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Growth and Environment

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Anyone asked to write 3000 words on the phenomena of human growth is likely to have a nightmare during which the immense portions he has left out will be chasing him up and down velocity and acceleration curves. Therefore this paper will be limited to specific problems including potentially productive relationships between human growth and the disciplines of epidemiology and preventive medicine.

I shall not report in detail what a pediatrician does every time he sees an infant or child on the first occasion - that is, he places the individual against the whole background of normal physical, intellectual and social growth variable expectancies with their distributions. To remind oneself of this background, including such details as dental growth and speech growth, one may consult any well written textbook such as Nelson's Pediatrics. Nor is it my intention to discuss the vast fields of congenital defects, including the newly discovered metabolic diseases and the interesting possibility that thalidomide may act as an immunosuppressive, nor the endocrine disorders, although the glands of internal secretion are a chief way in which heredity and environmental factors cause variability and disorders in growth and development.

I shall discuss some methodological issues and will then concern myself with relationships between human growth and the environment with some further comment on methods. It has no pretensions to being universal. The methodological problems will be those which the author has perceived as being sensitive areas requiring a fuller understanding, or an improvement in approach, for better utilisation; these will include consideration of stability in variables, reliability, the concepts of biological and skeletal age, the cross-sectional and longitudinal approaches and problems in measuring change. Environmental influence on growth will include effects of adverse circumstances, catch-up growth, the secular change, some sex differences and some geographical differences.

Stable Variables

Given the difficulties of measuring the whole person, observers have chosen clearly defined growth variables which may be followed from birth or even conception until maturity through decline until death.

A stable variable is one which not only demonstrates regular onward progression but is also characterised by a high correlation between measurements at different points in time. One might choose r = 0.50 as a minimum requirement, though this may vary according to the length of time and rapidity of growth. Such a variable is body height which reaches mature levels before the age of twenty and where there is little subsequent decline through old age. Body height has already reached 50% of mature levels by age three and there is then a 0.76 correlation with height at maturity. This is in contrast to body weight which does not reach 50% of mature development until age 10 (correlation with maturity 0.70) and strength which reaches the 50% level by age 12 (0.73 correlation with maturity). (Bloom, 1964). This early high correlation of the variable height means that fairly accurate predictions of final height are feasible from mid childhood and in fact tables have been devised (Bayley and Pinneau, 1952); the equations which form the basis of these tables incorporate the variable of skeletal age, representing biological maturity, which is interwoven with patterns of development towards final height. Height prediction is important for one occupational group - ballet dancers, who must know by age 9 within what limits their mature height will be. Weight prediction would be of greater import to practitioners of preventive medicine but this would not be possible until a much later age (at least prepuberty) and is bedevilled by the instability of the fat component in the total variable body weight. It is a difficult problem which, however, may yet be solved by separating out the weight components and using such factors as family patterns, previous fat levels and their fluctuations and cultural and psychological characteristics.

Reliability

The problems of reliability involved in measuring other stable variables (e.g. intelligence) are not so apparent for body height yet even here considerable errors may be introduced by the change from reclining body length to standing body height, by not measuring always at the same time of the day (height may diminish appreciably in a subject during the

course of a day of standing) or by not taking into account seasonal variation (the average velocity during the months of March, April and May is 2-2½ times that in September, October and November)(Tanner, 1962). Errors may also be introduced by inconstancy in the motivation to stand truly erect with the head in a constant position and by the instrument itself - the type of sliding adjustable headpiece attached to the usual precision balance may have an error of up to 2 cm - and the inevitable recording errors especially when the observer himself must write down the findings (Garn and Shamir, 1958). A reliable method is one which employs a Martin Anthropometer or similar instrument with a standard position.

Biological versus chronological age

At the time of puberty the variability of height increases markedly. Correlations with mature height decrease during this period. Two boys of the same age but of differing maturational levels may differ by as much as 20 cm in height and 20 kg in weight (Boutourline Young, 1963). Conversely individuals differing as much as two years in chronological age may be similar in most body measurements. Use of the concept of puberal (Greulich et al., 1942; Schonfeld, 1943) or biological age reduces this variability and presents norms against which physicians may interpret growth phenomena with the same precision as before puberty. Puberal age may be quickly and reliably measured by rating and combination of the three variables testicular volume, pubic and axillary hair and its calculation is essential in many clinical situations, for example, if one must interpret a haemoglobin level in a male during the course of puberty (Boutourline Young, 1962). The usefulness of this concept at puberty provokes thought as to whether an analogous measure might not be developed for old age, using for example degrees of senile osteoporosis or amount of collagen per unit area of skin (B.M.J., 1965), as well as other physical and psychological variables.

To illustrate the usefulness of the concept, in Fig. 1 I have plotted increments in fat and muscle against puberal age in adolescent male subjects from our own research. Of interest is the rise in muscle and dip in fat increments at mid puberty when the androgenic effect is maximal.

Skeletal age

Maturation is also reflected in bone development. Skeletal age is correlated highly with "puberal age" and has the added advantage of identifying early and late developers even during the long preceding period of childhood, thus making height prediction feasible as well as being of inestimable help in the identification of growth disorders. Clinically the method of Greulich and Pyle (1950) has been most used, whereas for research purposes there has been more recent use of scales which give a weighting to different bones in the hand and wrist (Tanner and Whitehouse, 1959; Tanner et al., 1962). Table 1 presents correlation of some growth phenomena with skeletal age as estimated (a) by Greulich and Pyle (b) by Tanner Whitehouse (c) long bones (d) carpus alone. In this table one may see further evidence that the Tanner Whitehouse method does in fact increase precision. However, in view of the extra time involved, the Greulich Pyle interpretation, possibly in an improved version, may well suffice for ordinary clinical use. Of great interest is the relatively smaller value contributed by the carpal bones to the overall picture. This has already been pointed out by Acheson (Acheson et al., 1964) whose own work (Acheson, 1957) preceded that of Tanner.

The cross-sectional or longitudinal approaches

Thus enjoined to find out how much the environment may affect individual human variables, to identify the environmental factors and then to manipulate them, the research worker must make some decisions. The first is the approach. Should this be cross-sectional or longitudinal. The advantages and disadvantages are well known. It is assumed that both types of sample are well chosen. The cross-sectional (normative) approach promises less grief in that the holding of subjects in a longitudinal study is a masochistic exercise for the principal investigator. However, to obtain equal precision in the estimates of increments in height, where the correlation from one period of time to another is of the order of 0.9, a cross-sectional sample of ten times the number would be required (Rodlin and Thompson, 1958). A cost precision index may thus be calculated. If, however, it is important to estimate acceleration or to calculate correlations with later states then there is no substitution for the longitudinal approach. The dangers implicit in retrospective data are also much less. In a recent study we were able to follow a hundred girls through menarche. After some years there was a follow up

study concerned with menstrual disorders. In this study the girls were asked to state the precise age at menarche. There was an appreciable error of recall related to the time elapsed since the event (Boutourline Young et al., 1963).

It seems likely that some future longitudinal studies will be broken down into smaller time sequences. Observations on the age periods: conception - 4, 4 - 9, 9 - 14, 14 - 19 years may be done at the same time on different but comparable samples; thus the first 19 years and 9 months of development may be observed in a five or six year period.

Problems of measuring change in psychological data

Difficulties in the manipulation of increments in psychological data arise in several major ways. One difficulty is that the higher the correlation between a first and a subsequent observation, the lower is the reliability of the difference. At the same time the lower the correlation between two tests the less they may measure the same characteristics. Another is doubts about the validity of the assumption that equal score changes at various points on a scale account for equal changes in the characteristic. Bereiter, Lord and others (1963) have discussed these and other problems and proposed some solutions.

Effects of Environment

Growth in height

Maximum height velocity is reached about the fourth intrauterine month and the negatively accelerated extrauterine curve continues until prepuberty when there is another period of positive acceleration. The childhood curve may be expressed as $L = a + bt + c \log t$ (L = height, t = age) (Tanner, 1963) and the puberal period perhaps best (Deming, 1957) by the Gompertz curve, a skewed S shaped exponential.

Illness, endocrine disorders and malnutrition may interfere with growth. While short term influences may have no permanent effect, more severe or long lasting insults may cause marked retardation from which however there is a rebound phenomenon upon relief from the unfavourable circumstances. This phenomenon is known as 'catch-up growth' during which height velocity may reach over twice the average to be expected at the age in question (Tanner, 1963), although the originally predicted levels may never be attained. Tanner has

pointed out that the catch-up phenomenon at birth appears to be a principal mechanism in the maintenance of variability in adult size. As a result of control of body length by uterine factors the correlation with mature body height is only .2 at birth but increases to almost .7 at 2 years (Tuddenham and Snyder, 1954).

Since most illnesses do not last long, the catch-up mechanism ensures that most effects on growth are not recognizable in the long run. Reports of growth impairment in association with moderate illness or repeated illnesses leave some doubt as to the cause, as mostly it is difficult to assess other environmental influences as well as genetic factors (Miller et al., 1960). However, severe chronic illness such as anaemia or nephrosis may cause permanent growth impairment although much remains to be learnt regarding the specific mechanisms involved. For example, in severe congenital heart disease impairment in height is related to degree of cyanosis and thus presumably the degree of anoxia is involved (Campbell and Reynolds, 1949). There is some evidence that psychological disorders may also interfere with physical growth (Widdowson, 1951; Patton and Gardner, 1963) although the mechanisms have yet to be understood. Acheson (1960) has recently summarized pertinent work by himself and others where growth is related to illness or poor environmental conditions.

Physicians are frequently asked to retard the growth of tall girls. Attempts to achieve this by the use of estrogens have not been effective (Bayley et al., 1962). Although the estrogens increased to a marked degree the rate of skeletal maturation, the final height did not differ significantly from that predicted. The girls grew more in a shorter time.

Late developers are sometimes brought for an opinion as to possible endocrine therapy. My own unit has records on 100 boys treated elsewhere with chorionic gonadotrophins. There is no evidence that this therapy caused any increase in final height but it did appear to be associated with some psychosomatic disorders.

The secular change in physical measures

In western cultures adults are taller and heavier than they were a hundred years ago. Men are some 10 cm taller and from 5 - 10 kg heavier (Tanner, 1962). Women have also become taller although in certain cultures (e.g. the United States) they have become lighter in relation to their height in the

past 50 years. The average American woman of 25 years has now become 6lbs lighter; instead the American male has become heavier (Society of Actuaries, 1959). In a typical western society the expectation of life from birth to 70 is greater for females than it is for males and the differential has increased markedly in the past thirty years. How much of this may be associated with weight differences is not known.

The timing of physical maturity at adolescence is also changing. In western Europe over the past 100 years menarche has been occurring three months earlier each decade (Tanner, 1962). There is accompanying earlier maturation in males. The lack of significant changes over one generation in a well-nourished American group (MacCammon, 1965) suggests that there is a limit to the secular change and indeed it is possible to calculate this, at least insofar as mature height is concerned.

The evidence on identical twins reared together as well as reared apart suggests that about 90% of the variance in height may be attributed to hereditary factors. The remaining approximate 10% will be determined by the environment. Bloom (1964) has calculated that abundant - deprived environments may cause height differences as follows: conception - 3 years 5.4%, 3 - 12 years 3.2%, 12 - 18 years 1.4%. In animal experiments McCay (McCay et al., 1935; McCay et al., 1939) has demonstrated variation in body length by means of restricted diets of up to 18% and in fact agricultural research statisticians know well that by special feedings at appropriate growth periods it is possible, within certain limits, to produce animals in specified combinations of bone, muscle and fat. As a matter of interest, in McCay's experiments the females resisted the unfavourable environment better and in general nutritionally deprived animals lived longer. The effects of undernutrition on length of life in rats has been discussed by Ross in Diet and Bodily Constitution (Wolstenholme and O'Connor, 1964), deriving from the Ciba Foundation Study Group No.17. This book is also a source of much other thought provoking information. From the weight of evidence available it must be inferred that the environment exerts its greatest influence during the period of most rapid growth and that the secular change is most likely associated with better nutrition and child care, although it cannot be excluded that a small part of the increase in adult height is due to heterosis (Hulse, 1960). In our own studies when mother daughter pairs were considered, the greatest decline in the age of menarche was found in families who had moved rapidly upwards in the social scale (Boutourline Young et al., 1963).

Further sex differences

A further example of male vulnerability is the course of growth in Japanese children exposed to atomic radiation following atomic bombings. Two years following exposure boys were significantly more retarded than girls in skeletal age. In children who received accidental radiation in the Marshall Islands, when observations were made after an interval of two years, the growth in height of girls was unaffected while boys were five centimeters smaller than expected.

On the basis of relationships between the intelligences and social and emotional behaviors of mother and child, Bayley (1963) has hypothesized that in infancy males are more affected than females by certain environmental factors in intellectual and emotional aspects of growth.

Geographical differences in growth

French and British studies in Africa (Dean, 1962) have shown that African infants do not differ greatly in their mean lengths and weights from current American standards. However, by one year of age they were not making the same progress and by the age of three were markedly behind. These changes have been ascribed to undernutrition and there is evidence that this is at least partly true but a recent paper reporting growth curves of healthy middle class Uganda children shows a concavity in both height and weight curves between 12 and 40 months (Rutishauser, 1965). Further work is necessary to determine if the growth curve is genetically different from British and American children, which seems unlikely, or if some essential nutrient is not available or effective despite the satisfactory economic circumstances. Catch-up growth subsequently occurs, as by 50 months the African children have again returned to the British growth curve.

It is of interest that conditions of severe nutritional adversity such as occurred in Holland during 1944-1945 may actually affect the weight of the foetus. A weight reduction of 240 gr occurred in new born infants during this period.

A recent advance in the identification of the relative parts played by calorie and protein deficiency in states of undernutrition has been made by the use of the hydroxyproline/creatinine ratio in the urine as an index of nutritional status and rate of growth (Whitehead, 1965).

Growth in other than physical variables

Intelligence has already been mentioned as a stable variable, that is, during healthy development it is not readily reversible. By age two the correlation with the findings at age 17 has already reached .41, by age 4 it reaches .79, by age 11 it is .92 (Bayley, 1949). Honzik (1957) has shown that adopted children, as they develop, correlate progressively more highly with their real parents and less with their adopted ones. However, it has been demonstrated (Anastasi, 1958) that identical twins reared in dissimilar environments may differ by as much as 20 I.Q. points and Bloom (1964) has hypothesized this as 10,6,4 respectively for the periods birth - 4 years, 4 - 8 years, 8 - 17 years. There seems little doubt that the development of intelligence is to some extent related to the environment, especially in the first years of life, although other workers (Burt, 1958; Shields, 1962) do not give as much importance to the environment as Bloom. However, data from the Fels Study (Kagan and Moss, 1959) indicate that maternal education may be an important factor in promoting a child's I.Q. score. In contrast to the findings with regard to height, there is now evidence that under favourable circumstances intelligence, and in particular its verbal aspects, may show slow positive development until age 50 (Bayley, 1955). Already twenty years ago it had been demonstrated in England (Raven, 1948) that in individuals with high initial levels there was little if any deterioration in performance in verbal intelligence scores until age 60.

Just as body height was chosen here as an example of a stable physical growth variable, so performance on reliable intelligence tests was cited in respect of psychic development. Other behavioral measures such as achievement scores and personality assessments could have been cited; these have been well described by Bloom (1964).

Relationships between variables

Individual variations in I.Q. score during a longitudinal study have been reported by Sontag and colleagues who showed relationships between measures of need to achieve and changes in intellectual performance in the years up to ten (Sontag et al., 1958).

It has been demonstrated that there is a positive correlation between height and intelligence (Shuttleworth, 1949; Scottish Council for Research in Education, 1953). As there is also a social class correlation with both height and intelligence, in that both increase progressively towards the

more privileged end of the social spectrum, it was thought that the explanation lay there. However, in a recent paper by Douglas (Douglas et al., 1965) it appears that neither sex, social class, family size nor phase of puberty can be advanced as an explanation. The reason must still be sought.

The environment and its measurement

Bloom (1964) has shown that the use of the variable "environment" markedly increases precision in the estimates of mature status of a human characteristic. This implies that in equations where it is known what a human characteristic should be under favourable circumstances one may solve for the variable environment and this may prove of real value for underdeveloped countries in calculations of necessary economic inputs, assuming that the welfare of the people is a central issue.

It is plain that a major difficulty in the biological and even more in the behavioral sciences has been measurement of the environment. Relationships between social class and intelligence have been known for some time (Havighurst and Janke, 1944) and some features of this have been emphasized (Boutourline Young et al., 1962), but social class may be a relatively crude measure. There is evidence that the limited variability in intelligence scores apportioned to environment is related chiefly to a specific education factor in the home. (Newman et al., 1937). This factor is related to stimulation for verbal development, the extent to which there is reward for verbal reasoning skills and reinforcement for a wide degree of problem solving.

Bayley (1965) has recently reported results of mental and motor testing from 1-15 months to what appear to be good samples of negro and white infants and to a smaller sample of Puerto Rican babies. There were no differences in mental scores up to the age of 15 months. This contrasts with repeated reports of considerable differences between these groups from the age of 4. It is clear that the period from 15 months to 4 years is very important for development of mental functions and further investigation of the environment is an obvious next step.

In the biological sciences a small experiment of our own has shown that holding good overall health care constant, the administration of meats in substitute for carbohydrates to the randomly chosen experimental subject of paired infants will significantly increase body length during the period 5 - 8 months and also for the period 9 - 12 months although to a

lesser degree in the second of the two periods (Boutourline Young et al., 1957). This reinforced our belief that the period of most rapid somatic growth is most susceptible to environmental influence.

It is clear that there is need to identify environmental variables closely related to human growth characteristics and to develop methods to measure them.

This paper has confined itself to aspects of growth and the environment which particularly interest the author. A host of problems such as relationships between both body build and sex with maturation rate have been deliberately omitted. The choice of topics has been the areas which have appeared "sensitive" - that is, open to good progress with well directed research attacks. The paper has sought to define in selected characteristics the proportion of variability determined by heredity and environment and from then on explored ways in which human growth variables, both physical and mental, may be related to specific environmental factors. It is hoped that such research efforts will not only point the way to control and remedy of disease and deficiency disorders, but also assist in obtaining for the ordinary person the development of his or her full potential.

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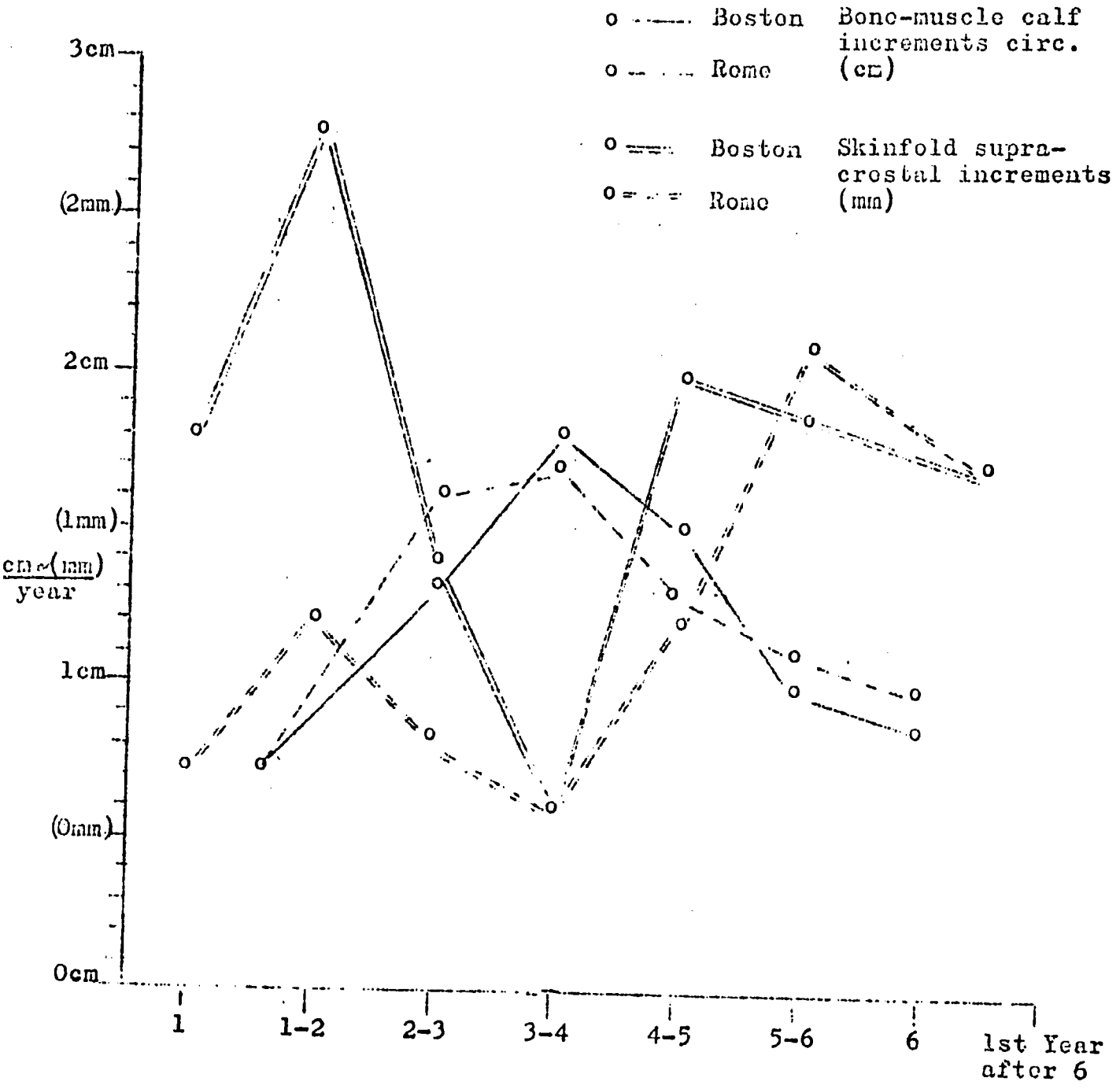
TABLE 1

Intercorrelations of some growth variables, measures of biological maturity and skeletal age in 78 Boston boys (average age 14.4 years, SD 1.3 years)

Variable		1	7	8	9	15	16	17	18	19	21	22	23	24	25
Weight	1	-	.73	.53	.73	.61	.58	.63	.58	.63	.46	.64	.64	.68	.70
Sitting height	7	.73	-	.52	.82	.77	.82	.85	.84	.82	.65	.81	.84	.82	.86
Leg length	8	.53	.52	-	.61	.44	.48	.49	.48	.49	.37	.44	.50	.47	.50
Arm length	9	.73	.82	.61	-	.68	.68	.74	.69	.73	.60	.73	.75	.78	.80
Dynamometer	15	.61	.77	.44	.68	-	.64	.72	.73	.76	.60	.72	.74	.71	.76
Axillary hair	16	.58	.82	.48	.68	.64	-	.87	.81	.87	.69	.74	.77	.69	.76
Pubic hair	17	.63	.85	.49	.74	.72	.87	-	.91	.92	.74	.83	.86	.83	.88
Test. volume	18	.58	.84	.48	.69	.73	.81	.91	-	.88	.70	.78	.85	.77	.83
Estimated puberal age	19	.63	.82	.49	.73	.76	.87	.92	.88	-	.78	.83	.83	.78	.85
Chronological age	21	.46	.65	.37	.60	.60	.69	.74	.70	.78	-	.70	.66	.66	.71
Skeletal age Greulich Pyle	22	.64	.81	.44	.73	.72	.74	.83	.78	.83	.70	-	.89	.87	.92
Skeletal age long bones	23	.64	.84	.50	.75	.74	.77	.86	.86	.83	.66	.89	-	.88	.94
Skeletal age carpus	24	.68	.82	.47	.78	.71	.69	.83	.77	.78	.66	.87	.88	-	.98
Skeletal age Tanner Whitehouse	25	.70	.86	.50	.80	.76	.76	.88	.83	.85	.71	.92	.94	.98	-

Figure 1

INCREMENTS



PUBERAL MATURITY