THE EQUIVALENCE OF AGE IN ANIMALS.

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(Received for publication, June 20, 1922.)

Donaldson[1] in his comparison of the white rat with man in respect to the growth of the entire body, assumed that the rat at the age of 3 years, is comparable in age to a man of 90 years, and that the same proportional relations hold for fractions of this period. The duration of life was employed as the basis of comparison. The objection against employing the duration of life as a basis for estimating the equivalence of age consists, as Donaldson pointed out, in the incomplete information at our disposal concerning the onset of old age and duration of life. Now it is well known that growth is periodic or cyclic. The warm blooded animals studied go through three periods or cycles of growth which may be termed infantile, juvenile, and adolescent cycles; or first, second, and third cycles. The curve of each cycle is symmetrical around its center, the maximum of the cycle. According to theories of growth developed by Loeb,[2] Robertson,[3] and Ostwald,[4] growth under normal conditions is limited by a series of consecutive chemical reactions, and the middle, or maximum, of each cycle represents the middle of the respective limiting chemical reaction. Assuming that these theories describe the facts, then the maxima of the corresponding cycles in different animals represent equiva-

[1] Donaldson, H. H., A comparison of the white rat with man in respect to the growth of the entire body, Boas anniversary volume, New York, 1906, 5.

[2] Loeb, J., The dynamics of living matter, New York, 1906, 58; *Biochem. Z.*, 1906, i, 34; *Biol. Centr.*, 1910, xxx, 347.

[3] Robertson, T. B., *Arch. Entwicklungsmechn. Organ.*, 1907–08, xxv, 581; Principles of biochemistry, for students of medicine, agriculture and related sciences, Philadelphia, 1920.

[4] Ostwald, W., Vorträge und Aufsatze über Entwicklungsmechanik der Organismen, Leipsic, 1908, v, cited by Loeb (1910).[2]

lent stages of growth; that is, equivalent physiological ages as far as growth is concerned. The maxima of the cycles may, therefore, be taken as points of reference in the course of life of animals, and the conceptional ages of these maxima may be employed for estimating the equivalence of age in different animals.

The age of maxima of the cycles may be conveniently determined by plotting the gains in weight per unit time at different ages against the corresponding ages. Such plots are shown in Figs. 1 and 2 which are self-explanatory.[5] From these plots it is seen at once that the maximum of the third cycle in the rat is 64 days of age, in the mouse 42 days of age, in man about 14 years of age; in other words, a rat of 64 days of age is physiologically as old as a mouse 42 days of age, a man 14 years of age, and so on for the other animals as shown in Table I. The maxima of the first and second cycles, and the junctions between the cycles, similarly represent equivalent physiological ages.

If there is the same linear relation between the duration of the period of growth and the duration of life in different animals then in order to estimate the equivalent physiological ages, for example the duration of life in different animals, it is only necessary to multiply the conceptional ages of the third maxima by some constant. Thus multiplying the conceptional ages of the third maxima of the rat and mouse by 13 gives 3.0 and 2.15 years respectively which are practically the values obtained by Donaldson[1] and Robertson and Ray[6] for the duration of life of these animals. Taking 13 as the constant of the linear equation connecting the duration of life with the conceptional age of the maxima of the third cycles, we obtain the duration of life of different animals as shown in Table II.

Table II shows that, with the exception of man and fowl, the calculated values for the duration of life of different animals are very close to the average actual duration of life under the most favorable conditions. The value for man, about 185 years, is probably too high, although a perusal of Metchnikoff's[7] discussion on longevity

[5] The sources of data on which the figures are based are given at the end of the article. Figs. 3 and 4 are omitted because of difficulty of reproduction.

[6] Robertson, T. B., and Ray, L. A., *J. Biol. Chem.*, 1920, xlii, 71.

[7] Metchnikoff, E., The nature of man, New York and London, 1903, 259.

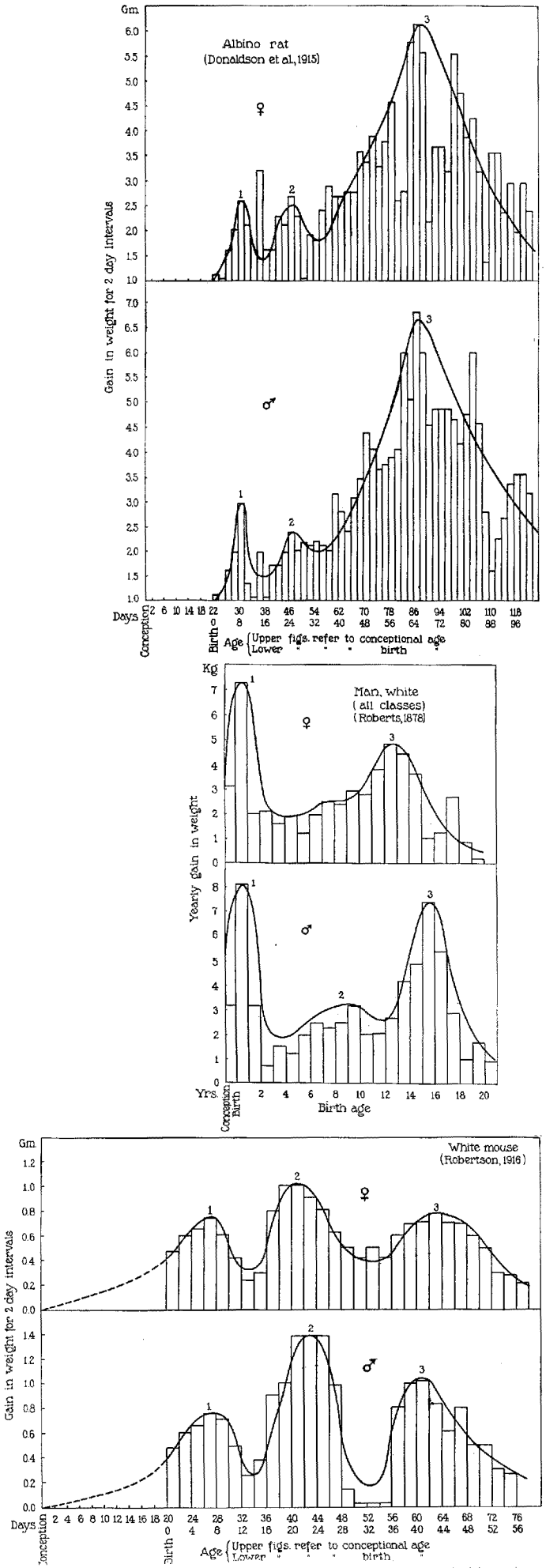

FIG. 1. Velocity curves of growth. Ordinates represent the velocities of growth; the height of rectangles represents gains in weight for the ages shown on the abscissæ. The maxima of the first and third cycles are presented on a base line of the same length.

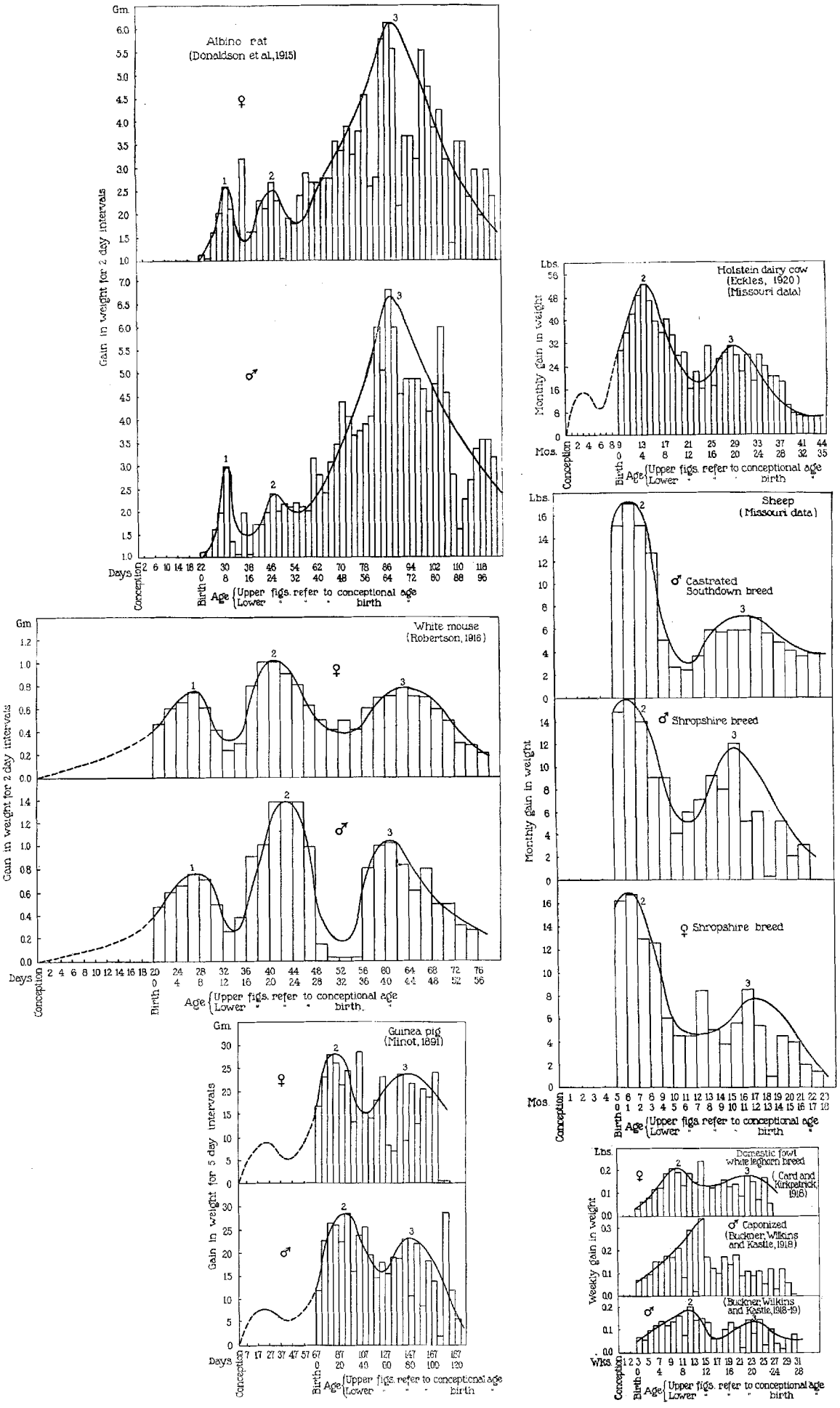

FIG. 2. Ordinates and abscissæ have the same meaning as in Fig. 1. The maxima of the second and third cycles are presented on a base line of the same length.

TABLE I.

Equivalence of Age.

Age of animals at the maxima of the three cycles and the junctions between the cycles.

Animal.	Age of maximum of first cycle.		Age of junction between first and second cycles.		Age of maximum of second cycle.		Age of junction between first and second cycles.		Age of maximum of third cycle.		Conceptional age at birth.
	Conceptional age.	Birth age.	Conceptional age.	Birth age.	Conceptional age.	Birth age.	Conceptional age.	Birth age.	Conceptional age.	Birth age.	
	days		*days*		*days*	*wks.*	*days*	*wks.*	*days*	*wks.*	*days*
Fowl	16	5 days before hatching.	18	3 days before hatching.	84	9	100	11	156	20	21
Guinea pig	23 (estimated)	44 days before birth.	32 (estimated)	35 days before birth.	85	2.5	115	7	145	11	67
		wk.		*wks.*							
Mouse	27	1.0	33	2	42	3	53	5	62	6	20
						mos.		*mos.*		*mos.*	
Ox (dairy cow)	160 (estimated)	4 mos. before birth.	190	3 mos. before birth.	420	4.5	690	13.5	850	19	285
								wks.			
Pig							158	5			120
		days		*wks.*		*wks.*					
Rabbit	40	10	65	5	110	11	160	18	185	5	30
				days						*wks.*	
Rat	31	9	38	16	47	3.5	56	5	86	9	22
								mos.		*mos.*	
Sheep					195	6.5	360	7	480	11	150
		mos.								*yrs.*	
Man	345	2							5,300	13.7	285

does not make this value appear to be outside of the limits of possibility. On the whole, this product of the conceptional age of the maximum of the third cycle by 13, is a useful approximation as regards the maximum duration of life of these animals. Equivalence of age at any other period after the third cycle, may be similarly estimated by multiplying the conceptional age of the maximum of the third or adolescent cycle by an appropriate constant. Thus multiplying this age by 2, gives a value corresponding to the age of 28 years in man; multiplying by 4, gives a value corresponding to 55 years of age in man as shown in Table II.

TABLE II.

Equivalence of Age after the Age of the Third Cycle.

Values obtained by multiplying the conceptional age of the maximum of the third cycle by a constant indicated at the head of each column.

Animal.	× 2	× 3	× 4	× 5	× 6	× 7	× 8	× 9	× 10	× 11	× 12	× 13
Domestic fowl, *yrs.*	0.8	1.2	1.7	2.1	2.5	2.9	3.4	3.8	4.2	4.6	5.1	5.5
Guinea pig, *yrs.*...	0.7	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.6	5.0
Mouse, *mos.*.....	3.8	5.5	7.6	9.7	11.7	13.8	15.8	17.9	20.0	22.3	24.1	26.2
Ox (dairy cow), *yrs.*	3.9	6.2	8.3	10.9	13.2	15.5	17.8	20.2	22.5	24.8	27.2	29.5
Rabbit, *yrs.*.....	0.9	1.4	1.9	2.5	3.0	3.5	4.0	4.4	5.0	5.5	6.0	6.5
Rat, *mos.*.....	5.0	7.9	10.7	13.6	16.8	19.3	22.2	25.1	27.9	30.8	33.6	36.5
Sheep, *yrs.*.....	2.2	3.5	4.8	6.2	7.4	8.8	10.1	11.4	12.7	14.1	15.4	16.7
Man, *yrs.*.....	28	42	57	72	86	100	115	130	147	159	173	187

In addition to equivalence of age, the plots presented bring out a number of other facts. The corresponding cycles in different animals differ with respect to their relative duration and shape. Figs. 1 and 2 bring out the fact that the mouse and rat show a long preinfantile period not found in the other animals. Fig. 1 brings out the difference in shape of the second or juvenile cycle in man as compared to the other forms. The width of the juvenile cycle in man is, relative to the whole actively growing period, not very much greater than in the other forms. The striking difference between man and the other forms consists in the relative flatness of the curve of the juvenile cycle; its shape is not that of the curve of an autocatalytic reaction. The absolute gain in weight during the maximum of the juvenile cycle is greater than during any other period of life in all forms, except the

man and rat. In man the gain in weight is greatest during the maximum of the infantile period, or more specifically during the 2nd and 3rd months of life as shown in Fig. 5. In the rat, the gain in weight is greatest during the maximum of the third cycle. The third cycle in the rat is relatively also the widest, occupying about 60 per cent of the growth curve. The interpretation of these differences with respect to the relative shape and durations of the cycles is beyond the limits of our present state of knowledge. They only

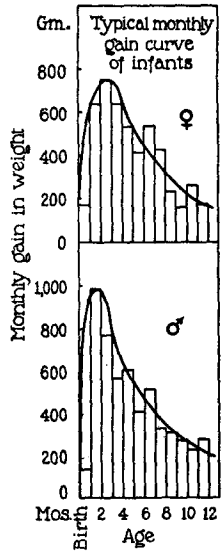

FIG. 5. Typical monthly gain curve of infants showing that the gain in weight is highest during the 2nd and 3rd months after birth.

show that either the limiting reaction of different cycles in different animals are fundamentally different, or that the conditions under which the reactions take place are different, or that both are different. The evolutionary significance of these differences will no doubt be illuminated by the accumulation of data on growth of related types of animals.

Another interesting difference brought out by the figures relates to the relative age at birth of different animals. Man, mouse, rat, and rabbit are born before the completion of the first or infantile cycle.

The other forms spend their infantile period *in utero*. The ox, sheep, pig, and guinea pig at birth are with respect to physiological age equivalent to man at the age of about 1.5 to 2 years; or to mouse and rat at 2 to 3 weeks. Man at birth is with respect to physiological age, equivalent to the ox at about 4 months before birth, that is about 5 months after conception; or equivalent to the guinea pig about 6 weeks before birth. Fig. 6 brings out the fact that the ox and guinea pig pass through a cycle *in utero*.

Fig. 2 also brings out the known fact that the maximum of the adolescent cycle usually comes earlier in girls than in boys. Fig. 1

TABLE III.

Age of Maximum of the Adolescent Cycle in Man.

Nationality.	Boys.	Girls.
	yrs.	*yrs.*
Chinese	15	13
Japanese	15	14
Philippine	15	13
Belgian	16	14
Danish	16	14
English	16	13
French	14.5	14
German	15	14
Italian	16	14
Swedish	16	14.5

is supplemented by Fig. 7 and Table III to bring out this fact, and incidentally to bring out the effect of race and economic conditions on the growth of children. The lower forms do not show appreciable difference due to sex. It is also interesting to note that the maximum of the adolescent cycle in girls comes at the same age as sexual maturity. According to Baldwin[8] the mode for sexual maturity in girls as shown by the first menstrual flow is 14 years. From Table III this is also the average age of the adolescent maximum.

[8] Baldwin, B. T., The physical growth of children from birth to maturity, *Univ. Iowa, Studies in Child Welfare*, 1921, i, 188.

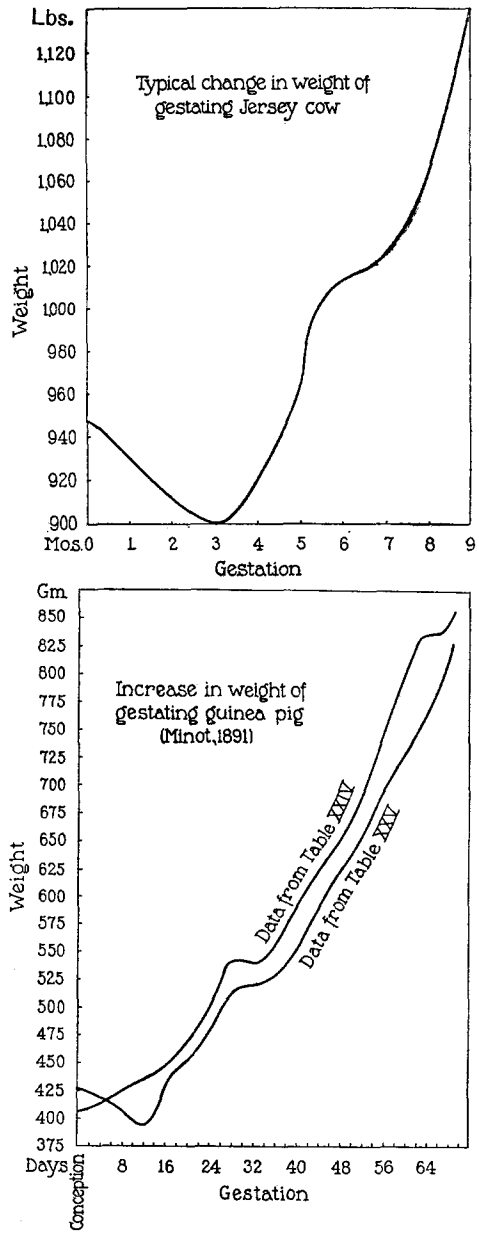

FIG. 6. Change in weight of gestating cow and guinea pig to illustrate the fact that the ox and guinea pig pass through a cycle *in utero*. The inflexion during the 5th month in the curve of the cow, and during the 4th week in the curve of the guinea pig correspond to the maxima in the velocity curves; the flattened segments at about 7 months in the cow, and 32 days in the guinea pig represent the junctions between the first and second cycles.

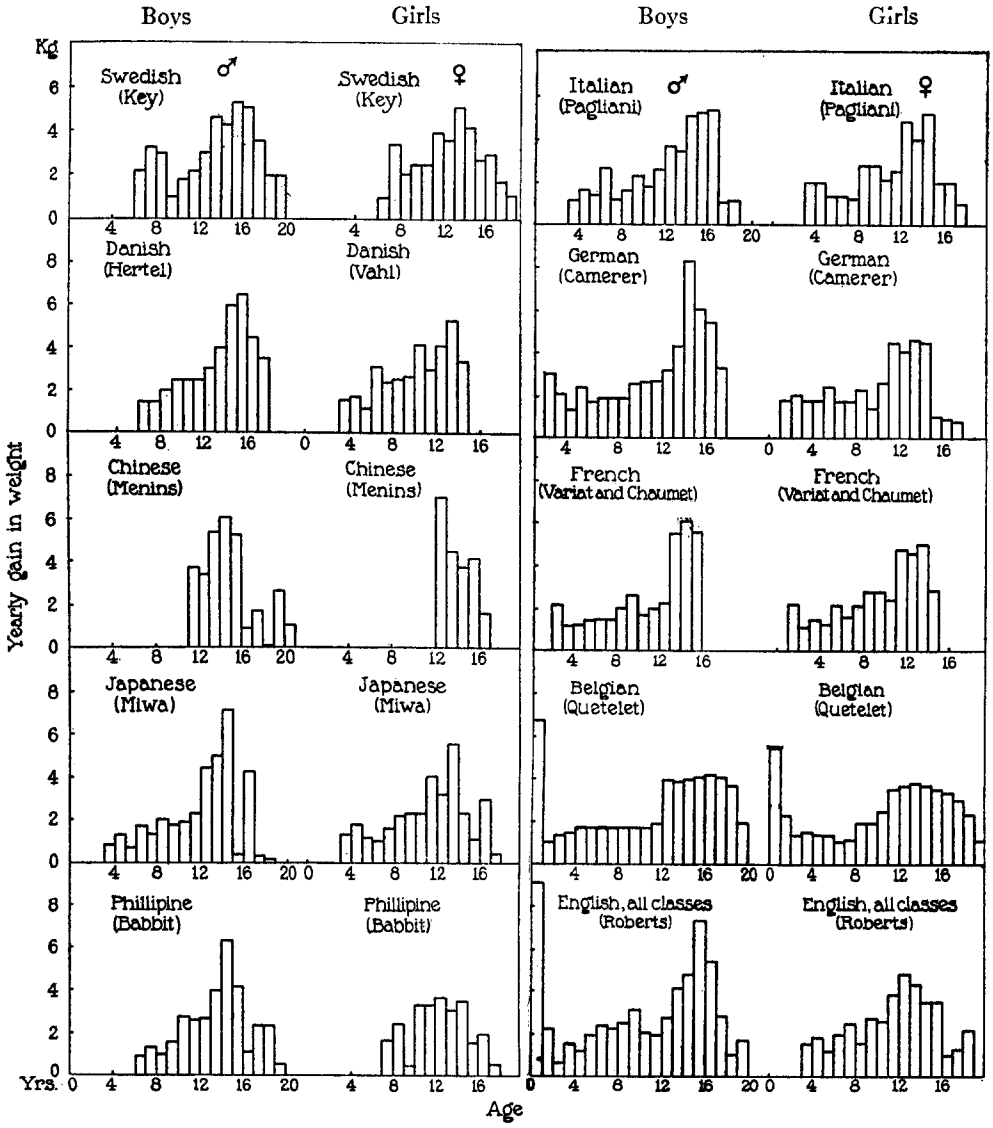

FIG. 7. Velocity curves of growth of European and Asiatic children.

The fact that the age of the adolescent maximum and sexual maturity coincide, does not mean that there is a causative relation between the two. The evidence, with few exceptions, seems to point to the contrary. Stotsenberg[9] found that the rate of growth of normal and castrated rats of the same litter, is practically identical. The curves of the castrated sheep and pig in the figures here presented are not noticeably different from the sexed animals. The curve of the caponized fowl, however, differs from the normal fowl, but this

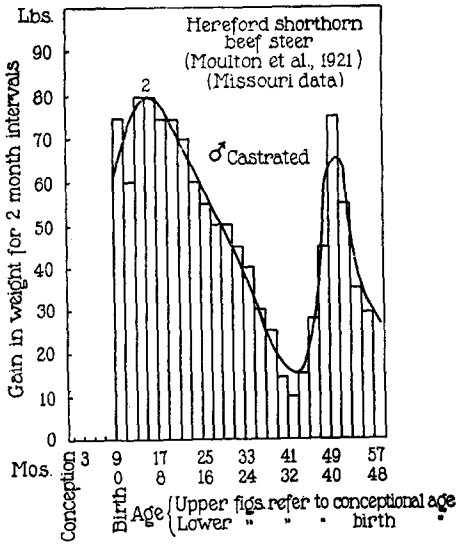

FIG. 8. Velocity curve of growth of the castrated ox. Ordinates and abscissæ have the same meaning as in Fig. 1.

may be due to evident secondary causes. An interesting case is shown by Fig. 8, the curve of the castrated ox. The maximum of the second cycle comes at the same age as in the cow, but the third cycle is either entirely missing, or is very indistinct. Then there is a curious cycle-like rise at about 35 months of age, which is not found in the cow. This apparent exception, however, may be due to some experimental error.

SUMMARY.

1. A method of plotting growth curves is presented which is considered more useful than the usual method in bringing out a number

[9] Stotsenberg, J. M., *Anat. Rec.*, 1909, iii, 233.

of important phenomena such as the equivalence of age in different animals, difference in the shape and duration of corresponding growth cycles in different animals, and also in determinating the age of maxima without resorting to complicated mathematical computations.

2. It is suggested that after the third cycle is past the conceptional age of the maximum of the third cycle may be taken as the age of reference for estimating the equivalent physiological ages in different animals. Before the age of the third cycle, the maxima of the second and first cycles are most conveniently used as points of reference.

3. It is shown that the product of the conceptional age of the maximum of the third cycle by 13, gives a value which is, with the possible exception of man, very near to the normal duration of life of animals under the most favorable conditions of life. In other words, the equivalent physiological ages in different animals bear an approximately constant linear relation to the duration of their growth periods.

4. Attention is called to certain differences in the shape and duration of the corresponding growth cycles in different animals and of the effect of sex on these cycles.

Sources of Data of the Figures.

1. Man: Baldwin, B. T., The physical growth of children from birth to maturity, *Univ. Iowa, Studies in Child Welfare*, 1921, i, 188. Gives complete bibliography and compilation of data in growth of children.
2. Rat: Donaldson, H. H., The rat, Memoirs of The Wistar Institute of Anatomy and Biology, No. 6, Philadelphia, 1915.
3. Mouse: Robertson, T. B., *J. Biol. Chem.*, 1916, xxiv, 369.
4. Ox: (*a*) Dairy cow: Eckles, C. H., *Univ. Missouri Agric. Exp. Station, Research Bull. 36*, 1920.
   (*b*) Castrated ox: Moulton, C. R., Trowbridge, P. F., and Haigh, L. D., *Univ. Missouri Agric. Exp. Station Research, Bull. 43*, 1921.
5. Guinea pig: Minot, C. S., *J. Physiol.*, 1891, xii, 97.
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8. Sheep: Unpublished data by Fox, H. D., Trowbridge, E. A., and Hogan, A. G., *Univ. Missouri Agric. Exp. Station*, in press.
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