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A COMPARISON OF THE WHITE RAT WITH MAN IN RESPECT TO THE GROWTH OF THE ENTIRE BODY

BY

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A COMPARISON OF THE WHITE RAT WITH MAN IN RESPECT TO THE GROWTH OF THE ENTIRE BODY.

BY HENRY H. DONALDSON

In collaboration with ELIZABETH HOPKINS DUNN and JOHN B. WATSON.[1]

IN order to give greater value to a further study of the growth of the nervous system of the rat, it was thought necessary to establish the general growth-relationships between the two forms mentioned in the title. We propose, therefore, in this paper, to compare in the white rat and man the manner in which the body gains weight between conception and maturity.

The white rat used for this study is distinctly smaller and more lightly built than the brown rat (*Mus decumanus*), and hence all the measurements assigned to it are somewhat less than those of the brown species with which we are familiar. It is commonly stated that the white rats kept as pets are albinos of the black rat (*Mus rattus*). This statement is certainly not true for the colony on which our observations have been made. At the moment more cannot be said; but investigations now in progress for the purpose of establishing the zoölogical relationships of the white rat probably will enable us at an early date to make additional detailed statements concerning our own colony.

In carrying out a comparison between forms so dissimilar in absolute size as the rat and man, it is of course impracticable to employ the same scale in the charts intended to exhibit the relations. Under these circumstances, two adjustments have been made in the method of recording, so as to render the results more directly comparable.

In the first place, the base-line, on which are plotted all the

[1] From the Neurological Laboratories of the University of Chicago and of The Wistar Institute of Anatomy, Philadelphia.

curves for change according to age, is of the *same* length for both forms. This means that we make the period representing the span of life in the rat extend on the chart over as long a distance as the corresponding span in man. The first difficulty met in attempting to do this accurately lies in our incomplete information concerning the onset of old age and the natural length of life in the case of the rat. From the best data which we can obtain, we have, however, concluded that the three-year-old white rat is very old, and is justly comparable to a man of ninety years. For the present purpose, therefore, we call the span of life in the white rat three years, and compare this with ninety years of human life. It is assumed that the same proportional relations can be used for fractions of the entire span of life. In this study our interest lies for the most part in the first year of rat life, corresponding, in accordance with the above relation, to the first thirty years of human life.

In the second place, the reduction of the values of the ordinates, so as to bring the two curves together at their termini, is a simple matter of adjustment, the details of which will be given in their proper place.

Data on the White Rat.

The material on which we depend for the body-weight of the white rat at different ages has been obtained from records made by Dr. Dunn and Dr. Watson, and from several other series preserved in the archives of the laboratory (see Tables I and II).

Dr. Dunn's observations touch the first fourteen days of life, and need a word of introduction and explanation.

Dr. Dunn's Series. — After birth the young white rat depends upon the mother for sustenance for about twenty days. Previous experiments had shown that during this period of dependence, especially during the first half of it, removing the young rats from the mother to weigh them resulted in checking their growth. The causes of this retardation are not far to seek, but they need not be detailed now.

We decided, therefore, to obtain the weight of the rats during the first fourteen days of life by weighing different litters

as they attained different ages, and thus weighing each litter only once. Since individuals taken from different litters often exhibit much greater differences in weight than is usually shown by the extremes of a single litter, it follows that by this method the extreme values at any age are somewhat greater than they would be, could the same litter have been followed through successive stages.

The make-up of a litter is always unpredictable, and ranges from those consisting entirely of representatives of one sex to those evenly divided between the two. However, in Dr. Dunn's work, no litter was weighed which did not have at least four individuals in it, and none with less than two of the same sex. Where the representatives of one sex were more numerous than those of the other, the number of the former was reduced by excluding the lightest *and* heaviest representatives, until it equalled the number of the other sex, or differed from that number only by one. Thus throughout there was approximately an equal representation of the two sexes in each litter, — a point of importance when determining the relative growth of the sexes during the first fourteen days. In calculating the body-weights at birth, and at one and two days, there have been added to Dr. Dunn's records those in the laboratory archives. This addition is explained in detail in the note to Table VII.

DR. WATSON'S SERIES. — Beginning with the fifteenth day, the records in the tables (I and II) up to a hundred and eighty-five days for the males, and a hundred and ninety-two days for the females, were obtained from animals carefully reared by Dr. Watson. He began his work with ten litters, nine of which were born in May, and one in June, 1903. From these ten litters there were chosen nineteen males and seventeen females, the effort being made to obtain two of each sex from each litter. The animals to be used were selected when the litters were fifteen days old, and the first weighing was made at that time. At twenty days the chosen animals were weaned; and at about sixty days (i.e., just before the period when sexual maturity is reached) the two sexes were separated, and neither group was allowed to breed. The conditions surrounding these animals during this period of observation were such as have been found

favorable for growth. The food was varied and abundant, but not excessive in amount. The care of the animals was very similar to that described by Dr. WATSON in his article on "The Effect of the Bearing of Young," etc. (1905).

The weighings were made just before feeding. The first record of the weight of the rats was made at fifteen days, and individual records were kept throughout the experiment. From the fifteenth to the thirty-first day the rats were weighed every second day; from the thirty-first to the ninety-second day, every third day; and from the ninety-second day to the hundred and twenty-fourth, every fifth day. From this last age to the end of the experiment they were weighed every seventh day. The rats became quite tame, and towards the end of the experiment would sometimes climb into the scale-pan of their own accord.

These observations, however, were not carried on without disturbance caused by the illness of some of the rats. Suffice it to say on this point, that when the rat, by its behavior, was found to be ill, and to be either falling behind in its rate of growth or actually losing weight, it was excluded from the record. The preceding portion of the record, which fell within the limits of those for the other normal rats, was, however, retained. It thus happened that at the end of the period of observation there were only fifteen males and eleven females which were considered in a normal, healthy condition.

As stated above, neither the males nor the females in Dr. Watson's series were mated. The effect of mating on the growth-curve for the males can probably be neglected, but in the case of the females it is an important circumstance.

Since, as a rule, laboratory animals of this sort are not isolated, it seemed most probable that other investigators would wish to compare the weights of the females which had been mated with the records which we have to present. To meet this possibility a second series of *calculated* weights, based on Dr. Watson's investigation on the effect of the bearing of young, is introduced, showing for those females allowed to bear young the estimated body-weight at different ages after the beginning of the first pregnancy. This is always greater than

the body-weight of the unmated females of like age. In this connection it is desirable to emphasize the fact that under ordinary circumstances the true body-weight of breeding females is difficult to determine. The weights of bearing females should be taken, as Dr. Watson has shown, only between the periods of pregnancy and after the rat has actually recovered from the prolonged strain of nursing the young; and the attention of those who have occasion to record body-weights of females is called to this point.

What we endeavor to show in the second series of numbers in Table II is the body-weight as modified by the bearing of young after the immediate disturbances due to the rearing of the litter have disappeared. In looking over Dr. Watson's records, as given in the paper cited above, it is seen that this cycle of disturbance, from the beginning of pregnancy to the end of the recovery from lactation, comprises from eighty to ninety days. We have assumed, then, that from impregnation to complete recovery would occupy a period of at least eighty days; and we have also assumed that the effects of the bearing of the young, so far as they influence the body-weight of the female, can be here represented as though they were steadily progressive.

In Dr. Watson's experiments on the effects of the bearing of young, the gain in weight extending through an average period of two hundred and forty days, and comprising the final recovery from the last of three litters, was found to be approximately .03 of 1 per cent. (0.03 per cent.) of the initial weight per diem; that is, mated animals increased in body-weight this much more rapidly than those which remained unmated.

Beginning in the present instance with the ninety-second day, at which time the effect of the first litter might be exhibited by a noticeable increase in the weight of the mother, conception having occurred ten days earlier, we have calculated and added the excessive growth of the mated females between the ninety-second day and the hundred and ninety-second day, the time at which this series closes. In doing this, the "initial weight" taken as the basis for the calculations was that at eighty-eight days (average, 136.0 grams: lowest, 115.6 grams; highest,

157.4 grams). The weights thus calculated for the breeding females are those used for the construction of the curve in Plates II and III.

After the hundred and ninety-second day, we have observations which have been collected in the laboratory at different times. They furnish seven cases at about three hundred and sixty-five days, or one year, all of these animals having been allowed to breed under the ordinary laboratory conditions.

In the case of the males, in Dr. Watson's series, no special remarks are called for. His records run only to the hundred and eighty-fifth day, and are continued by laboratory records which fall into four groups:—

10 individuals about 216 days old.
10 individuals about 256 days old.
6 individuals about 365 days old, or 1 year.
6 individuals about 730 days old, or 2 years.

We are thus able to get information concerning the change in body-weight of the female up to one year, and of the male up to two years.

In order to complete the growth-record in the rat, we need to know the changes in weight from the date of conception to that of birth. Unfortunately, it was not until the last moment that the need of this record was appreciated. The data will be gathered, but this will require some time; and for the present we shall use a curve the values of which have been calculated. The basis for this calculation is found in the records of FEHLING (1877), on the growth of the fœtus in the rabbit. The gestation period of the rabbit is from thirty to thirty-one days. This time is divided, in his table, into ten equal periods; and the weights, starting with the beginning of the fifth, are entered for each period. It is assumed by us that the nearly related rat, the young of which are as immature as those of the rabbit, and the gestation period of which is twenty-one days, grows in the same manner as does the rabbit (see Table III).

Under these circumstances, the change in weight of the rat can be approximately estimated; and the part of the curve which represents the increase in body-weight before birth, and

comprises the first two phases of the growth-curve, which are discussed further on, can in this way be provisionally represented.

The method of presenting the results on the body-growth of the rat which are entered in Tables I and II was carefully considered. Each age-group might have been examined statistically, and weight variants determined for it; but it was thought that the value of such results would be hardly enough greater than that given by printing the extreme weights for each age and group to warrant the additional labor and tables. The limiting individual records tend to be aberrant, and hence make a less favorable showing than could be obtained from a more elaborate treatment of the data; but this will hardly mislead any one who wishes to utilize these results. The entire series of individual records is preserved in the archives of The Wistar Institute of Anatomy, and is open to inspection there. All of the data for the rat are given in Tables I and II, and with these it will be necessary to compare the corresponding observations which apply to man.

TABLE I. DATA ON WHITE MALE RATS (UNMATED), SHOWING INCREASE IN WEIGHT OF BODY WITH AGE.

AGE IN DAYS (Gestation 21 Days).	BODY-WEIGHT IN GRAMS.			NUMBER OF ANIMALS.
	Average.	*Lowest.*	*Highest.*	
Birth	5.4	4.3	6.5	40
1	5.6	4.6	6.7	26
2	5.8	5.2	6.3	10
3	6.3	5.6	6.7	8
4	6.9	6.5	7.9	10
5	8.3	7.1	9.6	9
6	9.1	6.7	12.7	11
7	9.2	7.3	12.7	11
8	10.4	7.2	13.1	14
9	11.3	9.1	13.7	10
10	12.2	10.8	13.5	6
11	13.3	13.0	13.6	4
12	14.8	11.4	19.5	6
13	15.3	14.1	16.0	5
14	15.2	14.0	17.6	6
15	16.5	12.5	22.4	19
17	17.8	13.9	24.0	19
19	19.5	15.2	26.0	19
21	21.2	14.6	30.1	19
23	22.9	17.9	32.5	19
25	25.3	19.0	35.8	19

TABLE I. Data on White Male Rats (Unmated), showing Increase in Weight of Body with Age. — *Continued.*

Age in Days.	Body-Weight in Grams.			Number of Animals.
	Average.	*Lowest.*	*Highest.*	
27	27.4	19.8	38.3	19
29	29.5	22.1	39.3	19
31	31.8	25.9	41.2	19
34	34.9	27.4	43.3	19
37	37.8	28.5	48.0	19
40	42.2	30.8	52.2	19
43	46.3	33.7	62.4	19
46	50.5	35.9	66.2	19
49	56.7	38.9	73 9	19
52	62.5	39.8	82.5	19
55	68.5	40.6	87.5	19
58	73.9	45.1	100.1	19
61	81.7	49.0	116.6	19
64	89.1	52.7	129.6	19
67	99.3	57.7	140.2	19
70	106.6	71.2	148.5	19
73	113.8	71.4	152.4	19
76	121.3	89.8	157.5	19
79	128.2	97.0	161.2	19
82	135.0	105.1	165.5	19
85	143.8	117.0	168.5	19
88	148.4	124.5	174.0	19
92	152.3	124.0	179.6	19
97	160.0	124.0	180.7	19
102	168.8	120.0	192.2	19
107	177.6	120.0	206.0	19
112	183.8	125.0	215.6	19
117	191.4	130.0	223.0	19
124	197.3	123.0	238.2	19
131	202.5	132.4	249.2	19
138	209.7	145.6	248.4	19
143	218.3	155.5	259.4	19
150	225.4	162.4	268.2	19
157	227.0	162.4	271.4	19
164	231.4	159.0	271.8	17
171	235.8	165.2	289.0	17
178	239.4	167.9	291.2	17
185	239.8	176.0	294.0	15
216	252.9	190.5	294.5	10
256	265.4	190.5	310.0	10
365	279.0	203.6	320.0	6
730	308.5	285.0	375.6	6

TABLE II. DATA ON WHITE FEMALE RATS (UNMATED AND MATED),[1] SHOWING INCREASE IN WEIGHT OF BODY WITH AGE.

AGE IN DAYS (Gestation 21 Days).	BODY-WEIGHT IN GRAMS.						NUMBER OF ANIMALS.
	Average.		*Lowest.*		*Highest.*		
Birth	5.2		4.2		6.2		17
1	5.5		4.5		6.1		11
2	5.7		4.8		6.3		7
3	6.2		5.6		6.5		9
4	6.5		5.6		7.0		10
5	7.7		7.0		9.0		9
6	8.5		7.1		11.0		11
7	8.7		7.5		11.8		8
8	10.6		7.1		13.1		13
9	11.1		9.4		12.6		9
10	12.1		9.1		14.4		6
11	12.8		12.1		13.6		2
12	15.1		13.6		17.7		5
13	15.1		14.7		16.0		5
14	15.6		13.5		18.1		5
15	17.7		13.1		23.2		17
17	19.2		15.1		24.5		17
19	20.6		16.9		27.0		17
21	22.6		16.1		30.1		17
23	24.9		17.3		33.3		17
25	27.4		20.8		36.0		17
27	30.0		23.9		38.5		17
29	31.4		24.0		39.0		17
31	32.9		26.3		42.8		17
34	35.7		26.4		44.1		17
37	39.5		29.8		47.4		17
40	43.7		30.6		52.4		17
43	47.9		35.0		60.7		17
46	52.0		41.4		63.0		16
49	57.7		42.0		69.2		16
52	62.9		41.7		74.8		16
55	68.4		49.8		80.7		13
58	74.6		53.6		86.6		13
61	78.4		56.2		96.7		13
64	85.8		57.5		106.8		12
67	96.0		71.2		114.1		12
70	99.8		79.0		122.6		11
73	105.6		80.2		126.5		11
76	110.4		89.6		131.6		11
79	118.8		97.7		136.0		11
		Mated.		*Mated.*		*Mated.*	
82	124.7	—	101.0	—	139.2	—	11
85	131.5	—	105.0	—	143.2	—	11
88	136.0	—	115.6	—	157.4	—	11
92	139.6	139.8	118.7	118.9	161.4	161.6	11
97	145.9	146.3	119.6	120.0	174.5	175.0	11
102	152.4	153.1	124.6	125.2	185.7	186.5	11
107	154.9	155.8	129.6	130.3	191.4	192.5	11
112	160.2	161.4	138.5	139.5	193.6	195.0	11
117	166.5	168.0	142.5	143.8	199.0	200.8	11
124	170.7	172.6	146.4	148.0	206.7	209.0	11
131	178.6	181.0	151.2	153.0	214.7	217.5	11
138	182.2	185.0	151.0	153.3	210.2	213.4	11

[1] Under "Mated" are given the *estimated* body-weights for rats allowed to breed.

TABLE II. Data on White Female Rats (Unmated and Mated), showing Increase in Weight of Body with Age. — *Continued.*

Age in Days.	Body-Weight in Grams.						Number of Animals.
	Average.		*Lowest.*		*Highest.*		
		Mated.		*Mated.*		*Mated.*	
143	183.4	186.6	154.0	156.7	219.4	223.4	11
150	184.6	188.2	153.7	156.7	220.7	225.0	11
157	184.0	188.0	154.9	158.2	217.6	222.4	11
164	185.1	189.5	154.0	157.6	215.0	220.1	11
171	187.4	192.2	154.0	158.0	210.0	215.4	11
178	191.7	197.0	153.0	157.2	215.0	221.0	11
185	194.2	200.0	152.0	156.6	215.0	221.4	11
192	195.9	202.2	155.0	160.0	217.0	224.0	11
365		226.4		171.4		280.0	7

TABLE III. Calculated Growth of a Rat in Weight before Birth, based on the Observations of Fehling on the Rabbit Fœtus (Sexes not distinguished).

Rabbit.				Rat.	
Observed Growth of Fœtus.				Calculated Growth of Fœtus.	
Age in Days.	*Period.*	*Weight of Fœtus in Grams.*	*Ratio.*	*Age in Days.*	*Weight of Fœtus in Grams.*
12	5	.619	1	9	.087
15	6	6.167	10	11	.870
18	7	11.734	20	13	1.750
21	8	18.650	30	15	2.610
24	9	28.908	47	17	4.100
27	10	33.670	54	19	4.700
30–31	Term.	38.350	62	21	5.400

Data on Man.

The figures for man have been taken for the most part from Roberts's tables (1878). These are reproduced in Table IV; the weights, originally given in pounds avoirdupois, being changed to kilos, 2.2 pounds being taken as equal to 1 kilo. Unfortunately, the records for the male are incomplete at one year and at two years, no record being made in the first instance, and in the second that given being an average of only two observations. It is therefore necessary to supplement the curve at this point. The emendations which have been made are entered in parentheses at the right of Roberts's observa-

tions, and are based on figures published by CAMERER (1893). As will be seen, this emendation, based on three individuals weighed at two periods, makes the weight at one year 9.9 kilos, and at two years 12.8 kilos. The form of the curve given by these numbers corresponds very closely with that based on the record for the female (Roberts), and also with that obtained by Dr. MISHIMA (1904), in his careful study of Japanese children of both sexes during the first fifteen years of life.

It should, however, be further stated that in Roberts's records, the children at birth were weighed without clothing, while the records for all the other ages give a weight in which indoor clothing is included. This, of course, modifies the form of the curve between birth and the end of the first year; but after that point its influence on the shape of the curve can for our purpose

TABLE IV. DATA ON MAN (MALES AND FEMALES), SHOWING INCREASE IN WEIGHT OF BODY WITH AGE.[1]

AGE IN YEARS (Gestation 285 Days).	BODY-WEIGHT IN KILOS.			
	No. of Cases.	*Males.*	*Females.*	*No. of Cases.*
Birth	451	3.2	3.1	466
1	— (3)	— (9.9)	9.1	8
2	2 (3)	14.5 (12.8)	11.5	9
3	41	15.4	14.4	30
4	102	16.9	16.4	97
5	193	18.1	17.8	160
6	224	20.1	19.0	178
7	246	22.6	21.6	148
8	820	24.9	23.7	330
9	1425	27.4	25.3	535
10	1464	30.6	28.2	495
11	1599	32.6	31.0	456
12	1786	34.9	34.7	419
13	2443	37.6	39.7	209
14	2952	41.7	44.0	229
15	3118	46.6	48.3	187
16	2235	53.9	51.4	128
17	2496	59.3	52.5	74
18	2150	62.2	55.1	64
19	1438	63.4	56.4	97
20	851	64.9	56.1	128
21	738	65.7	55.5	59
22	542	67.0	56.1	53
23	551	67.0	56.4	29

[1] From Roberts's tables (1878), except males at one and two years, the data for which are interpolated in parentheses from Camerer's records, weight without clothing. So far as Roberts's records are concerned, the weight, except that at birth, includes the weight of indoor clothing.

be neglected. In the data taken from Camerer for the first and second year of the males, the weights are without clothing, and hence at those periods the weight of the male unclothed is compared with that of the female clothed. The amount to be added to the male, in order to adjust the difference, is probably from 6.5 per cent. to 7.2 per cent. of the true body-weight (see BOWDITCH [1877]), or .65 to .72 kilos at one year, and .83 to .92 kilos at two years. In the absence of exact data, we have not attempted any modifications of the figures as given by Camerer and reprinted in Table IV, but have entered on the chart the values without correction for clothing.

It is also important to enter for man, as has been done for the rat, the curve of growth from conception to birth. For this purpose, we have used the data furnished by FEHLING (Table V).

TABLE V. DATA ON MAN, SHOWING GROWTH OF HUMAN FŒTUS AT THE BEGINNING OF THE PERIODS INDICATED (SEXES NOT DISTINGUISHED).

Age in Lunar Months.	*Weight in Grams.*
Second month	1
Third month	7
Fourth month	20
Fifth month	120
Sixth month	285
Seventh month	635
Eighth month	1220
Ninth month	1700
Tenth month	2240
Term	3250

The portion of the curve for man in Plates II and III, between conception and birth, is based on the figures in the foregoing table.

CONSTRUCTION OF CHART IN PLATE II.

As previously mentioned, the base-line on which the ordinates for these growth-curves are erected has been so adjusted that one year of rat life equals thirty years of human life, the smaller intervals of time being given their proportionate values.

In entering the records to form the curves, it was found that

the best comparison could be obtained if they were related so that, on the axis of ordinates, 1 mm. equalled 1 gram of rat body-weight, and 1 mm. equalled 250 grams of human body-weight.

This was the scale of the original drawing, which has been reduced for reproduction. The data used for the curves are those in

Table III, for the fœtal rat.
" I, for the male rats.
" II, for the female rats.[1]
" V, for man before birth.
" IV, for man after birth.

In the case of man, the weights are taken from Table V, the values given by Camerer for the male at one and two years being employed.

As Minot (1891) has indicated, it is important to begin the growth-records of this sort at the fixed point of conception. The period of gestation in man is here taken to be two hundred and eighty-five days, and in the rat twenty-one days. As the general relation of the two life-spans is as 1 to 30, we might expect that the period of gestation for man would be thirty times as long as that for the rat. As a matter of fact, it is only about fifteen times as long; so that, in the curves as they are drawn, the time of birth for man comes relatively earlier than for the rat.

When we take into consideration the great immaturity of the rat and its relatively long period of gestation, there seems to be but one conclusion possible; namely, that in the fœtal rat as compared with man the growth-processes are decidedly feeble.

PHASES OF THE GROWTH CURVE. — In all cases where records have been made, — i.e., man, rabbit, and the guinea-pig (Minot), — fœtal growth is represented by a curve which rises first slowly, then rapidly; the more rapid rise appearing during the second half of fœtal life.

[1] The calculated weights for breeding females between the ninety-second and one hundred and ninety-second day in Table II were those used in making the curve.

Leaving aside for a moment the interpretation of this curve in terms of the rate of growth, it is to be observed that there is in man a period of rapid rise, beginning at the middle of gestation, and continuing during the first year of extra-uterine life; while in the rat (the curve for which is based on the rabbit) the same event is entirely completed at the time of birth. Minot's observations on the fœtal guinea-pig also show this phenomenon of a rapidly rising curve at this time. Such being the case, it is possible to recognize between conception and maturity five phases in the growth-curve,—phases which are characterized by variations in the rise of the curve.

To facilitate the identifications of these several phases of growth in the curves which are here given, the following table is presented to show how they are marked off.

TABLE VI. Phases of Growth (Males Only).

	Trend of Curve.	Man (Males).	Rat (Males).
Phase 1.		First 140 days of gestation.	First 9 days of gestation.
Phase 2.	More rapid rise.	From 141st day of gestation to end of first year.	From the 10th to the 17th day of gestation.
Phase 3.		From beginning of 2d year to the 5th year.	From the 18th day of gestation to the 2d to the 7th day after birth.
Phase 4.	More rapid rise.	From beginning of 6th year to end of the 16th.	From the 3d to the 8th up to the 70th day.
Phase 5.		From the 16th year to maturity.	From the 71st day to maturity.

The limits of these phases are so modified by sex, that certainly Phases 5 and 4 in the female curve come earlier, and the same is probably true of Phase 3. Concerning Phases 2 and 1, we cannot at the moment speak, as the form of the curve given for the rat is merely inferred from observations on the rabbit, and the sexes are treated together.

Comparison of Curves for the Two Sexes.—In comparing the curves for the two sexes in man, we find the well-known differences whereby in Phases 2 and 3 the female shows a smaller body-weight than the male. Somewhat beyond the

middle of Phase 4 the female grows more rapidly, and is for the time heavier. It should be remembered in this connection that the length of time during which the weight of the female remains greater than that of the male is much longer in a curve of the sort we are using than it usually is in the case of selected pairs. At the end of the fourth phase the female grows less rapidly, the curves recross, and the relations characteristic of maturity are attained.

On examining the corresponding curves for the rats (Plate II) we see the same relations repeating themselves in the same phases of the growth-curve.

As has been stated before, in the case of the rat the second phase is completed before birth; and the third phase then becomes evident, and continues for a few days after that event. In our present records it will be seen that the more active growth of the female begins as early as the seventh day after birth, and that in this particular set of observations the two curves cross about the fifteenth day. They remain crossed until the fifty-fifth day, when, after a few days of fluctuation, they recross and separate permanently.

In the rat, therefore, the curve for weight of the female is related to that for the male in the same way as are the corresponding curves in the case of man. In this instance, then, we have an animal widely removed from man in the zoölogical scale, belonging to an order palæontologically ancient, and exhibiting phylogenetically but a slight tendency to variation, which shows a series of growth-relations similar to those observed in man.

In a certain sense the purpose of this presentation is accomplished when we have shown in what relation the growth-curves of these two animals stand to one another. One is tempted, however, to go a step further, and call attention to the possibility that mammals as a class may grow in a like manner. This point has already been raised by Minot on the basis of his own observations of the guinea-pig, which, if I interpret them correctly, show a curve of growth for that animal which gives a long fifth phase preceded by a comparatively short fourth and still shorter third phase.

During the last of the third and beginning of the fourth, for about the first twenty-eight days of post-natal life, the female is slightly heavier than the male. This was the first instance where more vigorous growth in the female in lower mammals was noted and described.

Though not of an equal value with those just presented, there are some other records in the literature which seem to confirm the existence of this general relation.

CORNEVIN has tables (1892) showing the weight of growing cattle. These tables do not give all the information necessary; but, if curves for the growth of the two sexes in body-weight be plotted from the data as given on p. 481 of his paper, it appears that between the first and fourth months of post-natal life the female is heavier than the male.

Since in this species puberty occurs during the first year, this relation may express the pre-pubertal acceleration in the female. As the matter stands, however, the evidence is not very conclusive.

Ménard followed the growth of eight giraffes, taking the height at the withers. His measurements show a pre-pubertal superiority of the females at two years, puberty in this animal coming between the ages of three and four years. After puberty, the males have the greater height. Ménard remarks that the general size of the animals corresponded with the differences in the measurements which he has given, so that we can infer that they would probably have differed in weight in the same sense.

In his article on growth, in HERMANN'S "Handbuch der Physiologie," Vol. VI, 2, p. 262, the author, HENSEN (1881), gives a table showing a relatively greater rate of growth of young female guinea-pigs during the first fifty-one days of life. If, however, I interpret his figures correctly, the *absolute* weight of the females at this time was regularly less than that of the corresponding males, despite the more rapid rate of growth which the females exhibited.

In this connection it may be stated that the literature does not show any records by which opposite relation (i.e., more rapid growth of male) is demonstrated, — a fact which adds

weight to the foregoing interpretation of these imperfect data. A word of caution is needed, however, against linking too closely the period of more rapid growth of the female with puberty. It so happens that in man the two events are nearly related; but, taking the other cases that have been well worked out, we find in the guinea-pig that at twenty-eight days the female is already growing more slowly than the male, though sexual maturity does not occur until the hundred and twentieth day; while in the rat, puberty is not attained until the sixtieth day at the earliest, at which time the female is growing less rapidly than the male, the onset of the rapid growth of the female having appeared about the eighth day of life. Our information in the case of cattle and the giraffe is not complete enough to warrant comments. The relation of these two events is therefore less close than a study of the data on man alone would suggest.

To prevent any misunderstanding concerning the significance to be attached to the direction of the curves here used as indications of the several phases, it is necessary to add one or two words on their general interpretation. Where the record for the change of weight appears as a straight line, we know that this indicates equal absolute increments in equal times. If, however, at any point in its course, the curve bends towards the horizontal, it indicates that for that period the absolute increment is less than for the preceding, and if it bends towards the vertical, that it is greater. It appears, however, as has been pointed out by Minot, that the rate of growth, as measured by the percentage increase from interval to interval, diminishes, *in all cases* observed, very rapidly and with but slight fluctuations from the earliest moment at which we can measure the growth-process up to the end of the growing period. The curve necessary to represent an *equal rate of growth* would be an exponential curve approximating the vertical with greater or less rapidity, according to the value of the rate.

From this it follows, that, in the cases before us, we are always dealing with a diminishing rate, and that the variations occur merely in the rapidity with which this diminution takes place. Hence in the several phases to which we have drawn

attention, the parts of the curve showing rapid rise or slow rise, while they indicate variations in the increment of the absolute weight of the animal, at the same time indicate changes which represent in general a rapid though slightly varying diminution in the rate of growth.

Cause of the Phases.

Before leaving the study of these records, it seems desirable to consider for a moment the explanation of the several phases.

We recognize, in the first place, that the growth with which we have to deal is dependent mainly upon cell-multiplication and cell-enlargement; further, that after several classes of cells arise within the organism, it is probable that we have to deal with modifications in the growth of one class due to the activities of others. If we survey the span of life from the beginning to the end, we find that in the first and second phases, principally, cell-division is very active, while in all the later phases cell-enlargement is the main cause of the increase in total size. Moreover, the last process is influenced by the number of cells which in each species is destined to undergo enlargement.

Since, in the rat, birth occurs during the third phase, cell-division as a factor in growth would appear to be comparatively insignificant between birth and maturity, cell-enlargement being the chief cause for the changes taking place.

A priori, we might expect that this process of enlargement would give us a simple steadily rising curve which rather rapidly turned and flattened as maturity was approached. Since the curve departs clearly from this form, having after birth three well-marked phases, in the first and last of which it rises slowly, separated by one (fourth phase) in which it rises more rapidly, it seems highly probable that the enlargement of the body as a whole is a resultant of the complex influences represented by the interaction of several systems; but into this division of the topic it is not our purpose at present to go. We note, however, that birth in man is relatively an early event, while puberty comes later—something more than halfway from birth to maturity; the relative interval between birth and puberty being nearly three times as long in man as in the rat.

As a result of this study, we conclude that man and the rat attain their adult weight after having passed through a series of phases similar for both animals; and that, moreover, in both of them the increase in body-weight in the two sexes is related in the same way.

Details on the Period of More Rapid Growth of the Female Rat.

Before closing this paper it will be desirable to give a little more detail bearing on that part of the rat curve in which the growth in the female is more rapid than in the male.

TABLE VII. Data on the White Rat, being Dr. Dunn's Records of the Average Weights of the Individuals composing Different Litters from Birth to 14 Days, arranged by Litters.[1]

Age in Days.	Weight of Body in Grams.			
	No. in Each Litter.	*Males.*	*No. in Each Litter.*	*Females.*
Birth	4	5.77	4	5.26
1 day	3	6.01	2	5.69
" "	4	5.96	4	5.86
2 days	2	6.06	3	6.02
3 "	5	6.26	5	6.19
3 "	3	6.35	4	6.13
4 "	6	7.06	6	6.52
4 "	4	6.79	4	6.45
5 "	3	9.56	3	8.43
5 "	2	7.88	2	7.46
5 "	4	7.57	4	7.16
6 "	4	8.10	3	7.69
6 "	3	11.99	3	10.54
6 "	4	7.91	5	7.77
7 "	3	7.49	2	7.88
7 "	3	8.19	2	7.61
7 "	2	7.92	2	8.60
7 "	3	12.59	2	10.77
8 "	4	10.35	3	10.76
8 "	4	12.43	3	11.80
8 "	2	11.30	3	12.58
8 "	4	7.84	4	7.40
9 "	3	12.66	2	11.99
9 "	3	12.22	3	12.23
9 "	4	9.70	4	9.76
10 "	3	13.27	2	13.87
10 "	3	11.22	4	10.28
11 "	4	13.25	2	12.84
12 "	3	16.53	3	15.89
12 "	3	13.06	2	14.22
13 "	5	15.29	5	15.10
14 "	4	14.64	3	14.58
14 "	2	16.27	2	17.12

[1] Except for the ages, birth, one day, and two days, the average from the observations given above are used in Tables I and II.

If we analyze Dr. Watson's records, we find that there were seven out of ten litters in which both sexes were carried through the *entire* period of observation. In these seven litters, six of them show the female to be heavier at some time between the fifteenth and seventy-fifth day of life. In the seventh litter, the weight of the female, although always less, was closest to that of the male between the fortieth and fiftieth days. This seems to be ample evidence for the more vigorous growth of the female during the third and beginning of the fourth phases. Dr. Watson's observations, however, begin with the fifteenth day of life, at which time the female is already the heavier; and it was for Dr. Dunn to determine from her observations how the two sexes were related during the first fourteen days. The accompanying table (VII) shows the average weight of the separate litters, from which the weight of the rat during the first fourteen days has been determined. Where the average for the female is heavier for a given litter, the figures are printed in heavy-faced type.

For the ages birth, one day, and two days, Dr. Dunn's records have been supplemented by adding from the laboratory archives the following, the totals being also found in Tables I and II.

Age.	Number of Animals.					
	Males.			*Females.*		
	Dunn.	*Archives.*	*Total.*	*Dunn.*	*Archives.*	*Total.*
Birth	4	36	40	4	13	17
1 day	3	23	26	2	9	11
2 days	4	6	10	4	3	7

It appears that during the first six days of life, the average for the females is always less than that for the males. Beginning with the seventh day, and between this and the fourteenth day, nine out of the nineteen litters show an average for the female greater than that for the male. As reference to the table will show, these instances occur on the seventh, eighth, ninth, tenth, twelfth, and fourteenth days, but in the grand averages these relations are overbalanced, except on the eighth, twelfth, and fourteenth days. We infer from this that the

period of more vigorous growth in the female begins about the seventh day of post-natal life.

Of course, from the biological standpoint, it makes no difference whether the curves of weight cross or not; the important change is the more rapid growth of the female during this early period. To better illustrate these events during the first seventy days of life, the first part of the curve (Plate II) has been enlarged to four times the scale on which it is there drawn, and is shown in Plate III. As to the time of recrossing, or the beginning of the slower growth of the female, which our curves show at the beginning of the fifth phase, we have another series of observations by Dr. Dunn on five litters.

In all these five litters there was a time during the fourth phase when the female was growing more rapidly than the male. The change in the rate of growth by which the female grows more slowly again may occur any time between the twentieth and sixtieth days, while on the average the growth in the female is found to be most rapid, as compared with the male, between the twenty-fifth and thirtieth day of life. After this, of course, begins the relatively slower growth of the female, which sooner or later leads to the relations of weight characteristic of maturity. There is, then, no question that the relations expressed by Dr. Watson's records are entirely correct, in that they show a relatively more vigorous growth of the female during the fourth phase, with the usual result of making the females absolutely heavier at this time.

Conclusions.

I. Applying to both Rat and Man.

1. The curves recording the increase in the body-weight of man and of the white rat between conception and maturity exhibit similar phases, five in number.

2. The growth of the female, in relation to that of the male, is similar in both forms, as are also the relative weights of the two sexes at maturity.

II. Applying to the Rat only.

3. In the rat, as compared with man, the period of gestation is a larger fraction of the span of life, and puberty comes rela-

tively earlier, and longer before the mature body-weight is attained.

4. The age of puberty in the rat (60–70 days) is separated from the onset of more rapid growth in the female by a relatively long interval. The two events are therefore not necessarily closely associated.

5. In the rat, increase in body-weight during the last phase is continued for a relatively longer time than in man.

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EXPLANATION.

In the original drawing, 1 mm. = 1 gram of body-weight in the rat, laid off on the ordinate to the left; and 1 mm. = 250 grams of body-weight in man, laid off on the ordinate to the right in kilograms.

On the base-line, 1 mm. = 1 day of rat life, 12.15 mm. = 1 year of human life, and the zero-point is taken at the time of birth. To the left of the zero-point, 21 mm. are laid off, corresponding to the 21 days of gestation for the rat; and 9.4 mm. are laid off, corresponding to the 285 days of gestation for man.

The point of conception (*C*) coincides for the two curves; but as gestation in man is relatively only half as long as in the rat, and as the ages are in both cases counted from birth, the two curves are somewhat displaced, so that the 30th year of human life falls a little to the left of the 365th day of rat life.

The lines showing body-weights are heavier for man than for the rat; and in each case the curve for the male is indicated by the solid line, and that for the female by the broken one. For the records before birth no distinction for sex is made, and the solid line is used.

Where the curves for the two sexes run close together, the distances have been exaggerated in some instances in order to keep the lines distinct.

Chart reduced to one-third of the original dimensions.

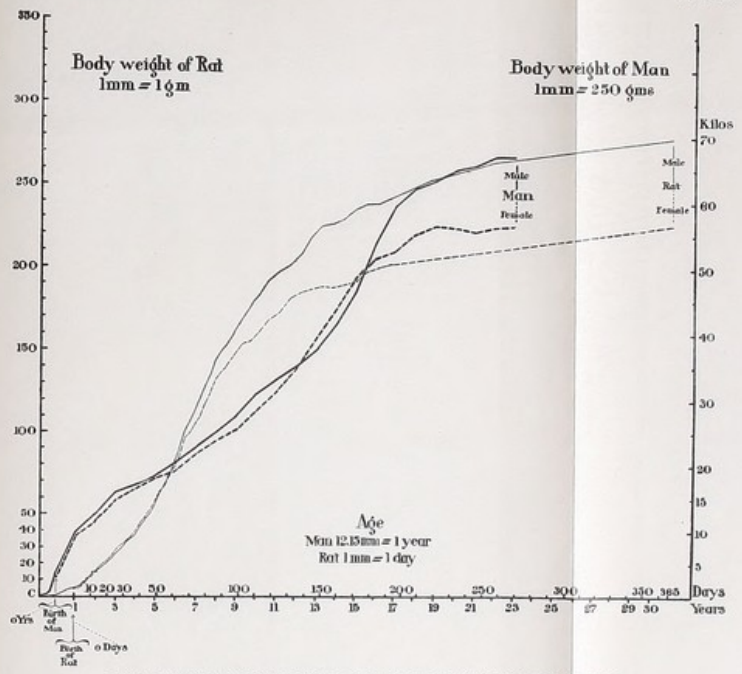

CHART SHOWING THE INCREASE IN THE BODY-WEIGHT OF MAN AND THE RAT WITH AGE.

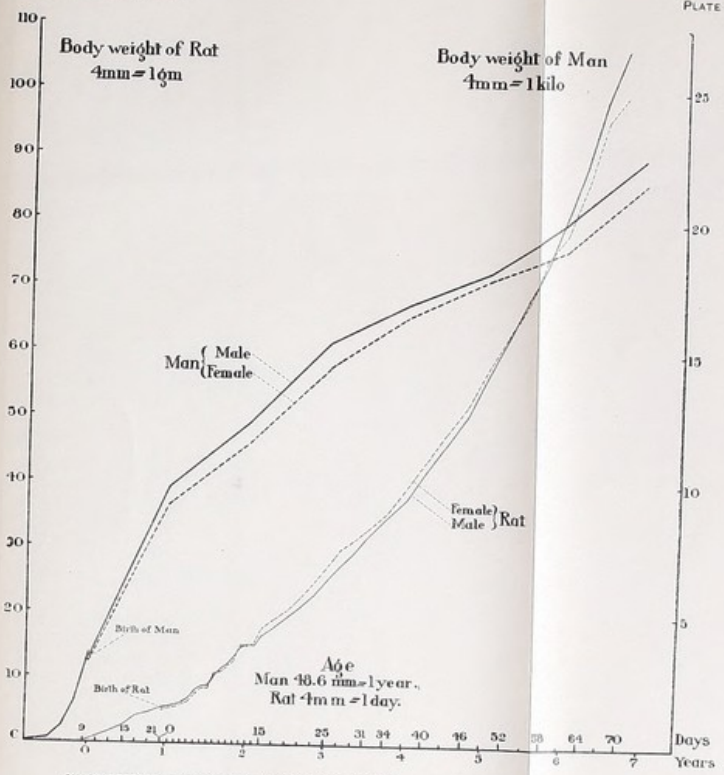

CHART REPRESENTING THE FIRST SEVENTY DAYS AS SHOWN ON PLATE II, ENLARGED TO FOUR TIMES THE SCALE OF THAT CHART.

The values given under the explanation of Plate II should all be multiplied by 4 to give the correct values for this chart, otherwise the construction of the two charts is similar.

Chart reduced to one-third of the original dimensions.