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GROWTH AND DEVELOPMENT

With Special Reference to Domestic Animals

IX. A Comparison of Growth Curves of Man and Other Animals

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CONTENTS

ABSTRACT

A quantitative comparison between the age curves of growth in weight of man and other animals is presented. 1. The most conspicuous difference appears in the relatively extreme length of the juvenile period in man, and in the relatively extremely low percentage rate of growth during the same period. 2. The position of inflection (puberty) is, relatively, very late in the period of growth in man. 3. Outside of the relatively very late initiation of puberty in man, the properties of the segment of the growth curve beginning with puberty are qualitatively and quantitatively the same in man and other animals. 4. There are qualitative differences between the properties of the segment of the infantile period of man and animals. In animals the percentage rate of growth during the infantile period appears to be constant, while in man it appears to decline with increasing age. 5. The age curve of prenatal growth in man indicates a relatively low percentage rate of growth as compared to the corresponding period in other animals. In addition to the quantitative differences there may also be a qualitative difference between the growth curves of man and animals during this period. 6. As in other animals, growth in length appears to be approximately linear whenever growth in weight is exponential.

ACKNOWLEDGMENT

The principal portion of the expenses involved in this investigation was paid from a grant by the Committee on Food and Nutrition of the National Research Council. Grateful acknowledgment is made for this cooperation, which was received through the recommendation of Dr. Graham Lusk, Chairman.

Grateful acknowledgment is made to F. B. Mumford and A. C. Ragsdale for their interest in and support of this work.

GROWTH AND DEVELOPMENT

With Special Reference to Domestic Animals

IX. A Comparison of Growth Curves of Man and Other Animals

SAMUEL BRODY

I. INTRODUCTION

The preceding bulletins of this series were concerned almost exclusively with the growth curves of animals other than man. Several considerations, mainly of a theoretical nature, made it desirable to examine the course, of growth in man and to compare it to the course of growth in other animals. The present bulletin is a general report on this work of comparison. Certain questions of detail relating to the growth of man, such as the influence of race, sex, and nutrition; the relation between weight, height, surface area, and metabolism have also been given consideration, but these results will probably be reported, together with the results of a similar nature on animals, in some future bulletin of this series.

Before proceeding with the subject matter of this paper, it may be convenient to recall a few general facts relating to growth curves, the details of which have been discussed in the preceding bulletins of this series (Missouri Res. Buls. 96, 97, 98, 99, 101, 102, 103).

The period of growth in weight or volume may be divided into two fairly distinct phases: (1) *a self-accelerating phase* during which the time rate of growth increases with the increase in size of the organism; and (2) *a self-inhibiting phase* during which the time rate of growth decreases with the increase in size of the organism. The age curve of growth when plotted on arithmetically coordinate paper has an increasing slope during the self-accelerating phase of growth, and a decreasing slope during the self-inhibiting phase of growth. The junction between the two phases of growth coincides, roughly, with puberty in animals and with flowering in plants. Puberty is thus a critical period in the life of the individual not only because it is the beginning of the reproductive period, but also because it marks the transition from a consistently increasing to a consistently decreasing velocity of growth (*cf.* Fig. 4 in Res. Bul. 97 of this series).

It may also be convenient to recall that the quantitative interpretations of the age curves of growth as given in the preceding bulletins have been based on what may be termed as a molecular mechanism. It is assumed that organisms are made up of reproducing individuals—cells, molecules, atoms. According to this assumed molecular mechanism of growth, the age curve of growth reflects the changing condition of equilibrium between two forces: (1) the force inherent in the reproducing entities to reproduce (grow) at a constant percentage rate characteristic of their kind, in accordance with the law of mass action; and (2) the "back pressure" of the limited environment in which growth takes place. The resultant of these two forces during the course of growth is represented graphically (on arithmetically coordinate paper) by an S-shaped curve with one segment of (usually) increasing slope, and another of decreasing slope as previously explained.

The shape of the age curve of growth in weight of man resembles in its general features the age curves of animals in containing the two principal segments. In its details, however, there are several differences between the growth curves of man and animals, and the purpose of this bulletin is to indicate these differences in a quantitative manner.

II. GROWTH IN WEIGHT

Perhaps the most impressive way of bringing into relief the differences between the age curves of growth in weight of man and animals is by means of equivalence charts, prepared according to the method described in Research Bulletin 102 of this series.

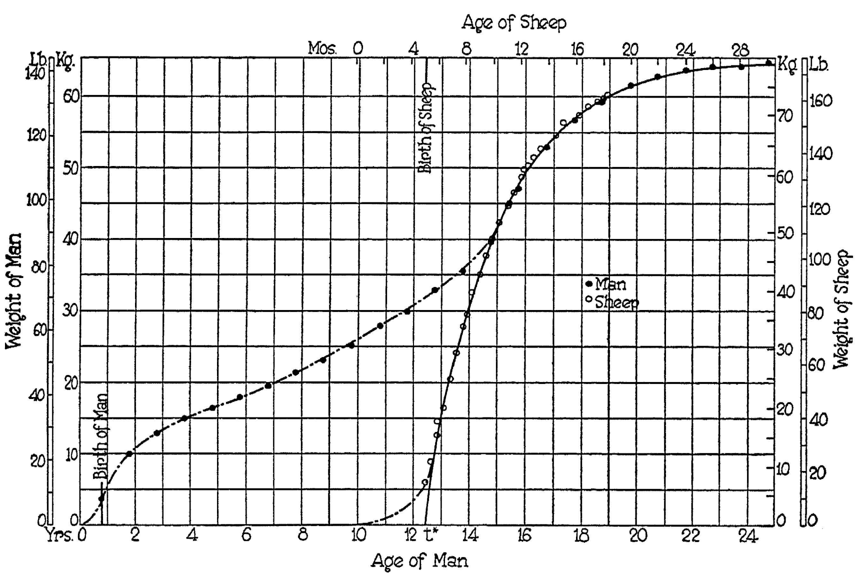

Fig. 1a—Growth equivalence (during the phase of growth following puberty) between sheep and man. Note that sheep and man have approximately the same mature weight; then note the relative number of months required to reach the mature weight in the sheep and in man. Note also the long juvenile period (3 to 15 years) in man, and compare with the practically insignificant juvenile period in the sheep. These differences between the curves of man and animals are typical. (C. D. Sparrow, H. H. Kibler, and R. C. Hase, undergraduate students in the University of Missouri, participated in the preparation of this and subsequent figures.)

Figs. 1a, 1b, and 1c represent equivalence charts between man and animals as they relate to the self-inhibiting (that is, post-pubertal) phase of growth. These charts serve for the purpose of illustrating the fact that the difference between the growth curves of man and animals is infinitely greater than the differences between the curves of widely separated species of animals. The growth curve of man is, quantitatively viewed, in a class by itself, unless it will be found to be related to the growth curves of other primates. (Dr. Edgar Allen of this University is now collecting data on growth of monkeys.)

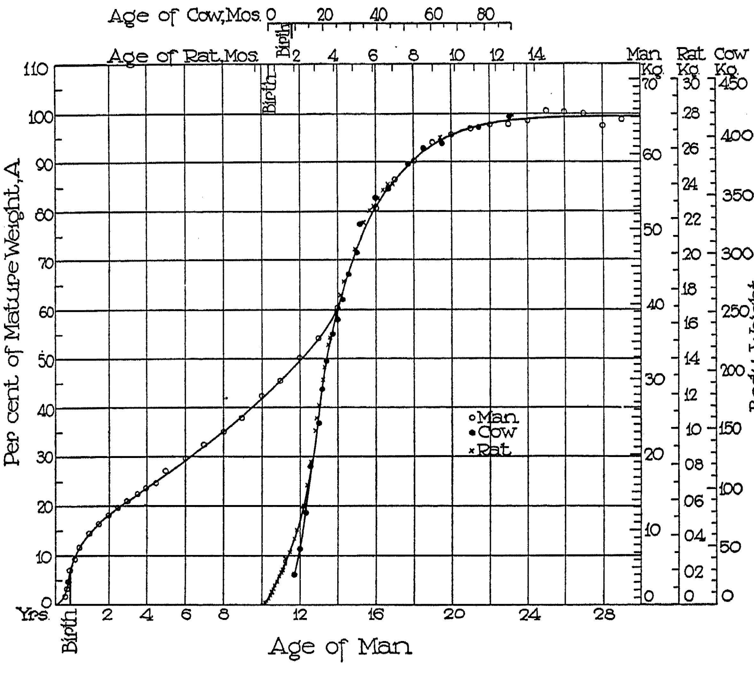

Fig. 1b—Growth equivalence between man, white rat, and Jersey cow.

Fig. 2 shows the difference between the growth curves of man and animals by another method. In this case the curves were plotted on the assumption that conception on one hand, and the age at which approximately 98 per cent of mature weight is reached on the other hand, are biologically equivalent points in growth curves of different species.

With Figs. 1 and 2 before us, we may enumerate the more obvious differences and similarities between the growth curves of man and animals.

1. The Length of the Juvenile Period.—The length of the juvenile period in man is about 10 years (4 to 14 years). This relatively enormous length of the juvenile period is, of course, the most distinguishing feature of the growth curve of man. The white rat has a relatively long juvenile period as compared, for example, to that in the cow; but in the rat it lasts only about 40 days (25 to 65 days of age). (See Fig. 2 for the relative lengths of the juvenile period in the rat and in man.)

2. The Position of the Pubertal Inflection.—In the curve of man, the major inflection (i. e., the junction between the self-accelerating and the self-inhibiting phases of growth which occurs at puberty) occurs when the body weight is, roughly, two-thirds of the mature weight; in

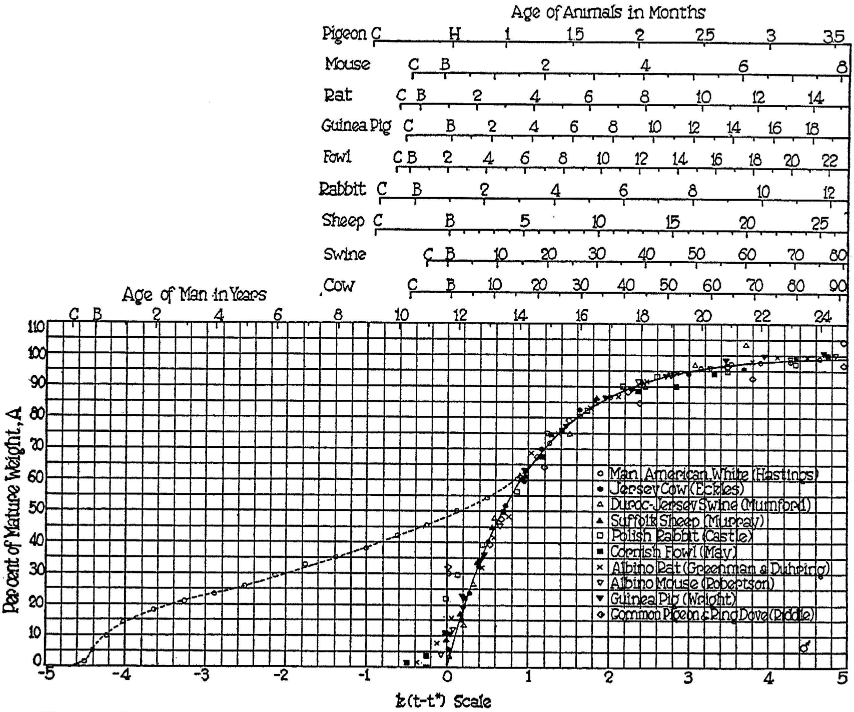

Fig. 1c—Growth equivalence (during the phase of growth following puberty) between man and animals plotted on a $k(t-t^*)$ grid as explained in Res. Bul. 102 of this series. The differences (as they relate to the juvenile and infantile periods) between the curves of man and animals are infinitely greater than the difference between the curves of widely separated species of animals.

animals, it occurs when the body weight is, roughly, one-third of the mature weight.

3. The Self-inhibiting Phase of Growth.—Following the major inflection (puberty), the course of growth in man and in animals is the same as shown in Figs. 1, 2, and 3. The time rates of growth decline, in both cases, by a constant percentage rate as explained in Research Bulletins 97 and 101 of this series. The numerical value of the percentage decline (100*k*) of the growth equation explained in the aforesaid

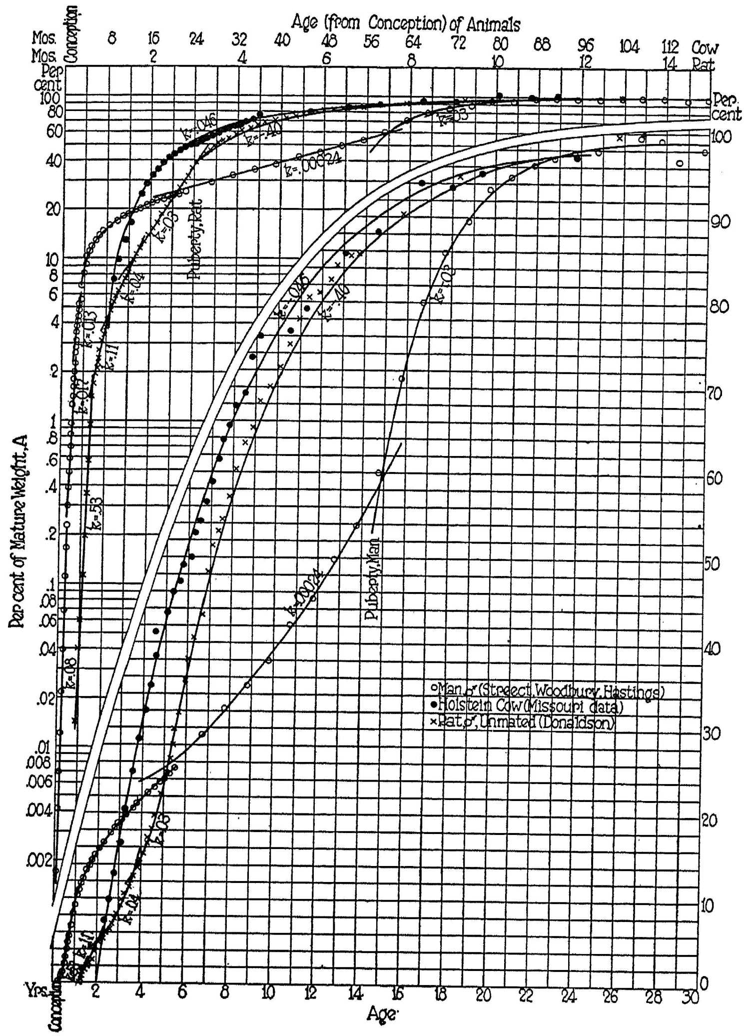

Fig. 2—A chart representing growth equivalence between man, albino rat, and Holstein cow, constructed on the assumption that conception, and ages at which approximately 98 per cent of the mature weight is reached, respectively, are equivalent points in the three species. The data are plotted on arithlog paper (on the axis of ordinates of which equal spaces represent equal *percentages* of growth), and on arithmetically coordinate paper. The theoretical curves have been extrapolated so as to facilitate differentiation of the several segments and to facilitate comparison of the corresponding segments in man and in animals. Note that age is counted not from birth, but from conception (man at birth is approximately 0.8 years of age; cow, 9.4 months; rat .73 months). The values of *k* (relative rate of growth) were computed on the basis of the day as the unit of time for the phase of growth preceding the inflection, and month as the unit of time for the phase of growth following the inflection. The axis of abscissae at the bottom represents man; at the top, animals. In place of *Streect* on the chart read *Streeter*.

The break in the curve between 4 and 6 years is greater than it should be as the data from birth to 6 years are by Woodbury, while following this period they are by Hastings (on another group of children). The data for prenatal growth are by Streeter.

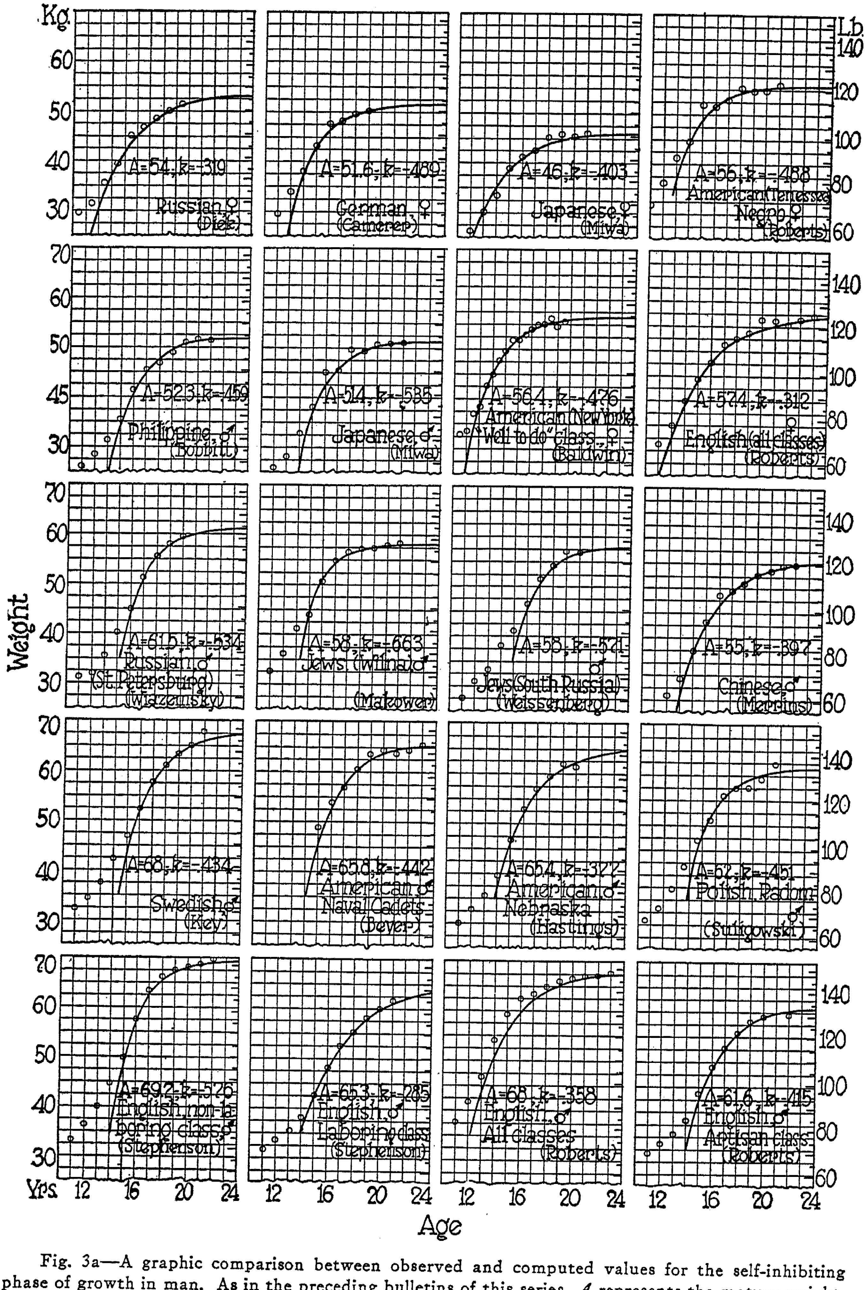

Fig. 3a—A graphic comparison between observed and computed values for the self-inhibiting phase of growth in man. As in the preceding bulletins of this series, *A* represents the mature weight, and 100*k* the percentage decline in the time rate of growth. The sources of data are given in Baldwin, B. T., *The Physical Growth of Children from Birth to Puberty*, Univ. Iowa Studies in Child Welfare, 1921, 1, 188.

bulletins) is less in man than in animals; but the differences are, relatively, not great. Thus in man the rate of decline in the time rate of growth is of the order of 3 per cent per month, while in the sheep, which has the same mature weight as man, it is of the order of 15 per cent per month. In dairy cattle it is of the order of 5 per cent per month. In brief, the curve of the phase of growth following puberty is qualitatively, and to a less extent quantitatively, practically the same in man and in animals.

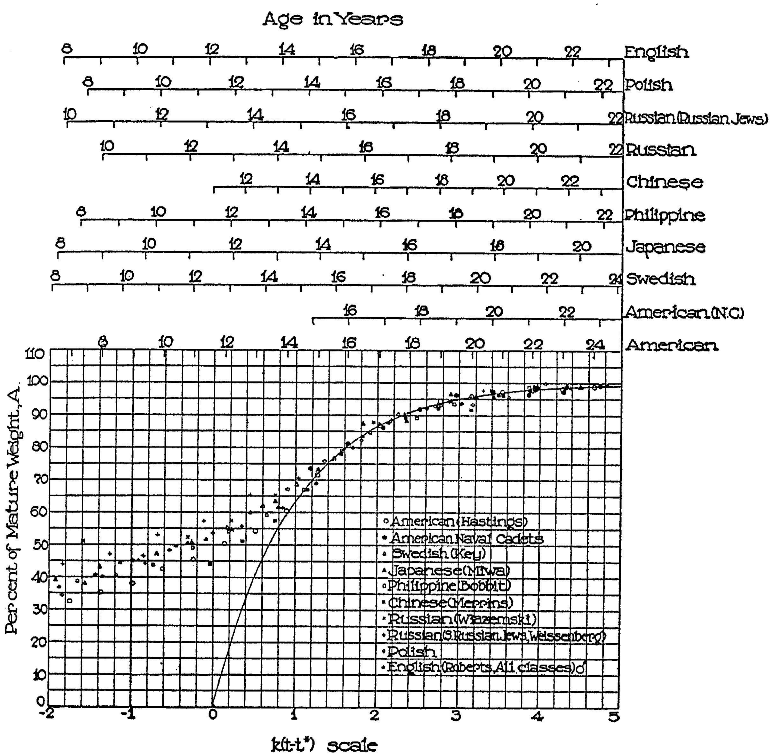

Fig. 3b—A graphic comparison between observed and computed values for the self-inhibiting phase of growth as obtained on plotting on a $k(t\text{-}t^*)$ grid. The data are for males. For sources of data see legend to Fig. 3a.

4. The Self-accelerating Phase of Growth.—The course of growth during the juvenile, and probably fetal, period, is *qualitatively* probably the same in man and in animals. The time rate of growth tends to increase at a constant percentage rate as shown in Figs. 4a, 4b, and 4c. There are, however, considerable *quantitative* differences between the curves of man and animals. The relatively enormous length of the juvenile period in man as compared to that in animals has already been mentioned. Another difference relates to the magnitude of the percentage rates of growth. In man, the percentage rate (100k) of growth during the juvenile period (4 to 14 years) is of the order of 0.03 per cent per day (10 per cent per year); in animals, it is of the order of 3.0 per cent per day (1000 per cent per year). The percentage rate of growth in animals is thus about 100 times as great as in man. In the fetal period, too, the percentage rate of growth in man is unusually low. Fig. 12 of Research Bulletin 98 of this series shows that the rate of growth

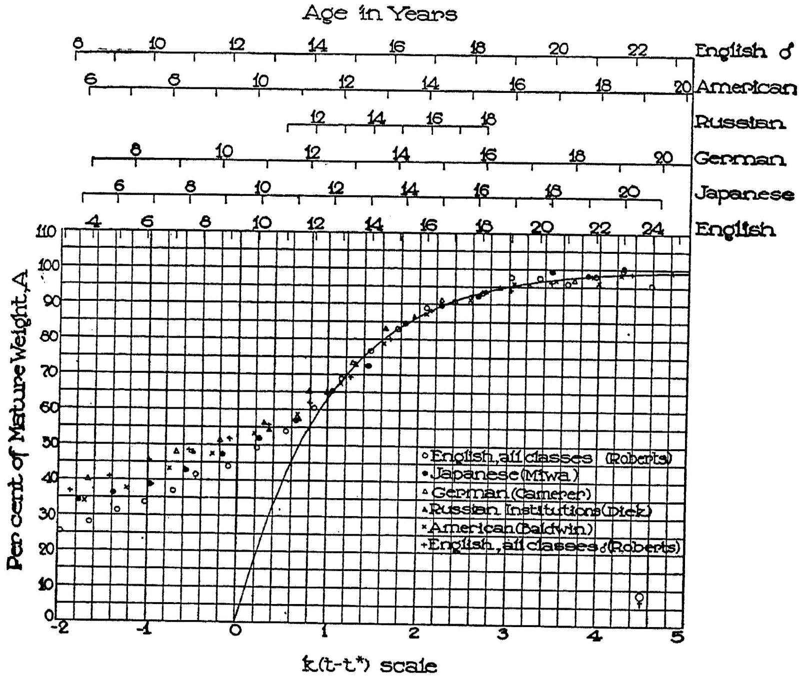

Fig. 3c—A graphic comparison between observed and computed values for the self-inhibiting phase of growth as obtained by plotting on a $k(t\text{-}t^*)$ grid. The data are for females excepting the one set indicated by the male symbol. For sources of data see legend to Fig. 3a.

during the third month of prenatal life in man is about 8 per cent per day; during the 3 months preceding birth it is of the order of 1.5 per cent per day. In the rat we have seen (see Fig. 6 of Res. Bul. 97) the rate of growth during the 9 days preceding birth to be of the order of 53 per cent per day; i. e., the percentge rate of growth in the rat is perhaps $\frac{53}{1.5} = 35$ times as great as in man. The difference between the percentage rates of prenatal growth in man and in animals does not,

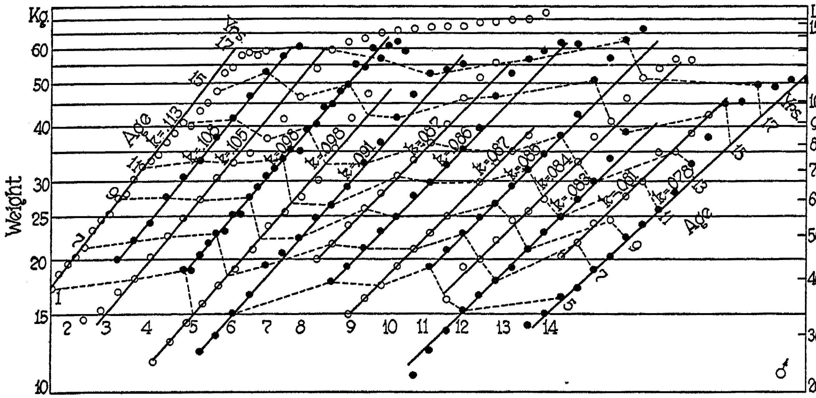

Fig. 4a—The course of growth of 14 groups of boys from 5 to 17 years of age. The numerals lettered in horizontally represent the following groups: 1. American (Baldwin, 1914, University of Chicago and Francis W. Parker Schools, Chicago; Horace Mann School, well-to-do class, New York); 2. Russian (Erismann, 1888, Moscow); 3. English (Roberts, 1878, all classes); 4. American (Baldwin, 1920, Francis W. Parker School, Chicago); 5. French (Variot and Chaumet, 1906, Paris, poorer class); 6. Italian (Pagliani, 1875-79, Turin); 7. American (Porter, 1893, St. Louis); 8. American (Hastings, 1902, Nebraska); 9. English (Tuxford and Glegg, 1911, all England); 10. German (Camerer, 1911); 11. South-Russian Jews (Weissenberg, 1911); 12. Japanese (Misawa, 1909); 13. Russian (Spielrein, 1916, children in Rostow not attending school); 14. Japanese (Miwa, 1893). Note that the curves are arranged according to the values of the rates of growth, *k*. Note also that the best cared-for children (Chicago and New York) come first in the series, while the children last in the series did not even attend school. For the original references to literature see legend to Fig. 3a.

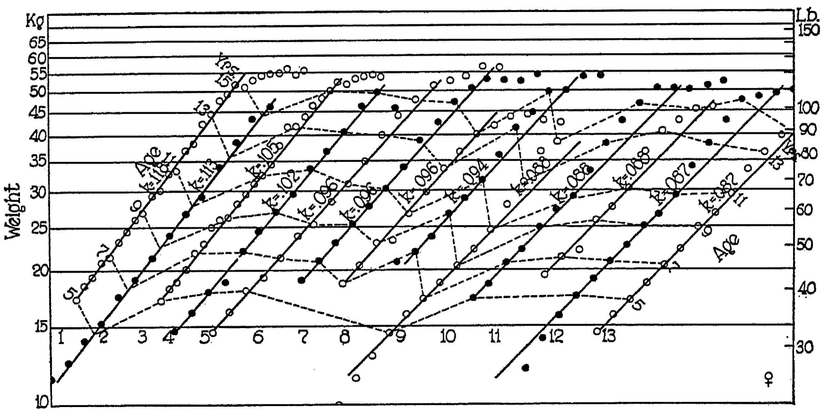

Fig. 4b—The course of growth of 13 groups of girls from 5 to 17 years of age. The numerals lettered in horizontally represent the following groups: 1. American (Baldwin, 1920, Horace Mann School well-to-do class, New York); 2. French (Variot and Chaumet, 1906, poorer class); 3. American (Baldwin, 1914, University of Chicago, Francis W. Parker School, Chicago and Horace Mann School, well-to-do class, New York); 4. Danish (Wahl, 1884); 5. English (Roberts, 1878, all classes); 6. American (Porter, 1893, St. Louis); 7. Philippine (Bobbitt, 1909); 8. American (Barnes, 1892, Oakland, Calif.); 9. Japanese (Misawa, 1909); 10. American (Hastings, 1902, Nebraska); 11. Russian (Erismann, 1888, Moscow); 12. German (Camerer, 1911); 13. English, (Tuxford and Glegg, 1911, all England).

For the original references to literature see Baldwin, in legend to Fig. 3a.

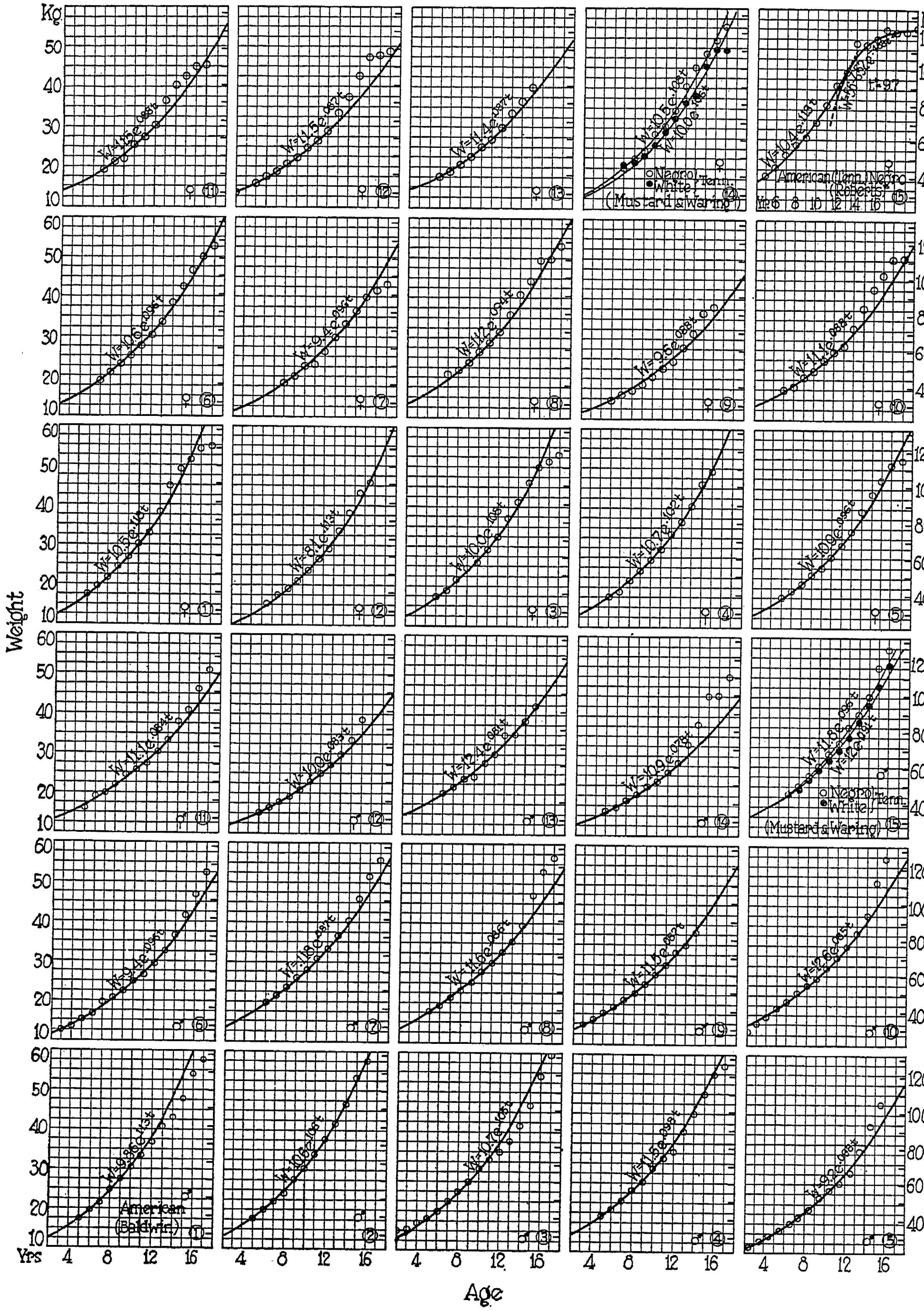

Fig. 4c—The data (observed and computed values) plotted in Figs. 4a and 4b on an arithlog grid, are plotted in this chart on an arithmetical grid. The numbers on the curves in this chart refer to the same data as the corresponding numbers in Figs. 4a and 4b.

therefore, appear to be as great as during the juvenile period. It is the juvenile period which, quantitatively considered is, superficially at least, the most conspicuous feature of the growth curve of man.

5. **The Infantile Period.**—In addition to the juvenile period, the infantile period in man is conspicuous by its differences from the corresponding segment in animals. It appears to show an inflection which is similar to the pubertal inflection in the curves of animals, but the inflection proves to be abortive. Sometimes between 2 and 4 years after birth the declining time rates of growth are changed into increasing time rates of growth, and practically constant percentage rates of growth. This constant percentage rate of growth often lasts from about the age of 4 until about the age of 15 years. It is this turn of events which principally differentiates the growth curve of man from that of animals. If the time rates of growth between the ages of 2 to 3 years did not change from a descending to an ascending course, the curve of man would appear not unlike that of animals.

6. **The Pubertal Acceleration.**—In children there is often an increase in the percentage rate of growth between the ages of 12 and 14 or 15 years after birth as shown in Fig. 4. Such an acceleration in the percentage rate of growth has not been definitely encountered in the growth curves of domestic animals. This increase in the rate of growth is referred to in the literature of growth as the "prepubertal acceleration." This acceleration can not, however, be said to constitute a qualitative genetic difference between the growth curves of man and animals, because it is not a universal feature of the growth curve of man (see Figs. 4a to 4c). This pubertal acceleration appears to be quantitatively related to the percentage rate of growth between 4 and 10 years. If the percentage rate of growth for a given group of children is relatively low during this earlier period, then there is usually an acceleration between 12 and 15 years; if it is high during this period then there is no acceleration. Figs. 4a to 4c illustrate this statement. It appears that the prepubertal acceleration is an expression of compensating growth in children who were relatively undernourished during the earlier years.

III. GROWTH IN LENGTH

The above discussion has been confined to the course of growth in weight. The course of growth in length, as pointed out in Res. Bul. 103 of this series, tends to be linear (growth at constant *time* rate) when growth in weight is exponential (growth at a constant *percentage* rate). Growth at a constant *percentage* rate in volume or weight and growth at a constant *time* rate in length (if growth in length is due to strictly terminal growth) both indicate the same condition with regard to the physiological environment, namely, that it remains constant as regards the factors limiting growth. Figs. 5a and 5b, are presented to show that in man, as in animals, exponential growth in weight is accompanied by linear growth in length.

The curve for growth in length during the juvenile period is not quite linear. This deviation from linearity may be due to the fact that growth in length may not be quite terminal. Another reason for this deviation from linearity is the fact of the pubertal acceleration of growth

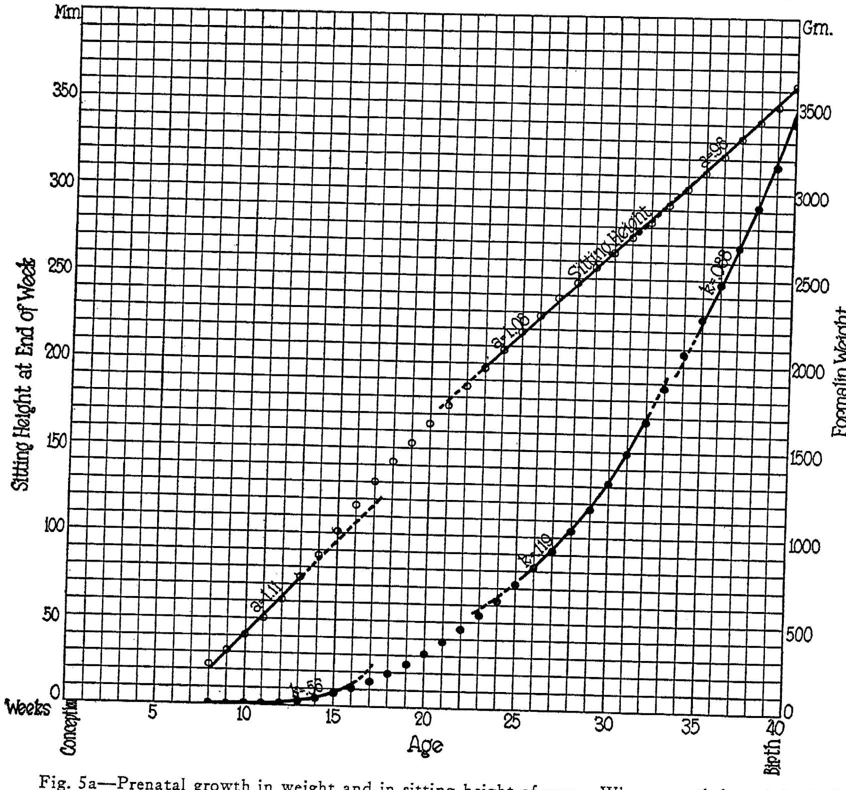

Fig. 5a—Prenatal growth in weight and in sitting height of man. When growth in weight (solid circles) takes place at a constant *percentage* rate (100k), growth in length (open circles) proceeds at a constant *time* rate (a) (plotted from data by Streeter). Compare to Fig. 12 Res. Bul. 98 of this series.

in weight. This must, naturally, be conditioned by an acceleration of growth in length.

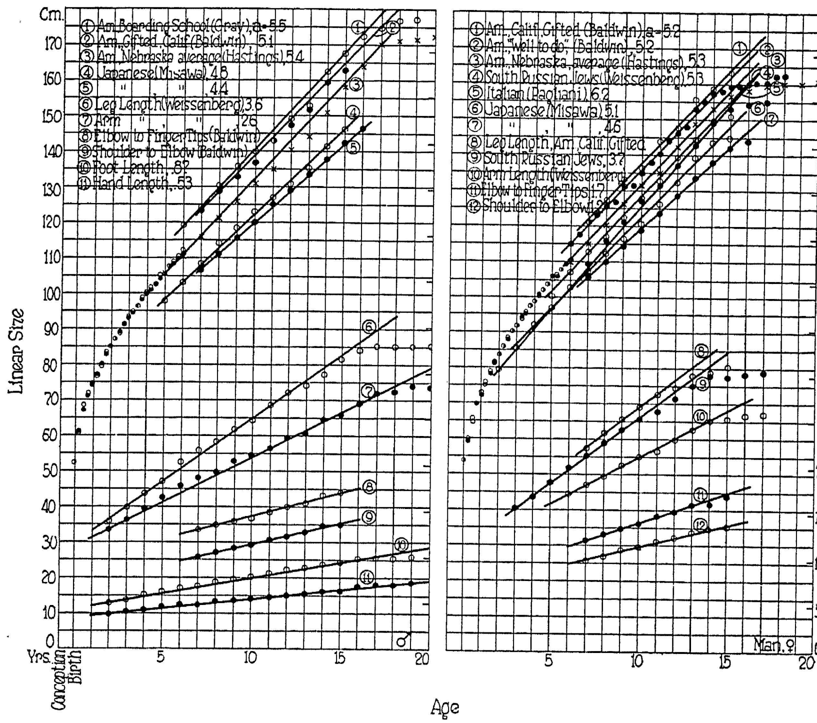

Fig. 5b—Postnatal linear growth in man. During the juvenile period, 4-14 years, we have found (*cf.* Fig. 4) that body weight tends to increase at a constant percentage rate. This chart shows that during the same period linear size tends to increase at an (approximately) constant *time* rate. The upper curves (1 to 5 for males, and 1 to 9 for females) represent standing height. The values of *a* (5.5, 5.1, 5.4, 4.8,) etc. represent the slopes of the curves, i. e., the approximate gains per year.

In Fig. 6, in which are plotted the data for the course of growth in length of children from different social-economic classes, was prepared for the purpose of throwing light on the question whether the pubertal acceleration is related to the nutritional condition of the child. This chart, while it does not give a definite answer to this question seems, nevertheless, worthy of publication as a contribution to this problem.

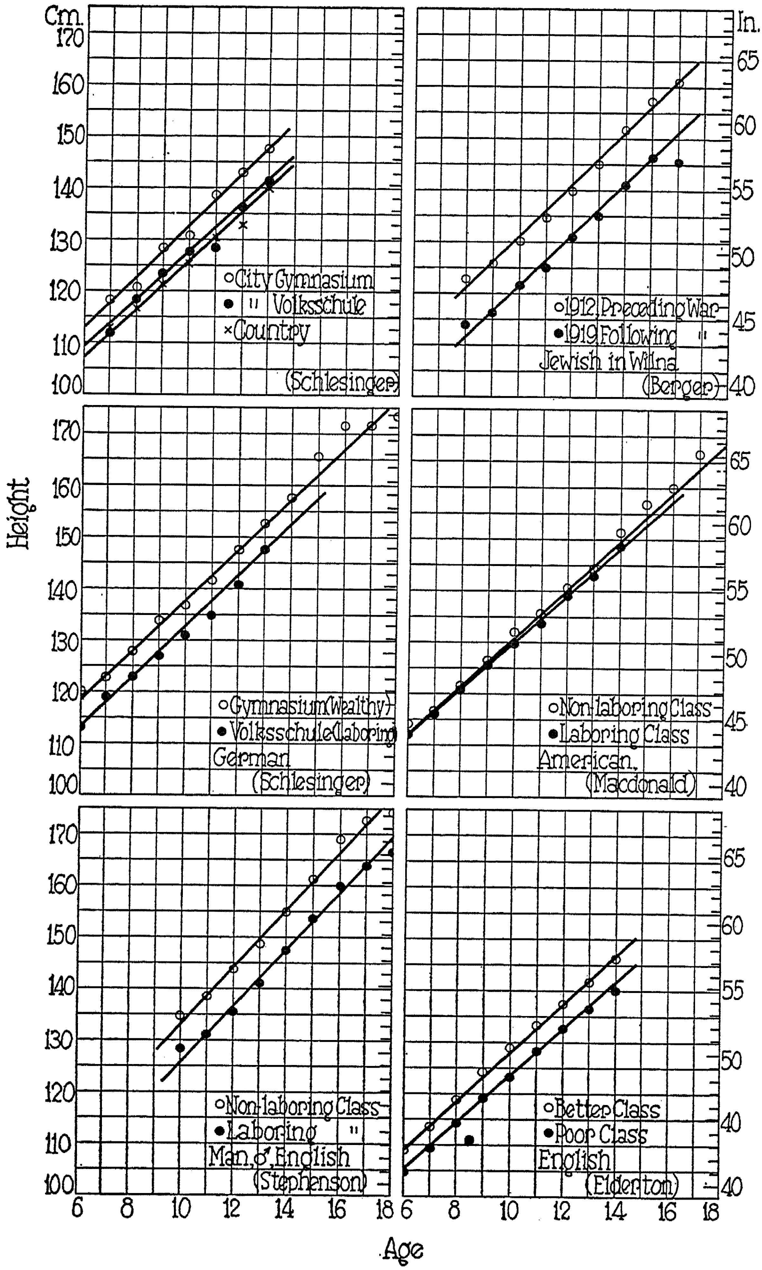

Fig. 6—Prepubertal growth in height of children in different socio-economic conditions. While the absolute height appears to be related to socio-economic conditions (except possibly in American children), no such definite relation is apparent between the economic conditions and the prepubertal acceleration.

IV. DISCUSSION

Having stated the facts, questions of interpretation concerning the differences between the curves of man and animals naturally suggest themselves. The social, educational and, probably, evolutionary, significance of the relatively long juvenile period in man is well under-

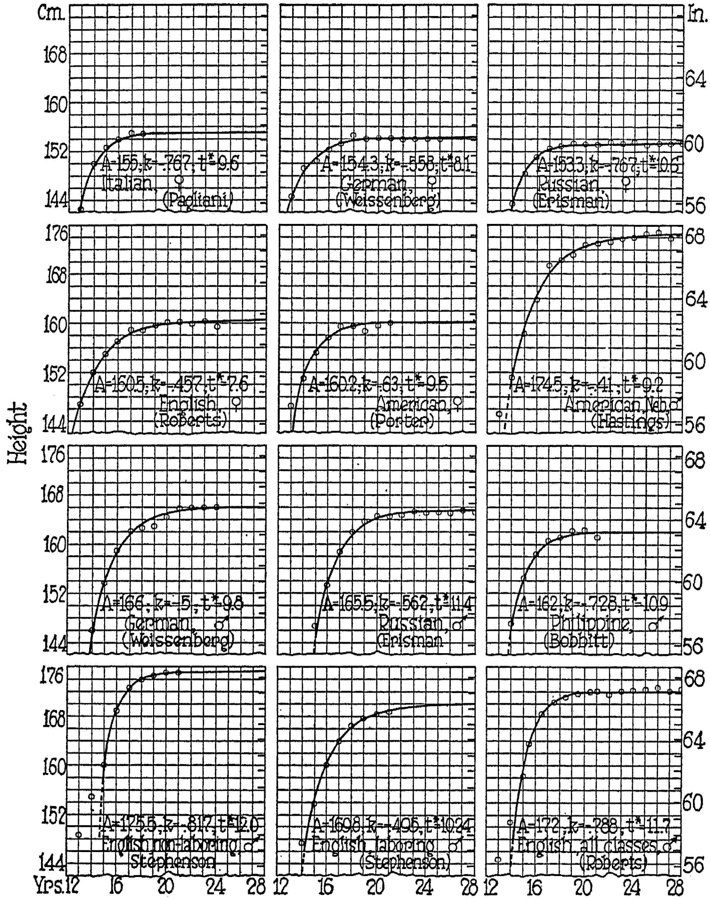

Fig. 7a—A comparison between observed postpubertal growth (circles) in height of man and computed values (smooth curves.) The smooth curves represent our usual growth equation $H = A(1-e^{-k(t-t^*)})$. The numerical data are given in Baldwin.

stood (*cf.* John Fiske, *The Meaning of Infancy* and Herbert Spencer's *Principles*). It may be noted that one of the unique characteristics of the human family, the simultaneous presence of several dependent children, is baesd on this fact. The detailed physiological mechanisms regulating the lengths of the various periods of growth are, however, not clearly understood. In general terms, it may be said to be fairly certain that some glands of internal secretion are often the limiting factors in the process of growth and development. Under-functioning of the pituitary body, for example, is known to be associated with infantilism, while over-functioning, with giantism. Thus 4-year-old children with disorders of the pituitary body have often been observed to have the physical development (particularly that of the genitals) of 14-year-old normal children. The effects of the removal, or of underfunctioning, of the

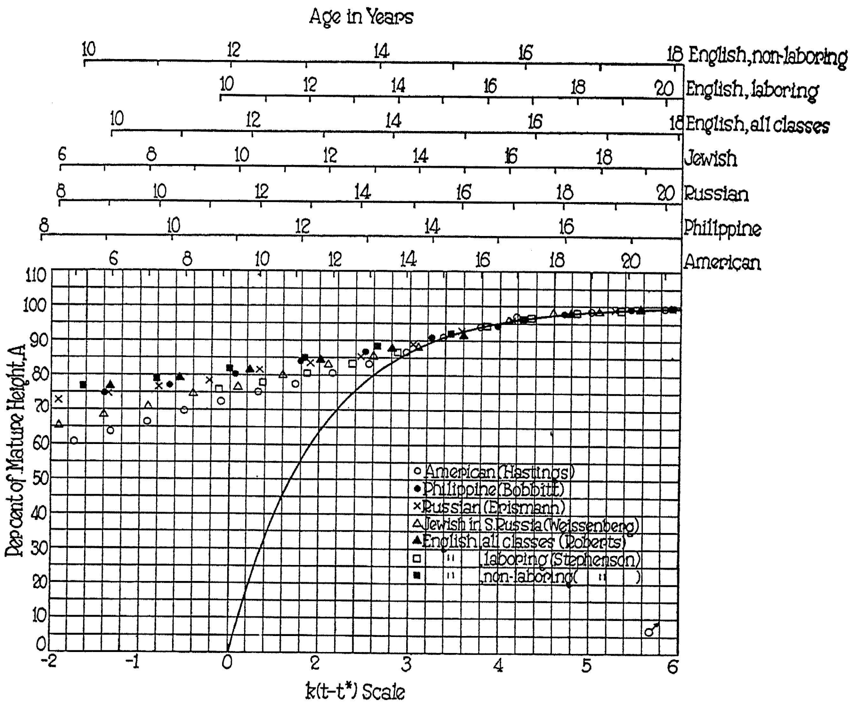

Fig. 7b—A comparison between observed postpubertal growth in height in man and computed values as plotted on a $k(t\text{-}t^*)$ grid. Males. (Data in Baldwin.)

thyroids on growth and development, or the effect of feeding thyroid on the growth and development of animals (particularly of tadpoles), are too well known to need mention. The pineal body and the thymus are also thought by some to be related to growth and development. By their function during the juvenile period they are thought to retard sexual development. From these considerations it may be inferred that the extraordinary length of the juvenile period in man is determined by his hereditary glandular makeup developed in the course of evolution.

This appears to be the belief of Dr. C. R. Stockard (personal conversation) and of Arthur Keith.

Following puberty (about 14 years) weight growth and linear growth follow the same course. That is to say, the increments for linear growth decline by a constant percentage with increasing age just as we have found that the increments for weight growth decline by a constant percentage. Fig. 7 is presented by the way of substantiating evidence of this statement. The agreement between observed values (circles) and computed values (curves) is fairly satisfactory.

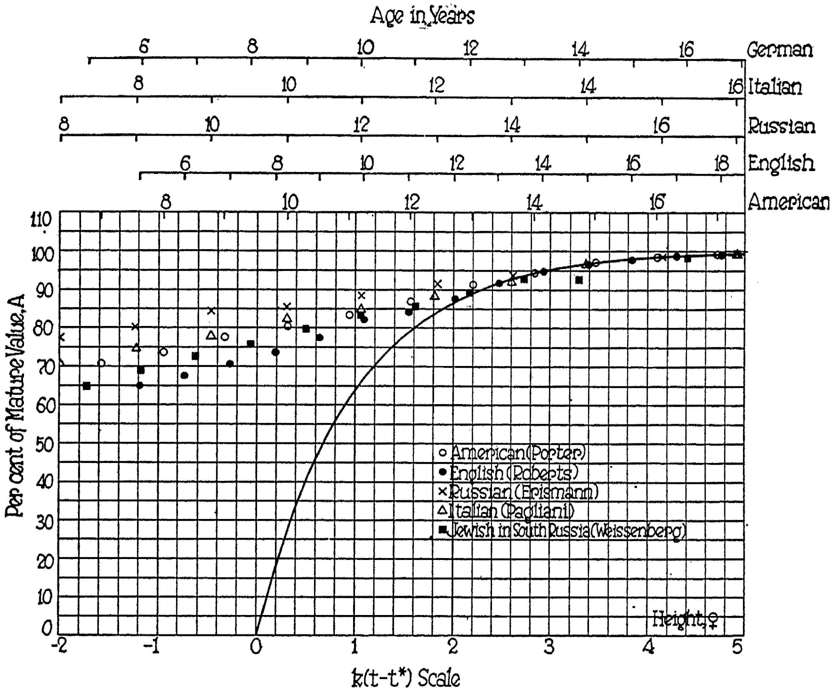

Fig. 7c—A comparison between observed postpubertal growth in height in man and computed values as plotted on a $k(t\text{-}t^{*})$ grid. Females. (Data in Baldwin.)

In the preceding bulletin (Res. Bul. 103 of this series) we have shown that the time rate of linear growth in dairy cattle declines by a constant percentage; so the present result on the course of linear growth in man (Fig. 7) is no surprise and entirely in agreement with the general theory of the preceding bulletin (Res. Bul. 103).

There is one difference, however, which is deserving of notice. In the case of dairy cattle we have found the relative decline, k, in the time rate of growth to be much greater for linear growth than for weight growth (2 to 3 times as great). That is to say, cattle (and to a less extent horses) reach the maximum linear measurements at a much earlier age than they do the maximum body weight. In man the linear measurements appear to reach their maximum values at nearly the same age as weight. This is evident from the value of k in Fig. 7. This may also be illustrated graphically as shown in Figs. 8 and 9.

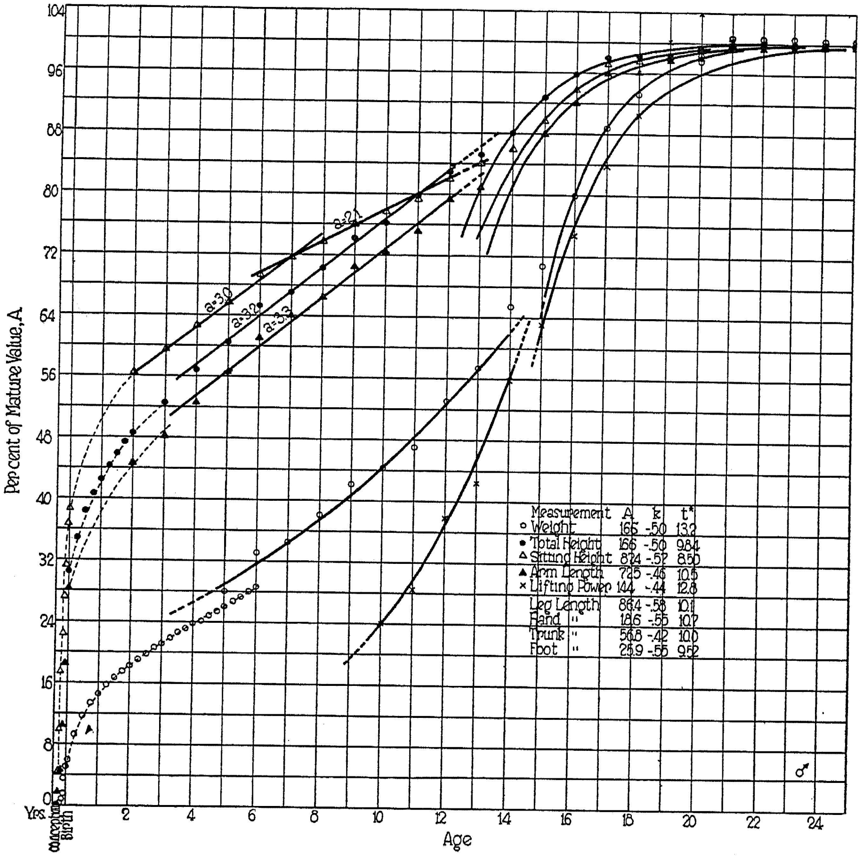

Fig. 8—A comparison of curves of growth in weight and in length. For the purpose of easy comparison, the data are expressed in terms of the maximum values (A in equation $H = A\,[1-e^{-k(t-t^*)}]$. The percentage decline in the time rate of growth is roughly the same for weight growth and for linear growth. The mature values for weight growth are reached at a somewhat later age than the mature values for linear growth due to a higher value of t^*. That is, the inflection between the self-accelerating and the self-inhibiting segment occurs at a somewhat earlier age for linear than for weight growth. In the case of dairy cattle (Res. Bul. 103), the value of k is much greater for linear growth than for weight growth. Data by Weissenberg.

Fig. 9, containing fewer curves and therefore less confusing, clearly shows the influence of the value of t^* on the age of maximum size. The value of t^* is less for height than for weight; as a result, the age curve for growth in height lags somewhat behind the age curve for growth in weight; that is, the maximum value for height is reached at an earlier age than the maximum value for weight.

Incidentally, Fig. 9 suggests a method for predicting the future weight or height of a child. Thus, at 9 years the graph shows the child to be 38 per cent of its mature weight. If a given child weighs 23 kilo-

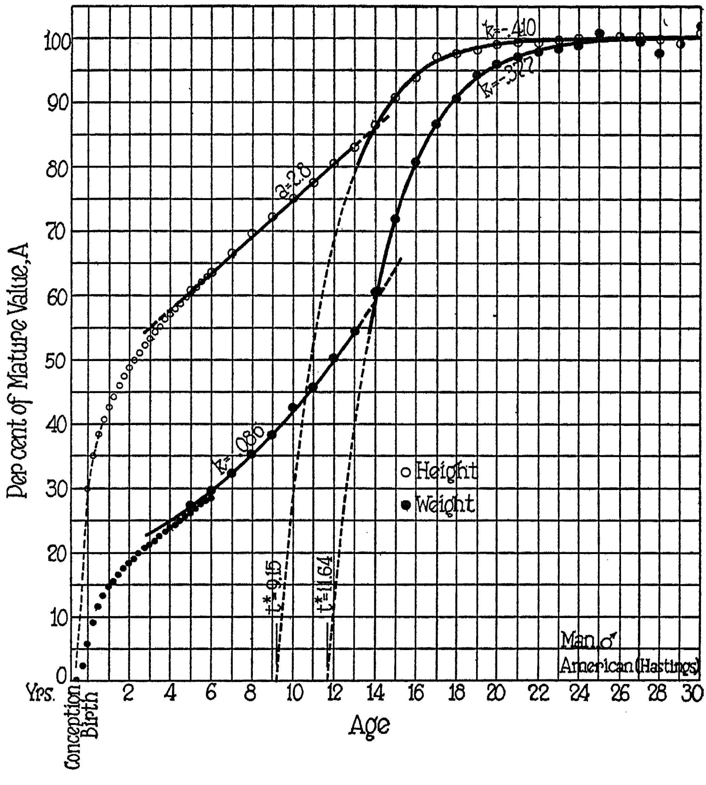

Fig. 9—Weights and heights at different ages expressed as percentages of the mature values.

grams at 9 years, evidently, its probable mature weight will be $23 \times \frac{100}{38}$ $= 60.5$ kilograms. Similarly, if we desire to know the probable weight of the child at, say, 12 years, then from the graph, at 12 years the child will be 50 per cent of the mature weight. Hence his probable weight at 12 will be $\frac{60.5}{2} = 30.3$; or $23 \times \frac{50}{38} = 30.3$. The probable future height may be predicted in the same manner.

Finally, Fig. 10 is presented showing the differences between age curves of growth in weight and in height of man and animals. The curves for weight and for height (at withers) of cows coincide during the whole period of postnatal growth, except that the height curve (indicated by triangles) begins at a higher percentage of the mature value, and reaches the maximum at an earlier age, than does the weight curve. But both the weight as well as the height data for the cow follow rather closely the theoretical curve. Not so in the case of the data for growth of man as already explained, and as indicated in the chart.

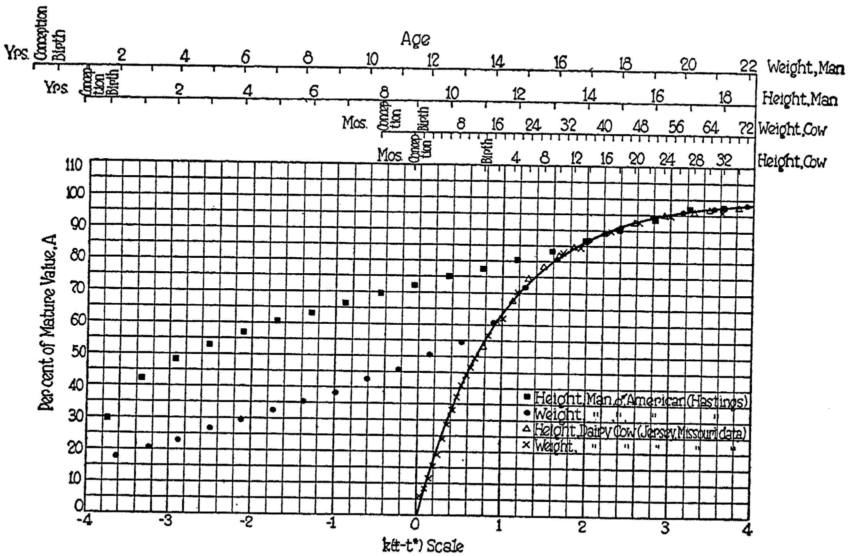

Fig. 10—Equivalence chart for growth in weight and in height for man and cow.

V. THE RELATION BETWEEN WEIGHT GROWTH AND LINEAR GROWTH

In the preceding bulletin (Res. Bul. 103) we have found that it is often possible to represent the relation between weight growth and linear growth of animals (dairy cattle and horses) by the equation

$$W = CL^n$$

in which W is the weight for the linear value L. The fitting of this equation was accomplished by plotting the logarithms of weight against the logarithms of the linear values; or, what is the same, by plotting the weights against the corresponding linear measurements on logarithmic coordinate paper when a linear distribution of the data points resulted.

When the growth data for men were plotted on logarithmic coordinate paper the resulting curve was found to have a much more complex pattern than the corresponding curve for animals given in Res. Bul. 103. In animals the same equation was found to represent almost the whole period of postnatal growth. In man, as shown in Fig. 11, the curve relating weight to height shows three fairly distinct segments, each of

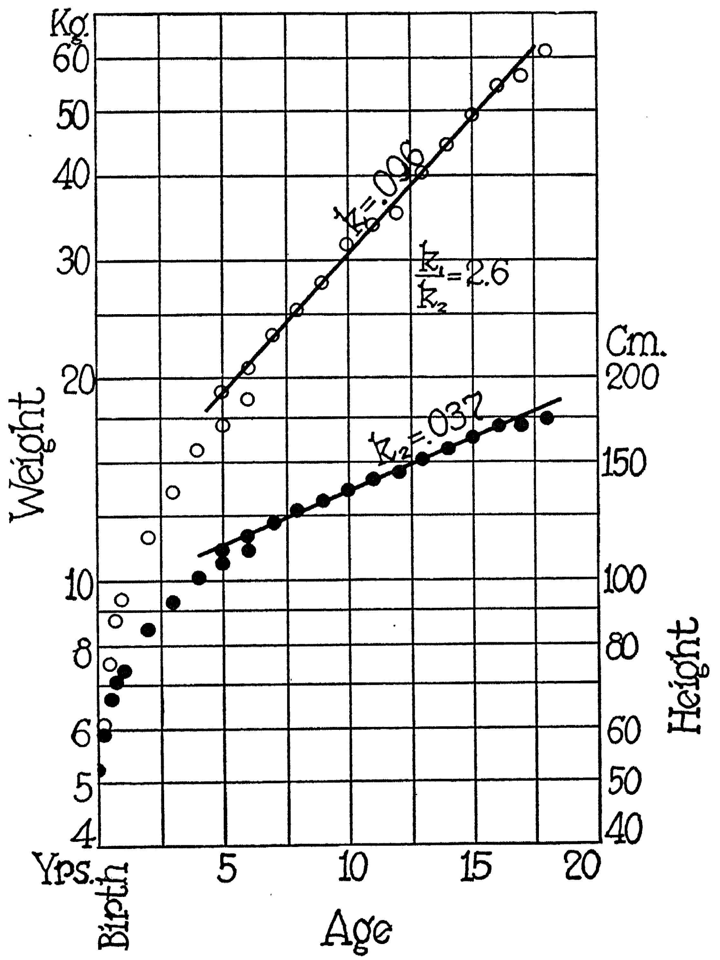

Fig. 11a—Age curves of growth in weight and in standing height as plotted on an arithlog grid. (Data by Baldwin. Birth to 6 years Iowa data; 5 to 17 years, Horace Mann School data.) Since between 5 and 15 years growth in weight takes place at approximately 9.6 per cent per year and growth in height at (approximately) 3.7 per cent per year, hence the weight increases as the $\frac{.096}{.037}$ = 2.6 power of height (and not as the 3rd power as some students of growth, and anthropologists, would have it).

which can be represented by a power equation. First, there is a segment representing the period of growth between birth and 10 months; second, ten months to 4-6 years; third, 4-14 years; fourth, 14 years to maturity.

From the values of the exponents (n in the equation) and from the slopes of the curves it is seen that the relation between growth in weight and growth in height is different for the four segments. From birth to

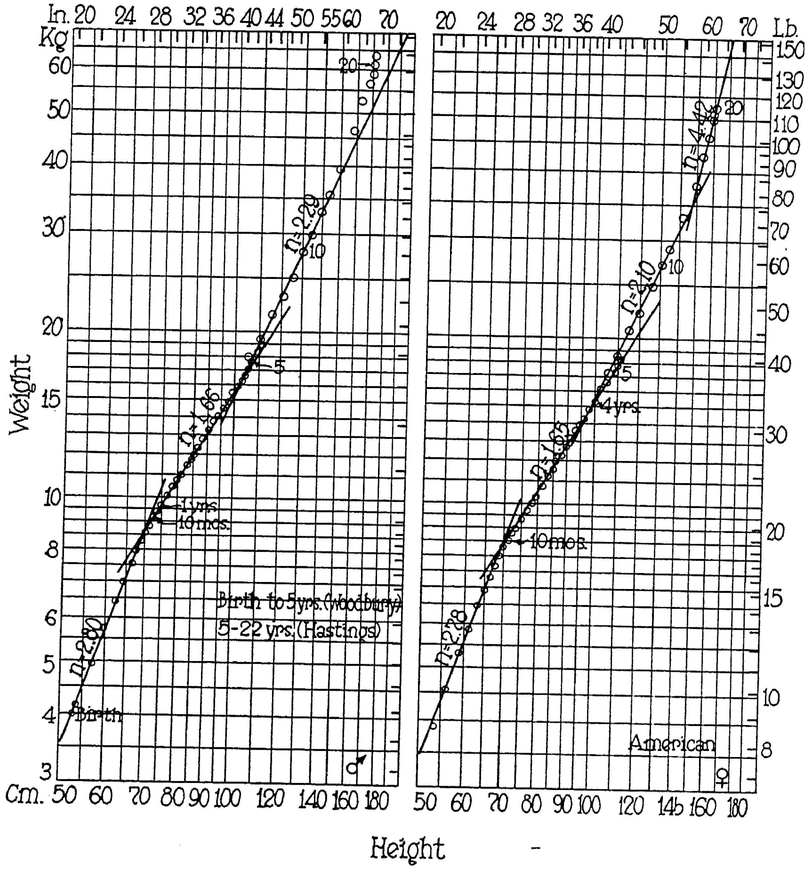

Fig. 11b—The relation between weight growth and linear growth in man as shown on a logarithmic grid. The curve appears to have four fairly distinct segments, namely birth to 10 months; 10 months to 4 years; 4 to 14 years; 14 to 24 years. The numerical value of n represents the actual slope of the line on this logarithmic grid. It is the exponent in the equation $W = CL^n$ in which W is weight for the length L. Since the value of n is higher for the period between birth and ten months than for the period between 10 months and 4 years, hence the relative increase of weight to height is greater for the former period. Note that the value of n is not 3 as writers on change in form with age believe.

10 months, for example, the increase in weight is relative to height greater than during the period between 10 months and 5 years.

The differences in pattern between the weight-height relationship for man and animals, of course, correspond to the differences of pattern in the age curves of growth in weight and in height for man and animals. In the preceding bulletin we have found that practically the whole curve of postnatal growth in cattle can be represented by the single equation

$$W = A\,(1\text{-}e^{-k(t-t*)})$$

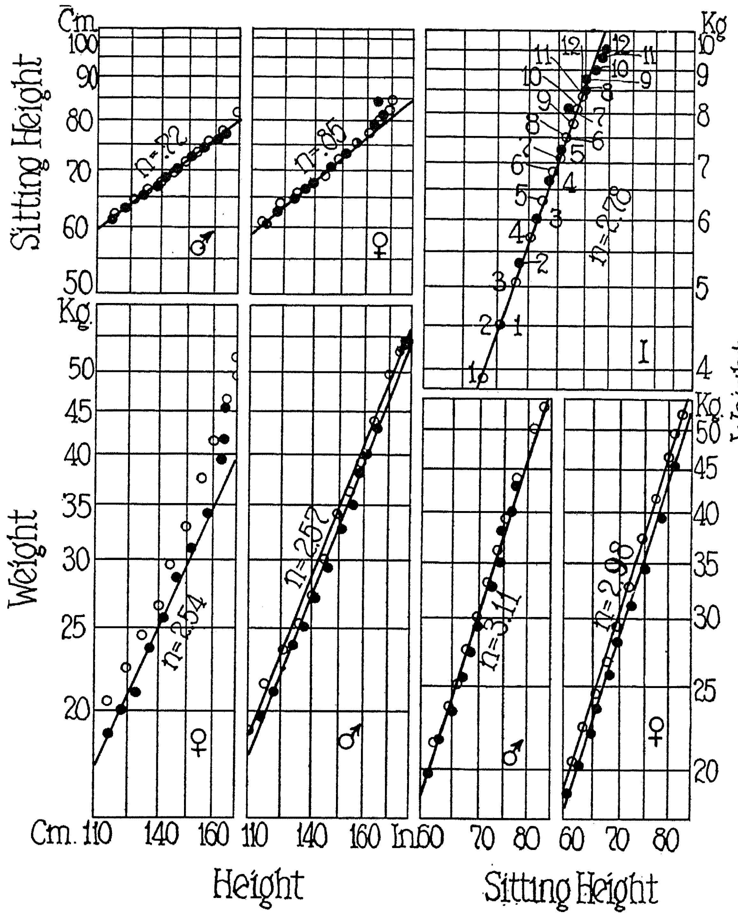

Fig. 11c—The relation between weight and height of different groups of children plotted on a logarithmic grid. Chart (I) represents this relation for relatively small (presumably undernourished) children in the slums of Glasgow (Noel Paton *et al*) and for the relatively large (presumably well-nourished) United States children (Woodbury). Note that both sets of data points fall on the same curve; a fact which suggests the idea that environmental (or possibly genetic) conditions influence linear growth and weight growth to relatively the same extent during this period. Numerals represent ages in *months* from birth.

The other charts plotted from data by Clark, Sydenstricker, and Collins represent the height-weight relationship of children in "good or excellent" condition and in "fair or poor" condition between the ages of 6 and 16 years. It appears that the height-weight relationship is a better index of the state of nutrition for animals than for man.

In man, on the other hand, the age curve of growth in weight, or in height, is made up of several fairly distinct segments. The complexity of the weight-height relationship in man is, therefore, but an expression of the complexity of the original age curves of growth in weight and in height.

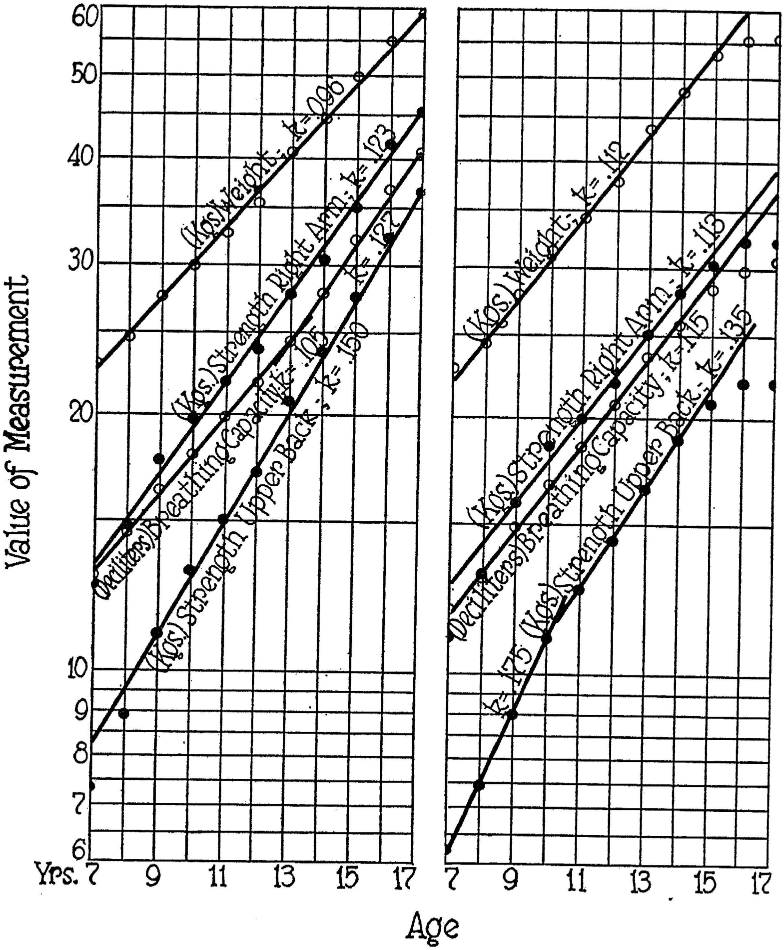

Fig. 12a—Age curves for weight, breathing capacity, strength of arm and strength of back plotted on an arithlog grid. (Plotted from data by Baldwin, 1921, p. 152.) The value 100*k* represents the percentage rate of growth per year. The linear distribution of the data points indicates that between 7 and 14-15 years the percentage rate of growth is nearly constant. This fact, and the numerical values of *k*, constitutes the essential contribution of this chart. Some obvious criticisms may be made against the statement that the distribution of the data points is linear; but considering the limits of error inherent in the data, this statement is perhaps not exaggerated. The chart on the left represents boys: on the right, girls.

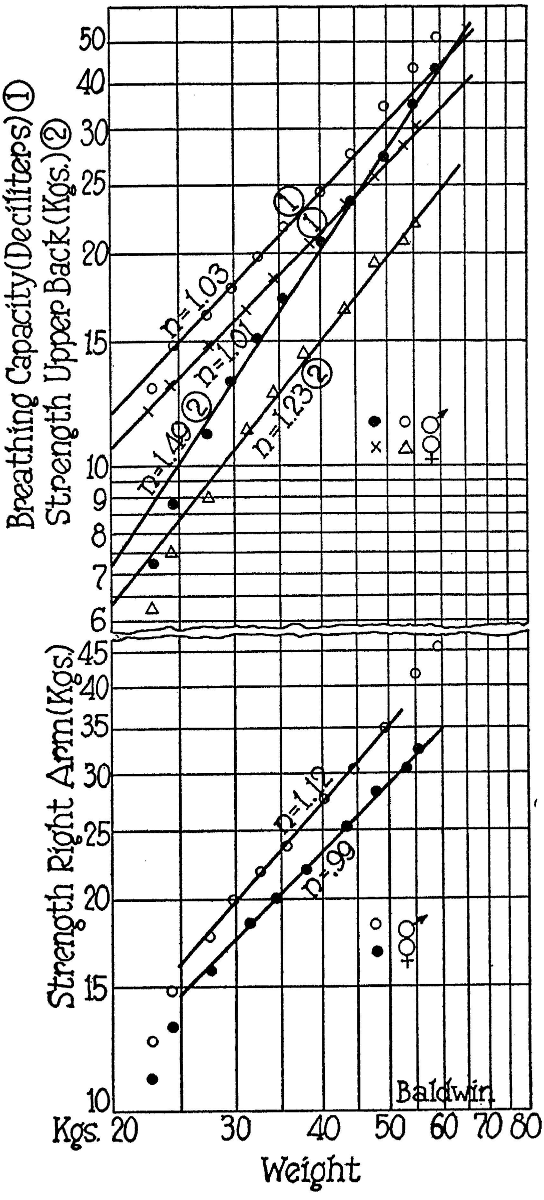

Fig. 12b—The relation of breathing capacity, of strength of back and of strength of arm to weight, as it appears on a logarithmic grid. Plotted from data by Baldwin, 1921, p. 152. The term n is the exponent in the equation $X = CW^n$ in which X is any measurement for the weight W and n is the slope of the line. The value of n indicates that breathing capacity and strength of arm and of back are directly proportional to weight during growth.

This introduction together with the corresponding legends will probably suffice to explain the charts that we are presenting in this section (Figs. 11a to 11c). In addition to the relationship between weight growth and linear growth we have also plotted some data relating other measurements with weight (Figs. 12a and 12b).

SUMMARY AND CONCLUSIONS

There are fundamental differences, certainly of a quantitative and probably also qualitative nature, between the age curves of man and other animals. This is not surprising. The surprising fact emphasized by this bulletin is the striking contrast between the remarkable similarity among the growth curves of animals on one hand, and the enormous differences between the growth curve of man and other animals on the other hand. The similarity between the growth curves of the cow and the guinea pig, for example, is infinitely greater than that between the curve of man and *any* domestic animal examined. In brief, the pattern of the age curve of growth in man is really unique and stands out very clearly distinct from all other growth curves (unless it will be found to resemble the growth curves of other primates).

An obvious practical inference is that one must be cautious in applying the results obtained on growing animals under given experimental conditions to the management of children; or in drawing inferences concerning the possible effects that given experimental conditions may have on children. The growth curves of man and of animals being so different, there is no *a priori* reason for assuming that a given set of experimental conditions would have similar effects on the development of man as on animals.

It appears that the period of postnatal growth in children may be divided into four periods, (1) infantile period, birth to ten months; (2) early-childhood period, 10 months to 4-5 years; (3) juvenile period, 4-5 years to about 14 years; (4) adolescent and post-adolescent period between 14 and 20 years. There is probably no physical growth after about 22 years—that is, growth in the sense of increasing living tissue or increasing physical powers.

The age curve of the post-adolescent period (14 to 22 years) appears to have the same general properties as the corresponding curve of animals. But the age curves of other periods (infantile and juvenile) appear to differ considerably from the corresponding curves in animals.

The differences between the age changes in the height-weight relationship of man and of animals correspond to the differences between the age curves of weight growth and linear growth in man and in animals. That is, the age curve of the weight-height graph also shows four fairly distinct segments: (1) birth to ten months; (2) 10 months to 4-5 years; (3) 4-5 years to 14 years; (4) 14 to 22 years.

It may be noted incidentally that the weight-height curves presented in this bulletin appear to indicate that the height-weight relation is not as suitable an index of nutrition for children as it is for animals. This difference points to the possibility that a given state of nutrition has a greater relative influence on linear growth of children than on animals.

SOURCES OF DATA

The sources of data are indicated either on the chart, or on the legend for the chart. The bibliography is given in Res. Bul. 96 of this series.