On the relation of the body length to the body weight and to the weight of the brain and of the spinal cord in the albino rat (Mus norvegicus var. albinus) / by Henry H. Donaldson.

COMPLIMENTS OF

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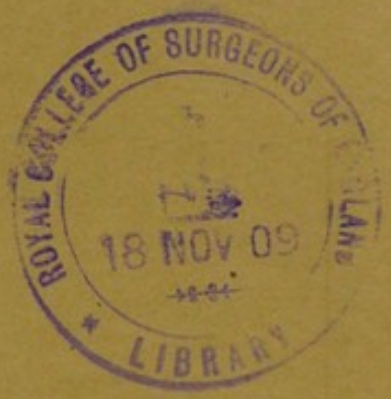

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ON THE RELATION OF THE BODY LENGTH TO THE BODY WEIGHT AND TO THE WEIGHT OF THE BRAIN AND OF THE SPINAL CORD IN THE ALBINO RAT (MUS NORVEGICUS VAR. ALBUS).

BY

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WITH THREE FIGURES.

In a recent paper (Donaldson, '08) the relations of the body weight to the weight of the brain and of the spinal cord in the albino rat have been described.

In addition to the determination of the body weight it was stated in the paper just cited (pp. 346-7) that measurements had also been made on the body length (trunk and head) of some of the rats, but to avoid confusion the discussion of this character and its relations was reserved for the present paper.

The reasons for making a series of linear measurements on the albino rat were briefly the following:—

1. To obtain a second general measure of the body growth of the albino rat in terms other than those of weight.

2. To gather data by which to determine the body weight and body length ratio for the variety measured.

This ratio is valuable because it gives a notion of the general shape of the animal and also enables us to state whether there are

differences in this relation according to sex, as well as to make comparisons with other forms.

It also permits the determination of the influence of dwarfing and other modifying conditions on the weight-length relation.

3. Both the weight of the brain and of the spinal cord can be related to the body length, and the measurement on body length thus made to furnish an additional datum from which the weights of the brain and of the spinal cord can be inferred. As we shall see, this datum is a much better one than body weight, especially in those cases where, for one reason or another, the animal has become emaciated.

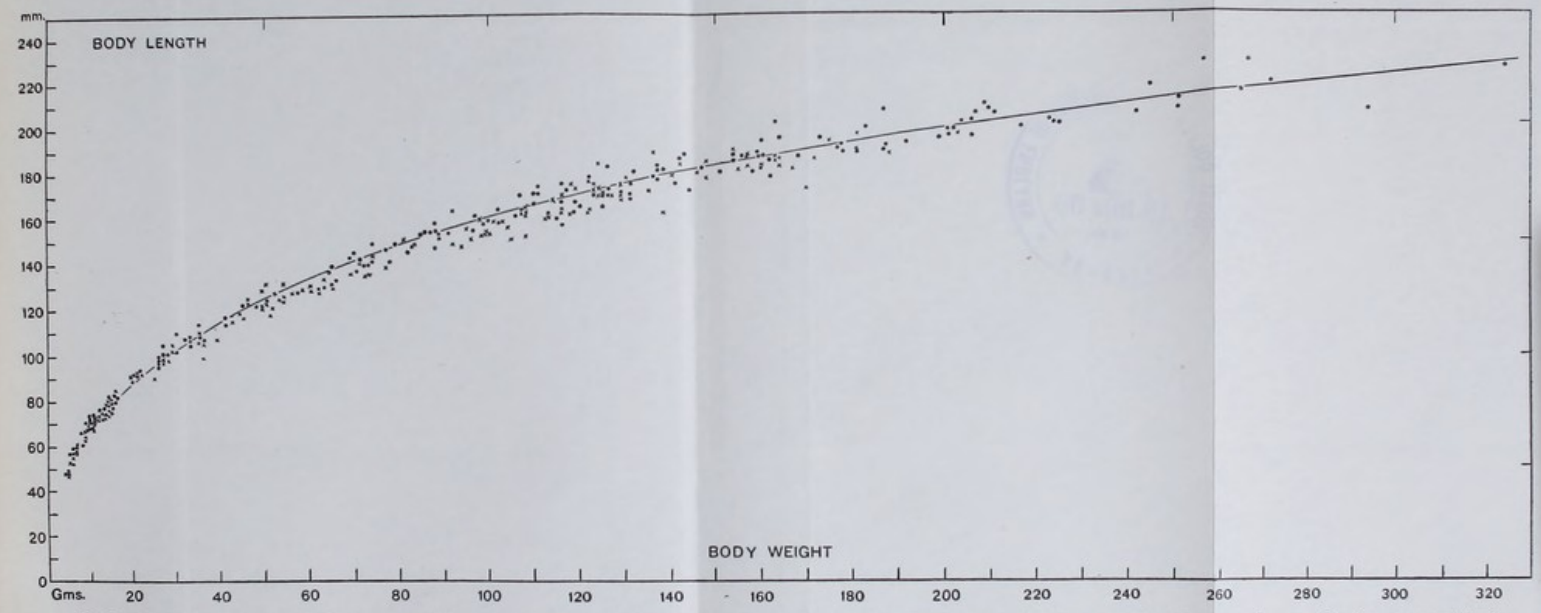
4. If we consider the body length of the rat to correspond in a general way with the sitting height in man, we have one more means of comparing the growth changes in the two forms.

In the following pages we shall discuss these points, so far as they have been worked out. For the mathematical treatment of the results I am indebted to my colleague, Dr. Hatai, who is publishing at this same time some notes on the formulas previously used by both of us (Hatai, '08; Donaldson, '08), as well as giving a new and more general formula for determining the weight of the brain from the body weight (Hatai, '09).

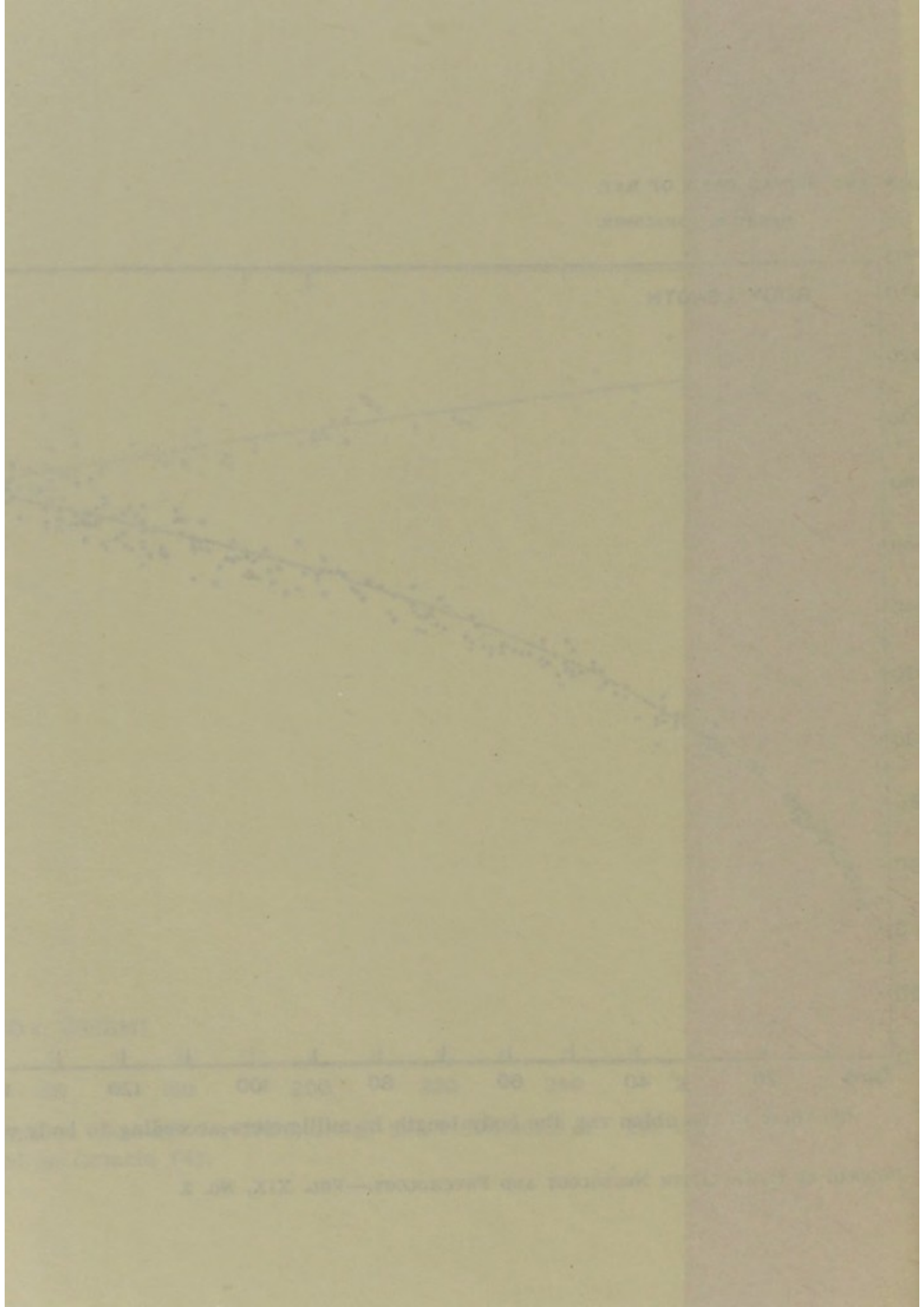
The technique of weighing and measuring was that described in the earlier paper (Donaldson, '08). A number of complete records on the albino rat have been added to those on hand at that time. Moreover, for the relation of body weight to the body length alone, additional records have been obtained by weighing and measuring animals which had been anæsthetized lightly.

It was my first intention to print the full series of individual records (233 males, 173 females) in a general table at the end of this paper. I have, however, decided not to do so for the following reasons:—

First.—Printing such a general table would involve repeating a number of the records already published in a former paper (Donaldson, '08), and would in turn need to be again repeated in a forthcoming paper on the change in the percentage of water during the growth of the nervous system.



To show in the abino rat, the body length in millimeters according to body weight in grams. Records for 170 males ●, and 148 females ✕. The theoretic curve for the sexes combined is based on formula (4).



Second.—The individual records have been tabulated and are on file at the Institute. They are therefore available for use by other investigators, and may be had by application to the Director of The Wistar Institute.

Third.—It is hoped that this condition will be only temporary, and that when this group of investigations is completed, the entire series of individual records employed for them can be printed in the form of tables in a special brochure, thus making them generally available. At this time only the mean values of the observation are tabulated.

We turn at once, therefore, to the consideration of the special questions:—

1. The body length of the albino rat according to body weight.

On Chart I, so far as is possible without confusion, the individual records for body length (170 males and 148 females) are entered according to the body weight. The continuous line on the chart shows the theoretical curve. As can be seen, the distribution of the records is such as to fit a theoretical curve that rises with diminishing rapidity, and so far as it can be plotted, is still bending towards the horizontal. A distinction between the sexes in the relation of body length to body weight, though present, is hardly to be seen on Chart I. The mean values for the body lengths are given in Table 2. Making use of these data, the weight length ratios have been determined for the series in hand.

Table 1 gives the numerical expression of the relations obtained by dividing the calculated body length (for both sexes combined, see Table 2) by the body weight.

The ratios thus obtained are given in Table 1, and these show that the albino rat becomes relatively shorter as its weight increases.

By means of a correlation table based on groups differing by 10 grams in body weight and 10 mm. in body length, the mean statures for given body weights have been calculated. This has been done for each sex separately, as well as for both sexes taken together, and the final values obtained are given in Table 2.

When the means for the males are compared with those for the

females (see Chart II, based on 179 males and 160 females) it will be observed that the latter run slightly below the former. The difference, though small, has significance, as we shall show later. However, for the general discussion at this time the results are not separated according to sex, but are treated together.

TABLE 1.

THE RATIOS OBTAINED BY DIVIDING THE BODY LENGTH BY THE WEIGHT IN THE CASE OF MUS NORVEGICUS VAR. ALBUS.

Body weight gms.	Body length mm. Both sexes combined (See Table 2.)	Ratios.
5	51.9	10.38
15	77.6	5.17
25	94.8	3.78
35	109.1	3.11
45	120.5	2.67
55	130.6	2.37
65	137.7	2.11
75	144.9	1.93
85	152.0	1.78
95	157.7	1.66
105	163.4	1.55
115	167.7	1.45
125	173.5	1.38
135	177.7	1.31
145	180.6	1.24
155	184.9	1.19
165	189.2	1.14
175	192.0	1.09
185	194.9	1.05
195	197.8	1.01
205	200.6	.97
215	203.5	.94
225	206.3	.91
235	209.2	.89
245	210.6	.85
255	213.5	.83
265	216.4	.81
275	217.8	.79
285	220.6	.77
295	222.1	.75
305	224.9	.73
315	226.4	.71
325	227.8	.70

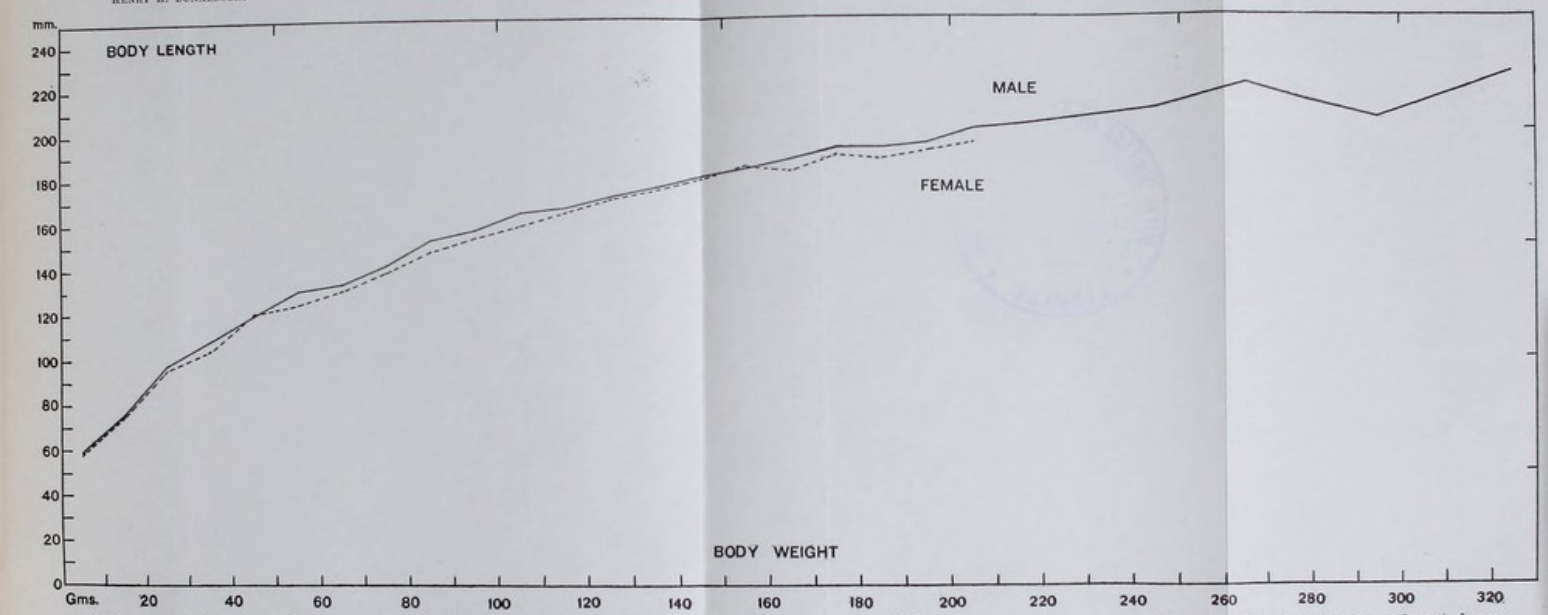
The theoretical curve which most closely represents the change in body length with increasing body weight, is given by the formula (4)

$$y = 143 \log (x + 15) - 134$$

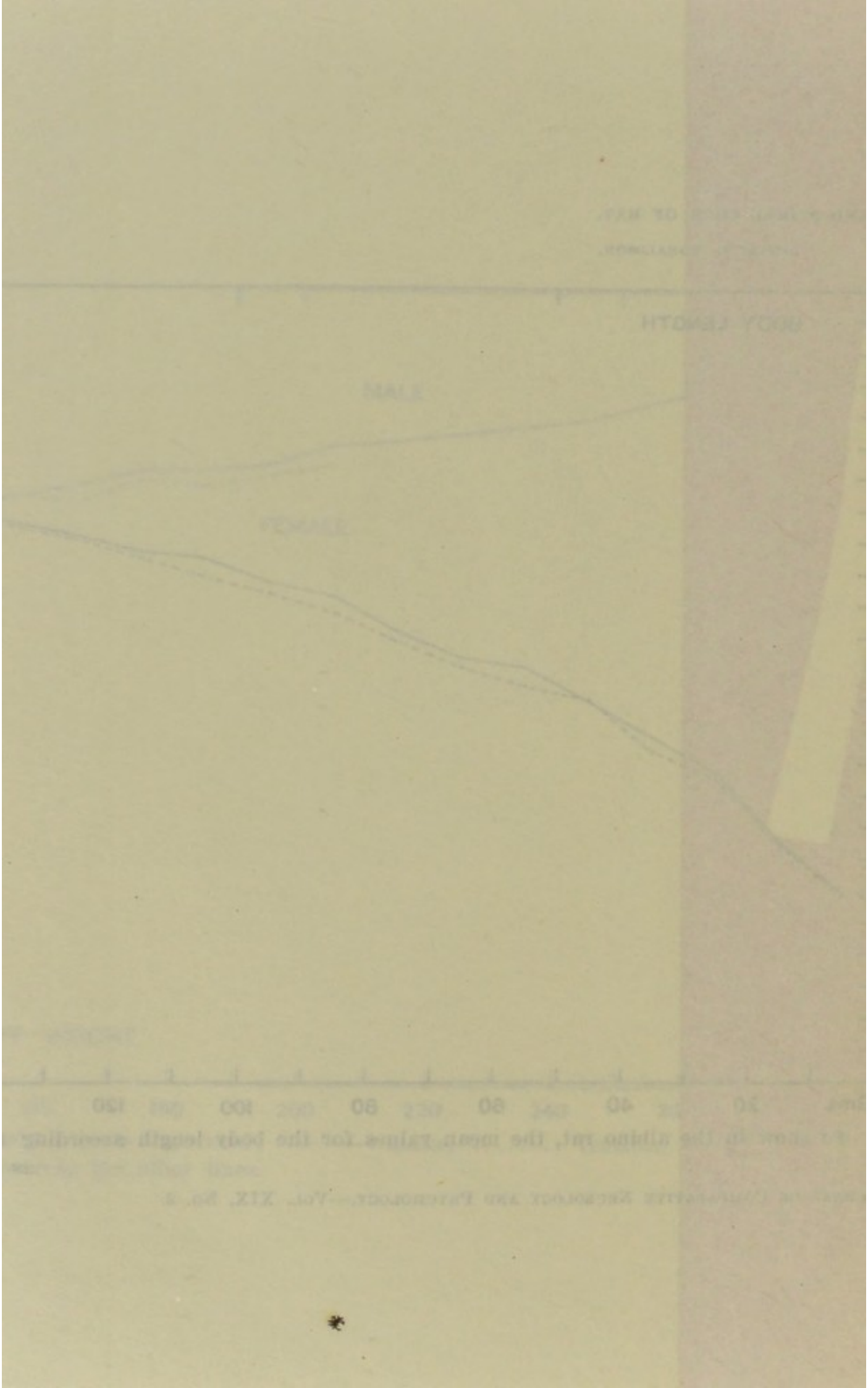
where y represents the body length and x the body weight.

This is a formula of the same type as those used for determining the weight of the brain and of the spinal cord in relation to the

CHART II



To show in the albino rat, the mean values for the body length according to body weight, sexes separated; ——— males, ... females. The theoretic curve is not drawn, as it would confuse the other lines.



weight of the body, and the type has been already discussed in a previous paper (Donaldson, '08, p. 350).

In this connection, however, there are some points to be corrected and further discussed. The consideration of these points is taken up in a paper by Dr. Hatai which appears at this time.

TABLE 2.

Mean body length according to body weight in Mus norvegicus var. albus. The body length as given in the last column has been calculated by the formula (4), $y = 143 \log (x + 15) - 134$.

Body Weight Gms.	Body Length Observed.						Body length in mm. calculated by formula (4)
	Frequencies. M.	Mean mm. M.	Frequencies. F.	Mean mm. F.	Frequencies. M.+F.	Mean mm. M.+F.	
5	12	59.2	12	58.3	24	58.8	51.9
15	15	76.3	24	75.4	39	75.9	77.6
25	11	97.7	8	96.3	19	97.0	94.8
35	8	108.8	8	105.0	16	106.9	109.1
45	5	121.0	11	121.4	16	121.2	120.5
55	7	130.7	13	125.0	20	127.9	130.6
65	9	134.0	5	131.0	14	132.5	137.7
75	9	141.6	5	139.0	14	140.3	144.9
85	8	152.5	4	147.5	12	150.0	152.0
95	6	156.6	10	154.0	16	155.3	157.7
105	6	165.0	9	159.4	15	162.2	163.4
115	12	166.7	9	165.0	21	165.8	167.7
125	7	172.1	15	171.0	22	171.6	173.5
135	9	176.1	4	175.0	13	175.6	177.7
145	5	181.0	4	180.0	9	180.5	180.6
155	9	184.0	6	185.0	15	184.5	184.9
165	7	188.0	6	183.3	13	185.7	189.2
175	4	192.5	2	190.0	6	191.3	192.0
185	5	193.0	3	188.3	8	190.7	194.9
195	2	195.0	0		2	195.0	197.8
205	7	200.7	2	195.0	9	197.9	200.6
215	4	202.5			4	202.5	203.5
225	2	205.0			2	205.0	206.3
235	0				0		209.2
245	2	210.0			2	210.0	210.6
255	3	215.0			3	215.0	213.5
265	2	220.0			2	220.0	216.4
275	1	215.0			1	215.0	217.8
285	0				0		220.6
295	1	205.0			1	205.0	222.1
305	0				0		224.9
315	0				0		226.4
325	1	225.0			1	225.0	227.8

The co-efficient of correlation between the body weight and body length, the records being grouped as stated above, is found to be .90.

It is possible, therefore, to infer the body weight from the stature, and *vice versa,* provided the body weight is normal.

At the same time it is evident that body weight is much more open to fluctuations than is the body length, and therefore the body length is the better standard.

2. The relation of the weight of the brain and of the spinal cord to the body length.

We shall consider each division of the central nervous system separately.

(a) The relation of the weight of the brain to the body length.

When the data on brain weight are plotted according to the body length, we obtain the distribution of individual entries (196 males,

TABLE 3.

CALCULATED BRAIN WEIGHTS AND SPINAL CORD WEIGHTS ACCORDING TO BODY LENGTH IN MUS NORVEGICUS VAR. ALBUS.

DATA FOR BOTH SEXES COMBINED.

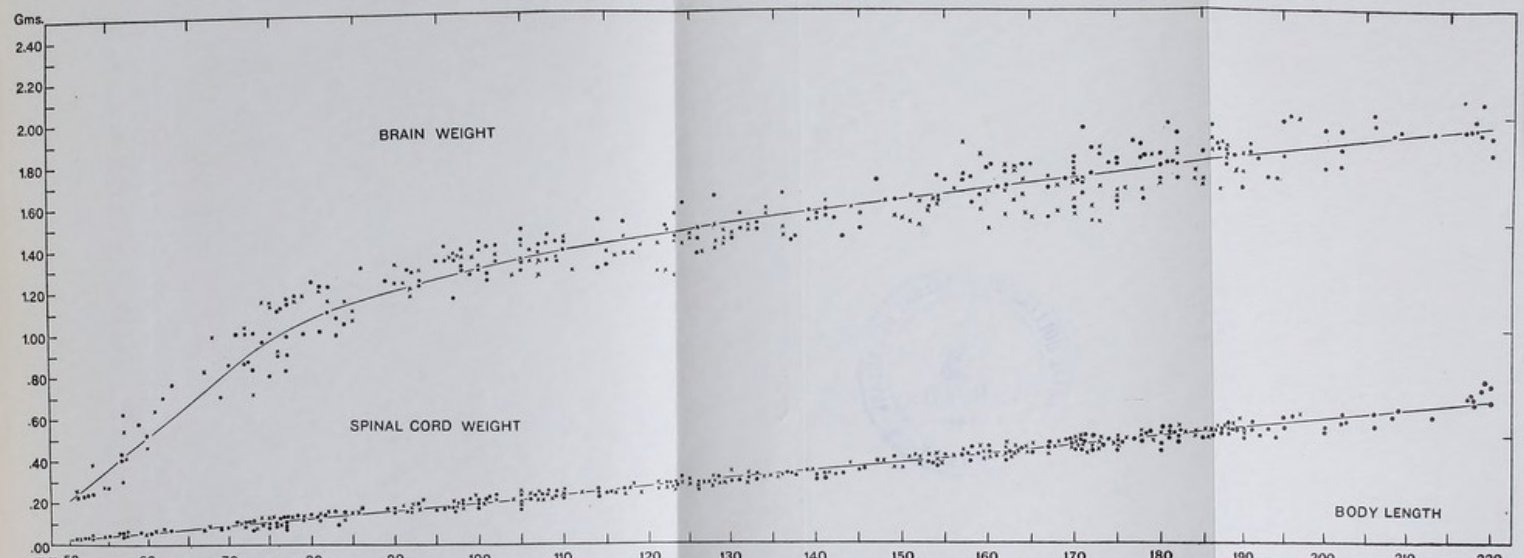
Body length mm.	Body weight gms. Calculated by Formula (4).	Brain weight gms. Calculated by Formula (8).	Spinal cord weight gms. Calculated by Formula (3).
50	4.5*	.204*	.031*
55	6.6	.409	.047
60	7.8	.522	.059
65	9.7	.660	.077
70	11.7	.827	.088
75	13.9	.962	.106
80	16.6	1.065	.129
90	21.8	1.191	.159
100	28.2	1.288	.194
110	36.6	1.379	.235
120	44.7	1.442	.270
130	55.1	1.504	.305
140	67.4	1.561	.346
150	81.6	1.612	.381
160	102.4	1.675	.428
170	118.7	1.714	.463
180	142.0	1.760	.498
190	169.5	1.811	.539
200	201.3	1.851	.580
210	239.1	1.897	.621
220	283.6	1.942	.656
225	324.0	1.977	.691

*Since the formulas do not allow of extrapolation toward the lower end of the curve, the averages of the observed values are here employed.

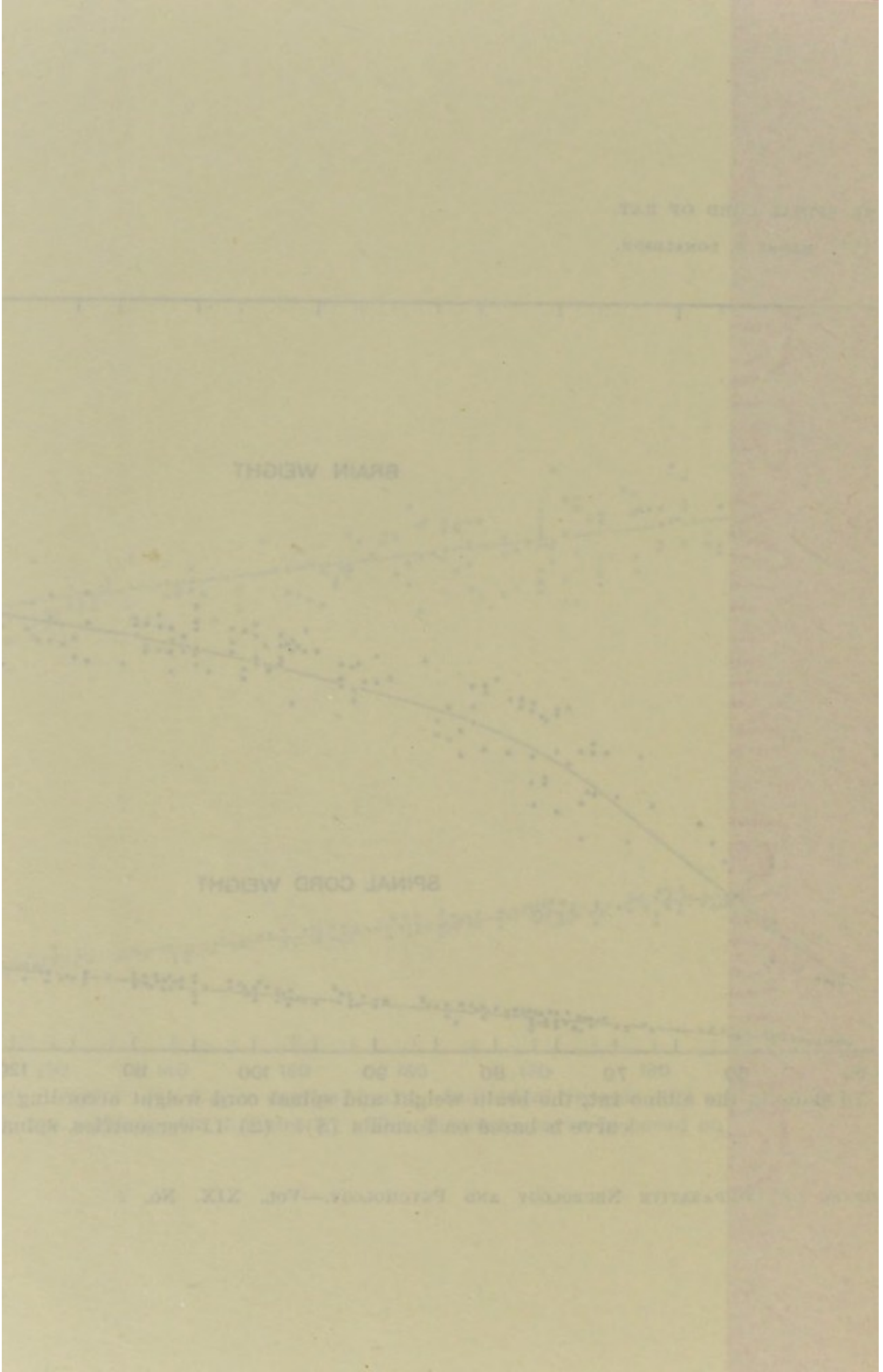
137 females as shown on Chart III. The difference between the two sexes is slight, and in this instance therefore the data for both sexes will be treated together.

The theoretic curve which fits the means most closely has been obtained in the following manner:—

For the body lengths given in Table 3, the body weights were calculated by formula (4) transposed as follows:—



To show in the albino rat, the brain weight and spinal cord weight according to body length. (1) Upper entries, brain. Individual records, 196 males ●, 137 females **X**. The theoretic curve is based on formula (8). (2) Lower entries, spinal cord, 189 males ●, 137 females **X**. The theoretic curve is based on formula (3).



$$x = 10^{\frac{y + 134}{143}} - 15 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4')$$

where x represents the body weight and y the body length.

On the basis of the body weights thus determined the weight of the brain can be calculated by the revised formula (8)

$$y = \frac{\log x^{1.56} (x - 8.7)^{.569} - 0.316}{2} + \sum_{0}^{\infty} \left(\log \frac{x^{1.56}}{(x - 8.7)^{.569}} + 1.424 \right)$$

$$\left[\frac{1}{1 + (\log x)^{n}} - \frac{1}{1 + (\log x)^{n-1}} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

as given by Hatai, '09, in this number of this journal, in which y represents the weight of the brain and x the body weight.

The computation is simpler, however, if we use

$y = .554 + .569 \log (x - 8.7) \ldots (1)$ (Donaldson, '08)

when $x > 10$, and a special formula

$$y = 1.56 \log (x) - .87 \ldots (7) \quad \text{(Hatai, '09)}$$

when $x < 10$.

The results obtained from these two formulas are identical with those from formula (8), and are given in the third column of Table 3. The corresponding curve is shown by the continuous line on Chart III.

When the means are determined by the aid of a correlation table, in which the records are arranged in groups differing by 10 mm. in body length and 0.1 gms. in brain weight, the co-efficient of correlation between body length and brain weight is found to be .86, which is high.

(b) The relation of the weight of the spinal cord to the body length.

When the individual records for the weight of the spinal cord are plotted in relation to the body length, we obtain results which are surprisingly regular. See Table 3 and Chart III (189 males, 137 females).

As in the case of the determination of the brain weights, the

body weights used were those calculated by formula (4), and then the theoretical curve which fits these results most closely has been obtained by the use of the formula (3). (Donaldson, '08.)

$$y = .585 \log (x + 21) - 0.795 \quad (3)$$

where y represents the weight of the spinal cord and x the weight of the body.

This curve apparently forms a straight line, though in reality it is a trifle convex towards the base line.

From the correlation table based on groups differing by 10 mm. in body length and .04 gms. in spinal cord weight, we obtain a coefficient of correlation which is .99, being almost perfect.

It will be seen from the foregoing that the weight of the spinal cord can be inferred from the body length with a high degree of accuracy.

In this connection an application of the foregoing data can be made at once. It was noted in a previous paper (Donaldson, '08, p. 360) that for rats of the same body weight, but of different sex, the central nervous system in the male was slightly heavier than in the female. The question naturally arises, therefore, whether there is any somatic character with which this difference in the weight of the central nervous system according to sex can be connected. I shall endeavor to show that in the sex difference in body length we find such a character.

It has been pointed out in the present paper (p. 158) that for the same body weight the males have a slightly greater body length than the females. It will be of interest, therefore, to determine whether this difference in body length is sufficient to account for the difference in the weight of the central nervous system.

It is to be remembered in this connection that when males and females of like body weights are compared, the brain in the male is absolutely heavier, but the spinal cord is absolutely lighter. (Donaldson, '08.)

The relative difference is slightly greater in the case of the spinal cord, but the absolute mass of the brain is so much greater than that of the cord that as a final result the entire central nervous system is found to be heavier in the male.

If we turn now to the preceding Table 2, we find the percentage difference between the body lengths for the two sexes (as determined from the average of the percentage differences between the five pairs ranging from 155 to 205 gms. in body weight) to be 1.74 per cent. in favor of the male. That is, on the average, mature males of a given body weight exceed by 1.74 per cent. in body length females of a like body weight.

If now we select the body length of 193 mm., which is that for the male having a body weight of 185 grams (see Table 2), and consider that this body length is 101.74 per cent. of the corresponding female body length, we find by calculation that the body length of the latter is 189.7 mm., thus giving an absolute difference of 3.3 mm. in favor of the male. In order to determine what difference in the weight of the central nervous system would correspond to this difference in body length, we may refer to the preceding Table 3, where the weight of the nervous system (both sexes combined) is given according to the body lengths. From this table it is possible to determine how much increase in the weight of the nervous system corresponds to an increase of 1 mm. in body length. Taking the entries from the body lengths of 180 to 210 mm., we obtain the following:—

From	Increase in body length	Average increase in the weight of the central nervous system
180-190	1 mm.	.0092
191-200	1 mm.	.0081
201-210	1 mm.	.0087
Average		.0087 gms.

If the average difference in weight for 1 mm., as shown by the table, is .0087 gms., 3.3 mm. would imply an absolute difference of .02871 grams. This amount is 1.20 per cent. of the weight of the nervous system for a rat 195 mm. in body length (this is the mid-value between 180 mm. and 210 mm., the limits taken in the foregoing table). In Table 6, of the previous paper, Donaldson, '08, it appears as an average of all the groups taken in pairs, that for rats of like body weight, but different sex, the entire central

nervous system in the male exceeds that in the female by 1.13 per cent.[1]

It will be seen from the foregoing that the increase in the weight of the nervous system in the female, when the body length is made equal to that of the male, is 1.20 per cent, and the anticipated difference is 1.13 per cent. It follows that the difference according to sex in specimens of like body weight is accounted for by the difference in stature, the female having the smaller central nervous system because the stature of the female is less than that of the male.

When, therefore, the influence of body weight and of stature is taken into account, the weight of the entire central nervous system in the two sexes is similar. It still remains true, however, that there is a characteristic division of this total weight according to sex, whereby the male has a slightly heavier brain, but a lighter spinal cord. These results are in accord with the more recent observations on the human nervous system. (Brain: Blakeman, '05; Lapicque, '08. Spinal cord: Mies, '93; Pfister, '03, and Donaldson, '08.)

Comparison of the Body Length of the Albino Rat With the Sitting Height of Man.

The objection is often made that the length measurements on the lower mammals cannot be compared with the measurements of stature in man because of the differences in the relation of the head to the trunk, and of the trunk to the legs.

As a matter of fact, however, the body length (trunk + head) which we have taken in the rat involves measurements of the pelvis, vertebral column and the skull quite comparable with those made in determining the sitting height in man. The chief difference is in the case of the skull which is measured from base to vertex in man, while in the rat the measurement is along the fronto-occipital axis, and so includes the nasal bones. These latter grow a trifle more rapidly than the cranium, especially in the male (Hatai, '07), but

[1]The value of 8 per cent given in Donaldson, '08, page 360, ninth line, is an error. The correct value is 1.13 per cent as given above.

the difference becomes insignificant in comparison with the other parts of the skeleton which contribute so much more to the total result.

We, therefore, conclude that a comparison between the body length of the albino rat and the sitting height of man may be properly made.

The purpose of making such a comparison is to determine whether the rat is similar to man in the way in which this character changes with age.

It is not a character which at the time needs to be studied in detail and so only very general statements are necessary.

In his study on the growth of school children at Worcester, Mass., West ('92) made records for the sitting height in both sexes between the ages of 5 years and 21 years. The results are charted in his Fig. 1 (p. 32) and given in his Table 1 (p. 35).

If we take the average values of the sitting height in man for the two sexes, first at 19 years of age and again at 5 years of age, we find the following:—

Sitting height at 19 years	873 mm.
Sitting height at 5 years	595 mm.
Difference	278 mm.

Percentage gain, 47 per cent.

For comparison it is necessary to determine the increase in body length in the albino rat during the corresponding interval.

Computing from birth as the zero age, and taking the time unit for the rat on one-thirtieth of that for man (see Donaldson, '06), we obtain the following:—

Nineteen years of human age correspond with 220 days of rat age.

Five years of human age correspond with 60 days of rat age.

Table 9, in Donaldson, '08, shows that 220 days correspond with an average body weight of 234 grams, and of 60 days, with 78 grams. The corresponding body lengths in the rat, as shown in Table 2, are for

234 grams	209 mm.
78 grams	147 mm.
Difference	62 mm.

Percentage gain, 42 per cent.

It appears, therefore, that while the sitting height in man increased 47 per cent during the greater portion of the active growing period, the body length in the rat increased 42 per cent during the corresponding period.

Though not exactly alike, these figures represent changes of the same order, and this is all that we desire to show at the present time. The value of this determination, so far as it can be foreseen, is to indicate that the spinal cord during growth is subject to approximately the same relative amount of passive lengthening in both man and the albino rat.

Conclusions.

1. In the albino rat the ratio obtained by dividing the body weight by the body length diminishes as the body weight increases.

2. Among rats of the same body weight, the males have a slightly greater body length than the females.

3. The correlation between body weight and body length is high, being .90.

4. The correlation between body length and brain weight is high, being .86.

5. The correlation between body length and the weight of the spinal cord is nearly perfect, being .99.

6. The greater weight of the central nervous system in male, as compared with female rats of like body weight, is completely explained by the greater body length of the males. This result agrees with the more recent observations on man.

7. The relative increase in the body length of the rat during active growth is similar to the increase in the sitting height of man during the corresponding period. Hence, in both forms, the

spinal cord is subject to a corresponding amount of passive lengthening.

8. The body length is a better datum than the body weight from which to infer the weight of the brain or of the spinal cord. This is especially true when there is any reason to suspect emaciation of the body.

9. A mean of the two determinations of the weight of the brain or of the spinal cord (1) from the body weight (when normal) and (2) the body length, will give better approximations than the determination based on either datum alone.

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