

OXFORD CHILD HEALTH SURVEY*

STATURE AND SKELETAL MATURATION IN THE PRE-SCHOOL CHILD

BY

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In the majority of children the two complementary processes of growth† and skeletal maturation‡ are so well balanced that they tend to be thought of as two aspects of a single process. This view is partly justified by the fact that the two processes start together and must stop together, since there can be no further increase in height once the epiphyses of the long bones have closed. Yet growth and maturation can proceed quite independently, as is shown on the one hand by the dwarf (whose skeleton matures while growing very little) and on the other hand by the giant (whose stature is excessive for his maturity). Between these two pathological extremes it is natural to look for a range of physiological variation in the balance of rate of growth against rate of maturation. The child who comes to maturity quickly has had less time for growing, and, if he has only gained height at the average number of inches per year, must be a smaller adult. But it has often been observed that children who mature rapidly tend also to grow more rapidly than others. The question therefore arises, whether the more rapid growth of such children is sufficient to compensate for the shorter growth period at their disposal, or whether these physiologically fast maturers tend, as a group, to be small adults. Bayley (1943a and b, 1946), and Bayley and Pinneau (1952), in a study of pubescent children, concluded that rapidly maturing children tend to be shorter in the end than those who mature slowly.

The present study has two purposes:

- (a) to discover whether observations on pre-school children provide any parallel to Bayley's findings;

- (b) to see how the normal balance between growth and maturation is affected by an adverse environment.

MATERIAL

The observations on which this study is based were all made at the 6-monthly examinations of healthy children which formed a part of the Oxford Child Health Survey. The conduct of this survey has been described in detail by Thwaites (1950) and by Stewart and Russell (1952). Of the many items of information recorded at these examinations, five are relevant to the present study of growth and maturation:

- (i) *Calendar Age*.—The numbers of children of each age for whom complete data were available are shown in Table I.

TABLE I
NUMBERS OF CHILDREN FOR WHOM BOTH STANDING HEIGHT AND TODD STANDARD WERE AVAILABLE

Age (years)	Social Class					
	Boys			Girls		
	I and II	IV and V	All Classes	I and II	IV and V	All Classes
1½	17	17	134	12	24	129
2	36	37	254	46	43	260
2½	42	35	238	40	43	257
3	35	36	242	42	43	261
3½	33	33	239	41	40	245
4	34	35	243	41	37	250
4½	31	32	225	40	42	238
5	31	36	233	38	41	234

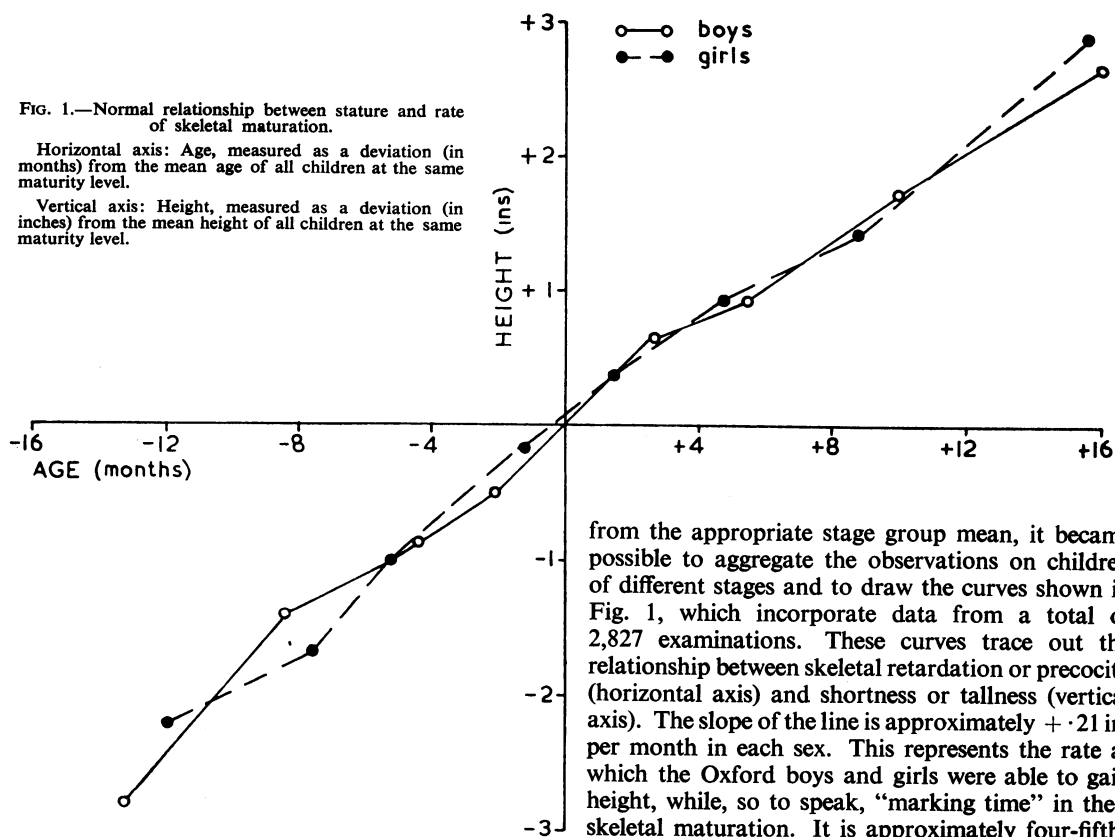
- (ii) *Sex*.—It is necessary to consider the sexes separately, since girls mature much more rapidly than boys.

- (iii) *Standing Height*.—This was taken with the child in bare feet. Since very few of the year-old babies could co-operate sufficiently for this measurement to be taken, the youngest age group represented in this study is that of 18 months.

- (iv) *Skeletal Maturity Status*.—This was assessed by the method of Todd (1937). Some unsatisfactory features of this method and of the concept of "skeletal age" ("stage" *passim*) have been discussed elsewhere

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† In this paper "growth" means increase in stature. The term "skeletal maturation" has been well defined by Krogman (1949): "Maturity is an end product, an achieved state, and maturation a series of way stations along the path towards this final condition. There can be no reasonable doubt about the inevitability of morphological maturity; all things being normal there must come a time when the process of growth reaches a terminus, a time when adult or mature values are reached."



(Acheson, 1954). Nevertheless it has been used in this paper for the sake of comparability with the American growth studies (Shuttleworth, 1937, 1938; Bayley, 1943 a and b, 1946; Bayley and Pinneau, 1952).

(v) *Father's Occupation*.—This is the basis of the conventional classification by social-economic status into five Social Classes (Registrar-General, 1951).

PHYSIOLOGICAL RELATIONSHIP BETWEEN SKELETAL GROWTH AND MATURATION

It is convenient to group the observations by stage rather than by calendar age, and then to compare the heights of the children who have reached a stage early (*i.e.* the relatively young ones) with those who have reached it late. When this comparison was made from the Oxford data it was found that the slow maturers were taller than the average for equally mature children, while the fast maturers were shorter. This held good for both sexes and for all the stage-groups adequately covered by the material (*i.e.* Todd's standards 5 to 10 for boys and 5 to 11 for girls). When all the ages and measurements had been expressed in terms of deviations

from the appropriate stage group mean, it became possible to aggregate the observations on children of different stages and to draw the curves shown in Fig. 1, which incorporate data from a total of 2,827 examinations. These curves trace out the relationship between skeletal retardation or precocity (horizontal axis) and shortness or tallness (vertical axis). The slope of the line is approximately $+0.21$ in. per month in each sex. This represents the rate at which the Oxford boys and girls were able to gain height, while, so to speak, "marking time" in their skeletal maturation. It is approximately four-fifths of the average height gain per month of the same group of children over the age range 18 months to 5 years. Thus these children do show a wide physiological variation in the balance between rate of growth and rate of maturation.

It must be conceded that the radiographs assigned to each stage group do not show skeletons of identical maturity. As the assessments are all made to the nearest Todd standard, there is a range of maturity within each stage group roughly equivalent to the amount of maturation taking place in 6 months of healthy development. It follows that an imaginary "average" child would not always appear exactly at the intersection of the axes in Fig. 1. He would repeatedly move up a diagonal line from a point about $(-3 \text{ months}, -0.7 \text{ in.})$, on entering a stage group, to a point about $(+3 \text{ months}, +0.7 \text{ in.})$ on leaving it. Thus any diagonal scatter of points within the ranges ± 3 months and ± 0.7 in. might be regarded as an artefact rather than as evidence of a real relationship between rate of maturation and height. But it will be seen that the points in Fig. 1 extend far outside these ranges, indicating real height contrasts between children with different

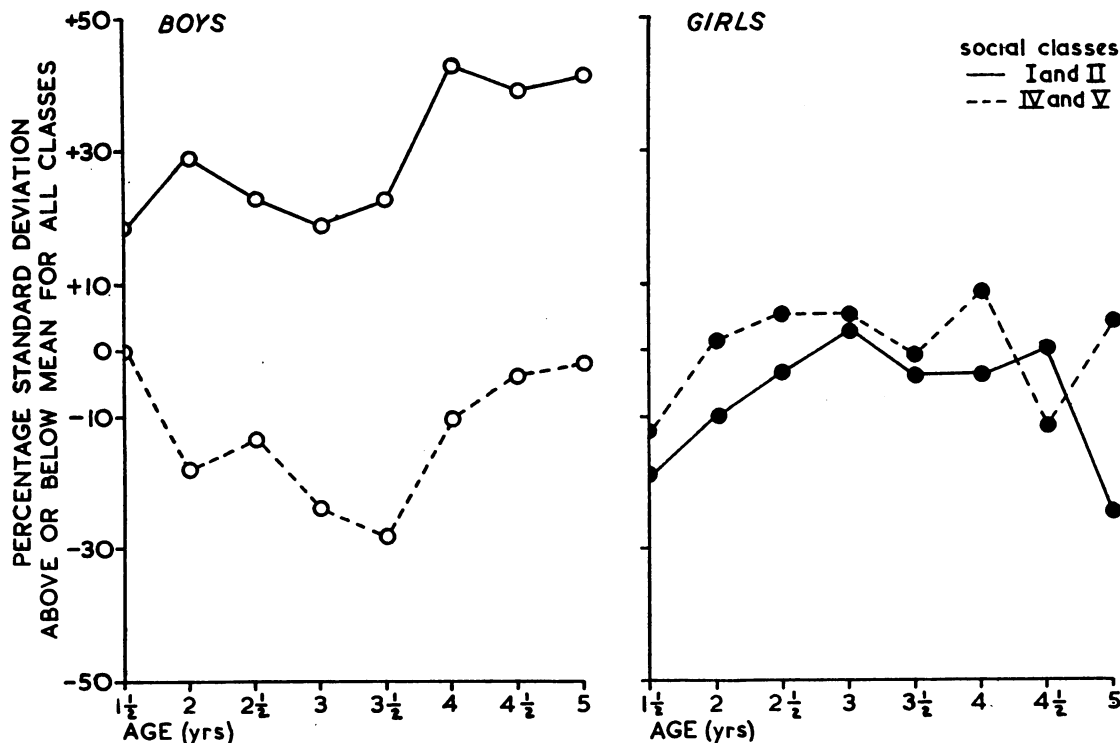


FIG. 2.—Comparative skeletal maturity of Social Classes I and II, and IV and V.

rates of maturation, as well as some artificial contrasts due to the approximate method of determining maturity status.*

There is no reason to doubt that children whose skeletons mature rapidly in the first few years of life tend also to mature rapidly in later childhood and in adolescence. Thus the present findings, together with those reported by Bayley (1943 a and b, 1946) imply that there is a group of children whose rapid maturation marks them out, well before they reach school age, as small adults of the future.

EFFECT OF ENVIRONMENT ON THE RELATION BETWEEN GROWTH AND MATURATION

It is well known that an unfavourable environment affects the growth of young children, and it has also been reported that bad environment can slow down the process of maturation (Stettner, 1920, 1921, 1931; De Wijn, 1953; Greulich, 1951; Greulich and others, 1953).

The question arises whether children whose maturation is held back in this way follow the same developmental pattern as the physiologically slow maturers, *i.e.* whether they tend to become rather

tall adults. This question cannot, of course, be answered without considering the effect of the same environment on the rate of growth.

Figs 2 and 3 are intended to throw some light on these points. These Figures were constructed as follows. First the means and standard deviations of height and of stage were calculated for each sex for eight age groups. Then separate means were obtained for a group of well-to-do children (fathers in Social Class I or II) and for a group of poor children (fathers in Social Class IV or V). These latter means were then expressed as percentages of a standard deviation above or below the mean for all classes, and were plotted against age in Fig. 2 (maturation) and Fig. 3 (growth). The information in these Figures can be roughly summarized by averaging the social class deviations over all eight age-groups, as shown in Table II.

TABLE II

MEAN PERCENTAGE LEAD OF WELL-TO-DO OVER POORER CHILDREN OBSERVED FROM 1½ TO 5 YEARS AS A PERCENTAGE OF THE STANDARD DEVIATION FOR ALL CLASSES

Sex	Height	Maturity
Boys	+60	+43
Girls	+36	-7

* A more precise method of determining maturity status (Acheson, 1954) was applied to a sub-sample of one hundred of the survey children, and led to curves very like those in Fig. 1.

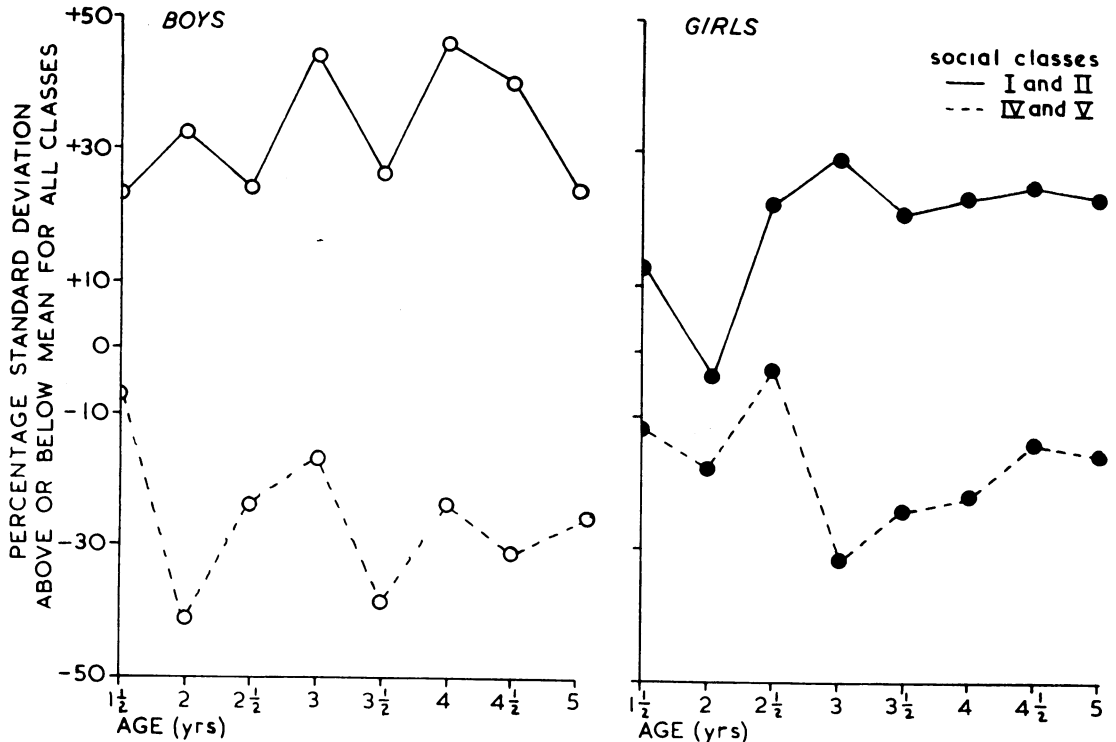


FIG. 3.—Comparative height of Social Classes I and II, and IV and V.

Fig. 2 shows that the Oxford boys in the poorest social groups were maturing more slowly than those in the best environment. The Oxford girls, on the other hand, did not show any regular social class difference in maturation. Thus the maturation of these girls, besides being more rapid than that of the boys, appeared to be less affected by environment. This tallies with the observations of Greulich (1951) and Greulich and others (1953) - on child survivors of starvation and atomic bombing.

Fig. 3 shows that the group of boys in which slow maturation might be attributed to environment suffered a more than proportionate slowing down of growth. Thus they differed from the physiologically slow maturers by showing signs of a relatively short final height. The girls, whose rate of maturation did *not* appear to have been affected by environment, also showed a clear social differentiation in height. It follows that, if stage groups are substituted for age groups as the basis of comparison, these girls must show greater social differentiation in stature than the boys. This is illustrated in Fig. 4, in which the height advantage of the well-to-do over the poorer boys of equal maturity is barely perceptible, while the well-to-do girls show a lead of more than half an inch. If these tendencies persisted throughout

the later stages of childhood, one would expect to find that social class differences in final height, in so far as they are determined by environment, would be greater in girls than in boys.

Although social class has been interpreted in this section as an index of environment, it should be borne in mind that some social class differences may themselves be genetic in origin. Between the fathers of Social Classes I and II and those of Social Classes IV and V there was a height difference of 1.7 in. in favour of the well-to-do, while the more prosperous mothers were 1.6 in. taller. But it is not practicable to push the analysis any further, since differences between the parents (many of whom grew up in circumstances very like those of their adult lives) must in turn owe something to environment.

DISCUSSION

The literature on child development contains many reports on rates of growth (*i.e.* increase in stature per unit increase in calendar age). These rates have been reported separately for the sexes, for economic groups, and for well and ill children. Such reports have thrown much light on the intermediate years of development, but they provide no satisfactory

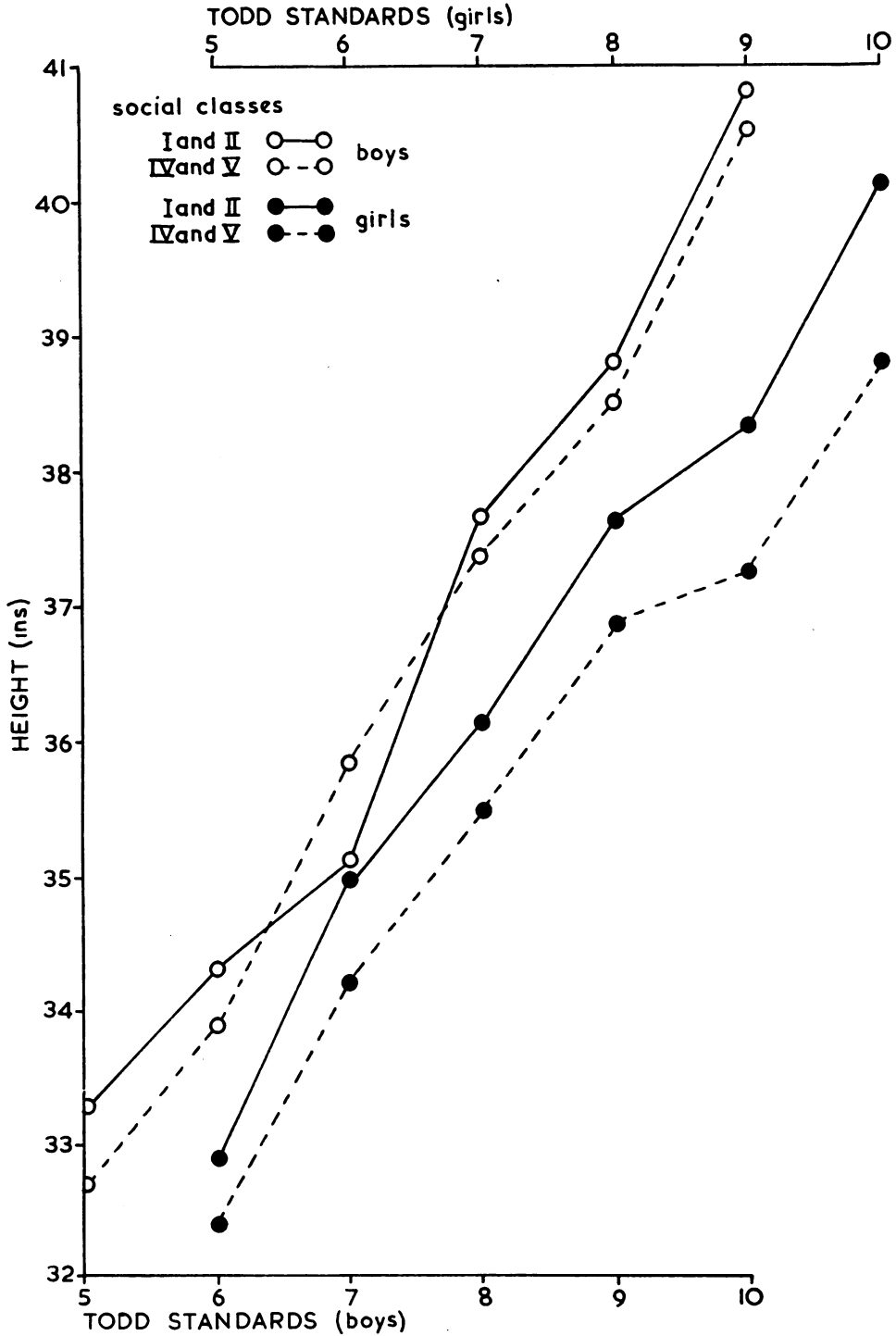


FIG. 4.—Heights of boys and girls in different social groups. Comparisons based on children of equal skeletal maturity.

evidence on one topic of considerable interest: the determination of final adult height. The final height of the mature individual depends on his rate of growth *relative* to his rate of maturation, summed over all the stages of maturation from conception to closure of the epiphyses.

It is reasonable to suppose that for children living under ideal conditions both the rate of growth and the rate of maturation would be determined completely by heredity. It is convenient to have a name for the ideal relationship between these rates, and we may therefore define the "growth potential" of a child as his increase in stature, under ideal conditions, per unit increase in maturity. If a child living in an imperfect environment suffered equivalent reductions in rate of growth and in rate of maturation, he would still succeed in fulfilling his "growth potential" and his adult height would not be affected. But the Oxford data suggest that imperfections in the environment do *not* have an equivalent effect on these two rates, and that it is by means of this inequality that environment can exercise an effect on adult height. If, as appears to be the case, the growth rate is the more affected the child will fail to fulfil his full "growth potential", and thus tend to become a smaller adult. In these terms the extra height of adults belonging to the richer groups of the community would be said to have two components: first a rather larger hereditary "growth potential" and second, a greater success (attributable to environment) in fulfilling the "growth potential" available to them.

It has been shown (Clements, 1953) that the children of to-day are taller, age for age, than the children of recent decades; there can be no question of attributing this change to a spontaneous increase in the "growth potential" of the community, in fact the difference must be due to improvements in nutrition, housing, clothing, and health. It has also been shown (Howe and Schiller, 1952) that the height of German schoolchildren fluctuated with their country's fortunes during the past 40 years, and that although the general trend was upwards, it was disturbed by such events as the slump of 1930 and the two world wars. However, it is not certain whether environmental improvements merely accelerate the process of development towards physical maturity, or whether they enable a greater proportion of children to fulfil their "growth potential". The present set of observations, since they were made on children less than one-third of the way towards maturity, cannot do more than suggest which of these alternatives is the correct one. But, taken together with the other available evidence, they do lend some support to the hypothesis of

increasing fulfilment of "growth potential", and thus of a net increase in the adult height of the population. It is a further point in favour of this suggestion that both Clements (1953) and Howe and Schiller (1952) report the greatest fluctuation in height in the poorest section of the community.

The apparent difference between the sexes in their response to environmental conditions may prove to be one of the most significant features of the Oxford data. That girls are less liable to retarded maturation than boys has been reported by Greulich (1951) and Greulich and others (1953).

The present observations suggest an interesting paradox: that the sex which brooks the least delay in its progress towards maturity may also be the sex which in adult life bears the clearest marks of poor childhood environment.

The fact that the average height of men is above that for women may be regarded as a special case of the association between slow maturation and above average stature in adult life.

SUMMARY

(1) From clinical and radiological observations on 580 pre-school children at Oxford it is found that:

(a) when all social groups are considered together for any skeletal maturity status, slowly maturing children are taller than the mean, and rapidly maturing children shorter than the mean;

(b) age for age, children of both sexes from the poorer social groups are smaller than children of well-to-do parents;

(c) the slow maturation found in the poorer boys is not associated with the greater-than-average height, which is a feature of slow maturation in the survey as a whole;

(d) the maturation of girls appears to be less affected by social environment than that of the boys.

(2) These findings are discussed in terms of a genetically determined "growth potential", which depends for its fulfilment on a favourable environment.

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