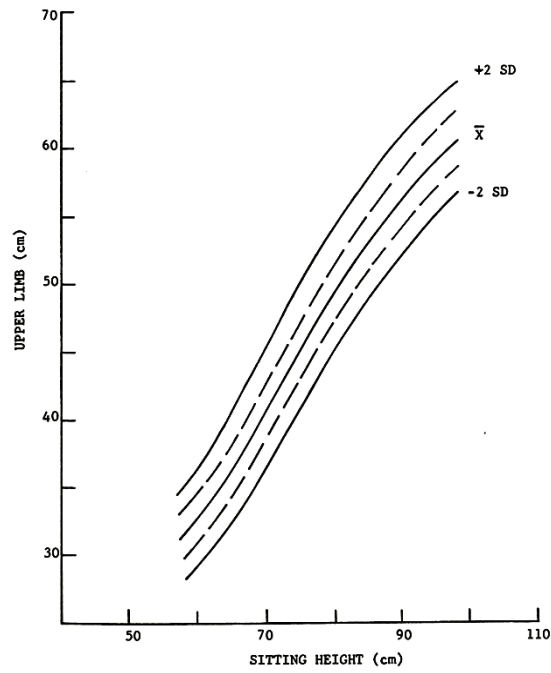
The highest correlation between variables are between upper limb and lower limbs (around 0.9), they are less between upper limb / sitting heights; lower limb / sitting

height (0.78 and 0.73 respectively). The lowest correlation was between forearm, thigh, lower leg, each with sitting height (around 0.6). This shows the limbs to be more highly correlated with each other than with the trunk length.

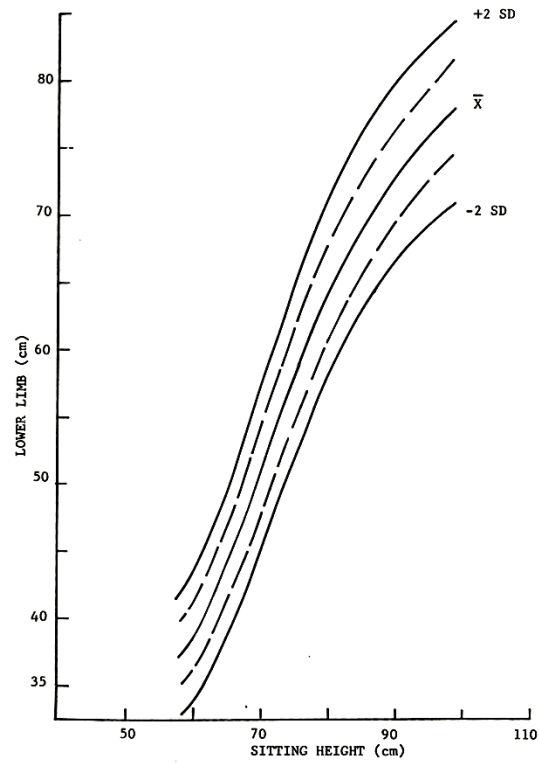
In boys, growth ceases in stature and sitting height at 17.0, and 17.5 years respectively; upper limb at 16.75; lower limbs at 16.5. In girls, 15.75 and 16.0 for stature and sitting height; upper limb at 15.0; lower limb at 14.5. So in both sexes, first segment to stop growing were lower limbs, upper limbs stop growing 0.25 years later, trunk is the last segment to stop growing, after these ages, the increase in height up to age 20 was less than 1 cm.



**Figure 5A:** Mean  $\pm$  One and Two SD of upper limb. Length at given lower limb, Irrespective of age - Boys



**Figure 5B:** Mean  $\pm$  One and Two SD of upper limb Length at Given sitting Height, Irrespective of Age - Boys



**Figure 5C:** Mean  $\pm$  One and Two SD of lower limb Length at given sitting Height, Irrespective of age - Boys

**Table A12:** Bivariate curvilinear regression standards: variation of upper limb with given lengths of lower limb, irrespective of age. - boys

LOWER LIMB (CM)	Upper Limb (cm)			
	N	Mean	S.E.	S.D.
32.0 – 36.9	20	30.72	.23	1.03
37.0 – 41.9	96	33.79	.13	1.36
42.0 – 46.9	169	36.86	.11	1.36
47.0 – 51.9	219	40.01	.09	1.35
52.0 – 56.9	256	43.29	.09	1.38
57.0 – 61.9	301	46.23	.09	1.53
62.0 – 66.9	351	49.72	.10	1.81
67.0 – 71.9	315	53.48	.10	1.83
72.0 – 76.9	237	57.17	.13	1.99
77.0 – 82.0	66	60.20	.25	2.0

**Table A13:** Bivariate curvilinear regression standards: variation of lower limb with given sitting height, irrespective of age. - boys

SITTING HEIGHT (CM)	Lower Limb (cm)			
	N	Mean	S.E.	S.D.
55.0 – 59.9	44	37.16	.34	2.24
60.0 – 64.9	160	41.60	.20	2.52
65.0 – 69.9	312	47.95	.18	3.15
70.0 – 74.9	405	55.16	.17	3.37
75.0 – 79.9	462	62.11	.16	.37
80.0 – 84.9	307	67.89	.20	3.45
85.0 – 89.9	240	71.31	.22	3.42
90.0 – 94.9	185	74.41	.30	4.0
95.0 – 100.0	49	77.80	.49	3.42

**Table A14:** Bivariate curvilinear regression standards: variation of lower limb with given sitting height, irrespective of age. - boys

SITTING Height (CM)	Upper Limb (cm)				
	N	Mean	S.E.	S.D.	
55.0 – 59.9	51	31.35	.24	1.71	
60.0 – 64.9	167	34.86	.14	1.76	
65.0 – 69.9	314	38.90	.11	2.0	
70.0 – 74.9	414	43.51	.10	2.09	
75.0 – 79.9	479	47.96	.10	2.28	
80.0 – 84.9	322	51.99	.12	2.15	
85.0 – 89.9	274	55.30	.12	2.05	
90.0 – 94.9	231	57.76	.17	2.53	
95.0 – 100.0	70	60.58	.26	2.18	

### Results of asymmetry in limbs

In case of upper limb, there is a tendency for asymmetry to favor the right side more than the left at all ages, more marked in boys than girls ( $X^2 = 12.7$ ,  $P < .001$ ,  $d.f. = 1$ ), 65% of cases have their right upper limb longer, 25% have the left side longer, and in 18% both sides were equal; ( $X^2 = 18.7$ ,  $P < .001$ ,  $d.f. = 1$ ). In lower limbs differences were not significant. In boys the mean difference in favor of the right side was  $0.31 \pm 0.02$  cm. during childhood, and  $0.69 \pm 0.2$  during adulthood. This demonstrates the increase in the values of asymmetry with onset of puberty till final size, also variability of asymmetry is greater in children with low and high birth weight than in those born within normal limits ( $X^2 = 14.08$ ;  $d.f = 7$ ;  $p < 0.05$ )

### DISCUSSIONS

The present study provides a base-line for the quantitative assessment of normal growth of the limbs and their segments at different ages. As mentioned, it was difficult to obtain a clear picture for patterns of growth for the limbs and their segments out of the literature due to different techniques, and using cross-sectional data to estimate velocities which gives false results. Our data showed that all segments displayed the general pattern of sex difference i.e the usual double cross-over at adolescence, boys are larger than girls during childhood, then girls earlier adolescent spurt makes them larger, until the boys later, and stronger spurt results in boys becoming larger again as older teenagers and adults, this cross-over (catch-up) by the boys to surpass the girls occur at about 13-14 years.

Contrary to findings in the literature, all limbs and their segments show a clear adolescent growth spurt as stature, with some variation in timing and intensity, it is this differential rates of growth between the different body segments that leads to the changes in body proportions from those of the baby to those of adults (at birth the lower limbs constitute 25% of child length, while in adults it makes nearly 50% of height), so from birth onward the lower limbs grow by a higher velocity than the head and trunk to compensate for the deficit in growth, this is called cranio-caudal maturity gradient and is manifested in early embryonic life by greater development of the cranial end (head & brain), than the caudal end (lower limbs) and is reflected on the functions of the brain, controlled movement of upper limbs becomes possible early in life, the infant can use his upper limb and eyes to grasp objects, but can not walk before one year, the motor area in the brain for the upper limb mature earlier than that for the lower limb.

The velocity curves presented based on longitudinal data are free from the artifact of the phase difference effect caused by grouping together children maturing at different ages when we use cross-sectional data leading to risks of ironing out any spurts of modest nature. Accordingly the magnitude of the peak height velocity in these curves are more than in cross sectional analysis, they demonstrate a clear and realistic composite picture as regards the different components of the body in boys and girls than the schematic illustrations found in the literature and based on cross sectional analysis, Healy (1962). The lower limb is the first to peak, then stature, upper limb, sitting heights is the latest segment to have its peak height velocity in both sexes, a difference of about 1.2 years between peaks of lower limb and that for the trunk in boys, and 0.9 years in girls, these findings corroborate with earlier workers Paula et al (2008), Peak velocity for the trunk length is not only latter than that for the lower limb, but tends to be greater (3.6cm/year for trunk and 3.3cm/year for lower limb). Also girls stop growing in their lower limbs earlier than boys by about two years, but they continue to grow in their trunk length, so that adult women have larger trunks than men for a given height. Contrary to previous studies, Cameron, Tanner, white house (2009), our data does not show any significant differences in timing of peak velocity for the proximal and distal segments within the same limb, it occur at 13.5 years in boys and 11.5 in girls, its magnitude is more for lower limb segments than upper limb segments (around 1.8 cm/year versus 1.3 cm/y in both sexes).

Bivariate standards which gives the variation of one limb measurement for a given value of another regardless of age can be used in Conjunction with the univariate standards by age to define the exact nature of any abnormality in growth especially in chondrodystrophies and other endocrinopathies where body proportions are disturbed e.g achondroplasia, growth hormone deficiency, Silver Russel syndrome etc. In achondroplasia the child is dwarfed with strikingly shorter upper and lower limbs, but an almost normal trunk, this is clearly shown when Lower limb length is plotted against trunk length. On the other hand, child with growth hormone deficiency is very short but well proportioned, his trunk – limbs proportion are not different from normal children of the same size.

In case of upper limbs in boys, asymmetry tends to favor the right side more frequent than the left side. 65% of cases versus 25%, ( $X^2 = 18.7$ ,  $P < .001$ ,  $d.f = 1$ ). Also more boys than girls have their upper limbs longer ( $X^2 = 12.7$ ,  $df = 1$ ,  $P < .001$ ). In boys mean difference for upper limbs in favor of right side was  $0.31\text{cm} \pm 0.02$  during childhood; and  $0.69 \pm 0.2$  cm. during adulthood. In case of lower limbs, in both sexes differences were not significant. Variability and magnitude of asymmetry for



upper limbs increases as age advances from puberty onwards in boys, and it was greater in children with low and high birth weight than in those born within normal limits ( $X^2 = 14.08$ ,  $df = 7$ ,  $P < .05$ ). We do not know whether this morphological asymmetry in case of upper limbs is related to functional asymmetry (handedness) since data on handedness were not available, Cole, Glees(1951) Steel, Mays(1995),Annett(2002).

Some investigators attributed that asymmetry is caused by the differences in the proportion of motor nerve fibers at the pyramidal decussating of the brain which is not equal in both sides. The proportion of motor nerve fibers from the left side of the brain to control the right side of the body is more, this provides a better neuro – vascular – skeletal development of the right side of the body .Also the brain is structurally asymmetrical , the left lobe is larger than he right one, Hoodley, Pearson (1929).

Our results confirms the findings of ancient Greek artists and sculptors, long before our era, that no human being is symmetrical and therefore, their great creations were asymmetrical. These results on limb asymmetry can be kept in mind during investigating children with limb asymmetry whether congenital or post traumatic e.g Silver Russel syndrome, and in treatment of fractures.

As mentioned , Eveleth and Tanner (1990), Attallah (1984 - 1994) , there is a great variation in body shape, size and trunk- limb proportion between different populations of mankind, as between Africans , Europeans and Japanese , Even individuals of the same height vary widely in their Trunk- Limb proportions which are genetically determine, these variations for mechanical reasons can affect physical performance in different athletic events.

Africans have longer arms and legs relative to trunk, narrow hips and more slender calves than white athletes competing in the same event. From a mechanical point of view a Negro have a lighter, slimmer body to drive. Thus his power-to-total-weight ratio, at any given size is more favorable in high jumps. Also the centre of gravity, being in most cases in the pelvis, starts higher up relative to body weight in long legged man than in short legged one of the same height which is an advantage in high, long jumps and hurdlers.

Runners, for instance and high jumpers, besides having longer limbs relative to the trunk, must have very little subcutaneous fat to dissipate their heat to the air during run. That is why in most Olympic Games African and Afro American athletes win most gold medals in these events.

Weight lifters, on the other hand, tend to have much shorter legs and arms relative to the trunk. Their arms exactly match their legs. They are short individuals with large trunk length. The short legs enable the lifter to keep a better balance, as well as diminishing the distance the

bar has to be raised. The short arms permit the bar to stay relatively close to the axis of the body during the lift, thus Lessing the torque of the body.

Asians, in contrast to Africans, have short legs and arms relative to their trunk which explains why Asian athletes were most successful in weight-lifting among competitors of all races in Olympic Games.

Disc throwers tend to have longer arms relative to the lower legs (i.e. longer arms and shorter legs). The longer the arms, the greater the momentum imposed to the disc at the time it is released and its velocity depends directly on the length of the arm i.e. the radius of the circle described by the discus before being released, also longer legs might cause instability.

These differences in trunk – limb proportions are inborn and not acquired by training, both height and body proportions are not affected by training, it is only muscles which can be made to hypertrophy by 30% leading to increase in the number of functional capillaries which will increase the rate of oxidation.

Accordingly, the present data can be useful for coaches to screen and select individuals for training in specific athletic events which suits best their body proportions , this will improve the outcome of the current methods of training .Tanner (1964) and Attallah (2019-1989) in their studies on Olympic athletes specialized in different events demonstrated clearly that certain body proportions (trunk – limb) are optimal for certain athletic skills, however favorable training and motivation may be, thereafter comes the training and the desire to achieve something never achieved before.

In the field of forensic sciences Attallah and Marshall(1986), presented multiple photogrammetric and anthropometric regression equations for predicting the most likely value for stature of an individual from some limb measurements , our data might be of value in forensic medicine when only some remains of human body are available , also, in living children with congenital defects like scoliosis it may be useful to estimate what the child's stature might have been in the absence of the deformity. Also our data can be used to improve garment industry and in the design of a more comfortable equipments in the field of ergonomics.

Present study also can be used for comparison with similar data from other ethnic groups, this will supply biological knowledge about human variability, geographical polymorphism and adaptability to the environment between different populations of mankind .This also gives another example that in every populations , the growth of its members is adjusted by means of selection to the environmental conditions in which they evolve Tanner (1962) ,Eveleth and Tanner (1990).

Lastly, it has to be mentioned that all limb measurements, presented in this study are based on

photogrammetric technique which proved to have a high reliability. Tanner and Weiner (1949), demonstrated that a photograph can serve as a substitute for the subject in yielding reliable measurements of small details using the standardized rigid pose for the subject as described by Dupertuis and Tanner (1950). Photogrammetry also provides a permanent record for the subjects actual appearance, retrospective editing is possible, being a non-touch technique, it avoids soft tissue deformation which usually accompany classical methods of anthropometry, this makes photogrammetry an ideal method to study limb asymmetry. But comparisons with other studies would only be made with comparable photogrammetric data; however our results are valuable in illustrating a real composite picture and sequence of events of the adolescent growth spurt in all components of the human body during adolescence.

Finally, perhaps it is interesting and worth mentioning here that some vertebrate like the Salamander, once wounded, their cells become activated and restore the limb back again. Limb regeneration for amputees in humans sound like scientific fiction , but scientists said it is possible, and prosthetics will be a thing of the past especially after the success of regenerating a more complex organ as the heart, Laflamme, Murry (2005) ; Plaugic ,Lizzie (2015).

## ACKNOWLEDGEMENTS.

N Louis Attallah is grateful to the Immortal Professor J.M. Tanner for providing facilities and support during period of the study at the Institute of Child Health, University of London.

**Contributors** NLA formulated, conducted, collected and analyzed the data, write and reviewed the draft. DL reviewed the full text article. NLA assume full responsibility for the manuscript.

**Competing interests** : none

**Provenance and peer review** not commissioned

## BIBLIOGRAPHY

- Anderson M, Green WT, Messner MB (1963). Growth and predictions of growth in the lower limb. *J Bone Joint Surg Am.*45-A:1-14
- Annett M (2002). Handedness and brain asymmetry: the Right shift theory. *Psychological Press Hove Uk.*
- Attallah NL (1978). Age at Menarche of school girls in Egypt, *Ann. Human Bio.* 5: 185 –189.
- Attallah NL (1980). Growth of the limbs and their segments during childhood and adolescence, a photogrammetric study, ph.D. thesis, University of London.
- Attallah NL (1984). A study of the physique of the different Nilotic tribes living in South of Sudan, adult males aged 25-30 years, *proc 5<sup>th</sup> Ann. Sci. Cong. Alex, Fac. Med.* 16-19.
- Attallah NL (1989). Variations in relationships of the lengths of limb segments to each other and to trunk length, and how it affects physical performance in athletic events; *world Fina medical congress on aquatic sports*, the London Hospital medical college Sept 1989.
- Attallah NL (1994). Patterns of growth of Saudi boys and girls from birth up to maturity in the Asir region of Saudi Arabia, before the turn of the twenty century, *Saudi Med. J.* 15: 6, 414 -423.
- Attallah NL (2013). Ontogenesis of man, from conception to adulthood and to his final destination. *Trafford Publisher USA, 100-110*
- Attallah NL (2019). Olympic Games and Olympic athletes, are they born or made? *Trafford Publisher, USA ,PP140*
- Attallah NL, Marshall WA (1986). The estimation of stature from anthropometric and photogrammetric measurements of the limbs. *Med. Sci. Law.* 26:53-59.
- Boas F(1932). studies in growth. *Human Biology*, 4: 307-350.
- Cole J, Glees P (1951). Handedness in monkeys. *Experimentia* 7:224 - 225
- Dennis M, Styne M, Grunbach M (2016). Physiology and disorder of puberty in williams textbook of endocrinology (13 ed ).
- Dupertuis CW, Tanner JM (1950). The pose of the subject for photogrammetric anthropometry with special reference to somatotyping. *Am. J. of Phys. Anthro*, 8: 27- 47.
- Eveleth PB, Tanner JM (1990). World wide variation in Human Growth, 2<sup>nd</sup> ed. *Cambridge University Press.*
- Garney B (2002). leg discrepancy, Gait and Posture 15:195-206.
- Healy MR (1962). Effect of age grouping on distribution of a measurement affected by growth, *Am J. phys. Anthropol.* 20: 49-50.
- Hoodley MF, Pearson K (1929). On measurement of the internal diameters of the skull in relation (i) to the prediction of its capacity (ii) to the preeminence of the left hemisphere. *Biometrika* 21:85-123.
- Krogman WM (1970). Growth of head, face, Trunk and limbs in Philadelphia white and Negro children of school age, *Monograph of Soc. For studying child development* 35: 3, 80 pp.
- Laflamme NA, Murry CE, (july 2005).Regenerating the heart , *Nature Biotechnology* 23(7):845-56.
- Marshall WA, Harrison JM (1971). Normal standards for the relationship between the lengths of limbs and of limb segments in young British men: A photogrammetric study. *Human Biology*, 43: 526 – 535.

- Paula M, Kelly, Alain D (2008). Lower limb growth: how predictable are predictions ?. *J Child Orthop* 2(6):407-415. pbio.1000477
- Plaugic L (june 2015). Researchers have grown a partially functioning rat limb in a lab. *Theverge.com*. Washington post .com. Retrieved 8 june 2015.
- Steele J, Mays S (1995). Handedness and directional asymmetry in long bones of the human upper limb. *Int J of Osteoarchaeology* 5 : issue 1:39-49.
- Tanner J M (1962). *Growth at Adolescence* .Oxford, *Black well scientific publication*. 2<sup>nd</sup> edition 1962.
- Tanner J M (1964). *The Physique of the Olympic Athlete*. London: *George Allen and Unwin Limited* Tanner JM, Weiner JS (1949). The reliability of the photogrammetric method of anthropometry, with a description of a miniature camera technique. *Am. J. of Phys. Anthrope*. 7: 145 – 186
- Tanner JM, Whitehouse RH ( 1971). The pattern of growth in children with growth hormone deficiency before, during and after treatment. IN: *Growth and Growth Hormone, Excerpta Medica International Congress Series*, No. 244.
- Wolport L (2010). Arms and the man, the problem of symmetric growth. *PlosBiol*8(9):e1000477. <https://doi.org/10.1371/journal.pbio.1000477>