THE DECENNIAL PUBLICATIONS OF
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ZOÖLOGY ANATOMY PHYSIOLOGY NEUROLOGY
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THE DECENNIAL PUBLICATIONS
FIRST SERIES VOLUME X

CHICAGO
THE UNIVERSITY OF CHICAGO PRESS
1903

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WEIGHT OF THE CENTRAL NERVOUS SYSTEM OF THE FROG

ON A FORMULA FOR DETERMINING THE WEIGHT OF THE CENTRAL NERVOUS SYSTEM OF THE FROG FROM THE WEIGHT AND LENGTH OF ITS ENTIRE BODY

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As the living substance which constitutes the animal body becomes differentiated into distinct tissues, the animal as a whole becomes more highly organized. The fundamental tissues which are thus formed — namely, the epithelial, connective, muscular, and nervous — are distinguished by the fact that each of them exhibits one or more of the general characteristics of protoplasm developed to a greater or less degree, whereas other of the characteristics are much less evident or apparently entirely lacking. The combined activities of these differentiated tissues are exhibited in the life-history of the entire animal.

For the understanding of such an animal it is important to know the proportions of the several tissues present in any instance, and whether we study the animal from the standpoint of the number and size of the cell elements which constitute each tissue, or from the more general standpoint of the weight of modified living substance possessing the peculiar physiological characteristics of the tissue, the animal could be described in terms of the analysis, that is, in quantitative terms of the several systems of tissues which compose it.

Thus, when tested in this way, animals like the dog, rabbit, and cat are found to be dissimilar in their make-up, and a snake, for example, has a different tissue composition from a frog. To determine that these animals are thus differently constituted is merely a first step, and is naturally followed by the attempt to determine whether there are any laws governing the quantitative relations of these tissues either in the animal series or in the same animal during its life-cycle.

If it could be shown that one system varies in a definite relation to any or all the others, we should have made a further step toward a comprehensive knowledge of the animal examined; and it is believed that the facts here to be presented constitute such a step.

The following paper describes the weight relations of the central nervous system (brain and spinal cord combined) of the frog, to the tissues constituting the rest of the body. The connection of this investigation with work already done along similar lines can be stated very briefly.

An attempt by Snell (1892) to correlate the increase in the weight of the encephalon with some change in the remainder of the body led him to conclude that among mammals and birds the weight of the encephalon increased in proportion to the area of the body, when animals of different sizes, but otherwise similar, were compared.

DuBois (1898) took up this conclusion of Snell and elaborated it (for mammals alone), making a more careful analysis of the conditions underlying the calculation, and finally giving a formula for the relative weight of the encephalon in mammals, which is very satisfactory, and which differs but slightly from the formula given by Snell.

The study of the work of Snell and DuBois led me to attempt the extension of their results. Their formulæ apply to the *relative* weights of the encephala in mature mammals, so that, in order to get the absolute value, the weight of one of the pair of encephala must be known. They do not discuss the increase of the encephalon in weight in the same mammal during its growing period, nor do they extend their observations to other classes of vertebrates or to the entire central nervous system. In the present instance we have sought to determine whether we could obtain a formula which would express the weight of the entire central nervous system at any time during the growing period of an animal, and in this instance have chosen the frog. For the study of this problem there were available in the laboratory records on two species of frogs, the bullfrog and leopard frog. It may be noted in passing that for a study of this kind the frog presents certain advantageous peculiarities, as it exhibits only a comparatively slight alteration in the bodily proportions during growth.

Like other vertebrates, its increase in length is most rapid during the earlier portion of the growing period, and later, the increase in length becoming slow, the body enlarges at right angles to its long axis, and the animal becomes thicker.

Nevertheless, the weight relations between the muscles of the legs and the remainder of the body remain nearly constant (Donaldson, 1898; Donaldson and Schoemaker, 1900), and in this respect the frog shows but very slight changes in proportion.

In the foregoing characters the two species which have been examined, the bullfrog (*Rana catesbiana*) and the leopard frog (*Rana virescens*), were nearly alike. For each species the series of observations was extensive, comprising data on the body weight and length, and also on the weight and length of the brain and spinal cord, together with other measurements not needed for this investigation (Donaldson, 1898; Donaldson and Schoemaker, 1900).

On looking at the curve previously published, for the weights of the brain and spinal cord arranged according to the body-weight (Donaldson and Schoemaker, 1900, p. 117), it appeared that the weights for the central nervous system (brain and spinal cord combined) were so related as to suggest a logarithmic curve, and this suggestion was at once tested.[1]

The trial was made by forming a curve depending on the logarithms of the body-

[1] In a paper entitled "Zur Anthropologie des Rückenmarkes" (*Corresp.-Bl. d. deutsch. Anthrop. Gesellsch.*, No. 10, 1895), Ranke presents observations on the weight of the spinal cord in dogs of different body-weights. He suggests that the curve which illustrates his Tabelle 3 has the form of a logarithmic curve, but does not test the suggestion. I have determined the curve formed by the logarithms of the body-weights of the dogs examined, and find that it gives a much flatter curve than that based on the weights of the spinal cords. In this instance, therefore, a logarithmic relationship between the nervous system (spinal cord) and the rest of the body does not appear, but, so far as I am aware, this is the first record of the suggestion that such a relationship might exist.

weights. To raise these logarithms to the value of the observed weights of the central nervous system they required to be multiplied by a constant factor. It was found that the factor which gave a correct value for the smallest frog was too small for all of the succeeding cases, the resulting numbers falling more and more below the observed numbers as the frog became larger. In order, therefore, to make the curve based on the calculated weights fit with that based on the weights observed, there was needed a second factor, the value of which should steadily increase as the body-weights of the frogs became heavier. Such a factor was found in the length of the frog, which increases rather rapidly at first and more slowly later. The unmodified lengths showed, however, too rapid an increase in the course of the series, but various trials revealed that the fourth root of the lengths gave a set of numbers which could be satisfactorily used.

It was found, then, that the number obtained by multiplying the logarithm of the body-weight by the fourth root of the length of the body was always a nearly constant fraction of the observed weight of the central nervous system. In the case of the bullfrog the fraction thus obtained was one-thirtieth of the observed weight, while in the case of the leopard frog it was one twenty-eighth. It could, therefore, be made equal to the observed weight by multiplying it by a constant factor having the value of the denominator of the fraction. In this manner a formula was developed as follows:

$$C.N.S. = (\text{Log } W \times \sqrt[4]{L})\, C.$$

Here the weight of the central nervous system ($C.N.S.$), in milligrams, is made equal to the logarithm of W, the body-weight, expressed in grams, multiplied by the fourth root of L, the length of the body, in millimeters, the product of these factors being raised to the value of the observed weight of the central nervous system by multiplying by a constant, C. This constant, in the case of the bullfrog, has the value of 30, and, in the case of the leopard frog, the value of 28. To illustrate the application of this formula, we may take as an example the first record, No. 6, in Table I, p. 7. Here W, the weight of the body, is 5.02 grams, and L, the length of the body, is 93 millimeters. As this is a bullfrog, the value of the constant C is 30. Thus:

$$\begin{aligned} C.N.S. &= (\text{Log } W \times \sqrt[4]{L})\, 30 \\ &= (0.7007 \times 3.105)\, 30 \\ &= (2.17)\, 30 = 65.1 = 65 \text{ milligrams.} \end{aligned}$$

The calculated weight of the central nervous system is therefore 65 milligrams. The observed value was 62 milligrams; thus the calculated exceeded the observed value by 4.8 per cent. In like manner the weight of the central nervous system was calculated in each of the cases entered in the table. While the formula applies to all the cases which are presented in the tables given in this paper, it does not apply to all the cases in the original tables (Donaldson, 1898, pp. 328–30; Donaldson and Schoemaker, 1900, pp. 120, 121), and its validity can, therefore, be seriously questioned, unless we are able to show that those cases to which it does not apply are capable either of explanation or correction. The formula is constructed so as to express the normal changes in the weight and length of body as related to the weight of the central nervous system—changes which are taking place as the frog grows larger. But it remains to be determined, first, how early in the history of the frog the formula can be applied, and, second, whether sex, season, and nutritive conditions are able to affect the result; the nutritive condition including not only those changes which may occur from day to day, but those which occur from spring to autumn.

Repeated examination shows that the formula does not apply to frogs until they have attained a body-weight of approximately 5 grams. For example, in a bullfrog with a body-weight of 3.53 grams the observed weight of the central nervous system was 56 milligrams, whereas the calculated weight was only 49 milligrams. A similar result is obtained when the test is applied to the leopard frogs under 5 grams of body-weight; hence, for frogs of this size, the calculated weight of the central nervous system is too small.

The failure of the formula to apply to the smallest frogs is probably due to the precocious enlargement of the central nervous system—a character of all young vertebrates, and one still evident in frogs when less than 5 grams in weight. We conclude, therefore, that the relations found in the mature frogs are not established until they have attained a body-weight above 5 grams. From this point on the formula applies to all normal specimens.

For the consideration of other sources of error it will be most advantageous to examine the two species of frogs separately. We begin with the bullfrogs.

The original table for the bullfrogs (Donaldson, 1898) contains fifty-two cases. The first five cases (Nos. 1–5) are from frogs below 5 grams in body weight, and for this reason are excluded. Among the remaining forty-seven cases, six (Nos. 7, 32, 34, 37, 40, 47 in the original table) are marked "dry," which means that through drying their body-weight had been reduced below the normal. These also are excluded. No. 9 in this table is plainly abnormal, as is seen by comparing the body-weight with the length (body-weight, 8.75 grams; length, 127 millimeters), and for this reason is also excluded. For the foregoing exclusions no explanation is required, as, under the circumstances, one could not expect the formula to apply to them. There are, however, six more cases to be excluded, namely Nos. 10, 11, 43, because the body weight had been increased by the absorption of water; and Nos. 45, 48, and 49, because long captivity had produced a loss of weight through starvation.

The absorption of water by frogs whose vitality is much reduced is a familiar reaction, and the effects of starvation have been reported in earlier observations from this laboratory (Donaldson and Schoemaker, 1900, p. 112).

In this series no correction for season is required, as the records are all from July and August frogs, and hence comprise midsummer frogs only.

The final table contains, therefore, thirty-four records of approximately normal frogs to which the formula had been applied. These are presented in Table I.

TABLE I

Containing thirty-four records from bullfrogs (based on Table VII, Donaldson, 1898). This table shows in successive columns the original tabular number, the sex, body-weight, length, and the observed and calculated weights of the central nervous system in milligrams. The last two columns show the percentage deviation of the calculated from the observed weights of the central nervous system; the percentages being computed on the observed values as the standard.

TABULAR NUMBER	SEX	BODY		WEIGHT OF CENTRAL NERVOUS SYSTEM IN MILLIGRAMS		PERCENTAGE DEVIATION OF CALCULATED FROM OBSERVED WEIGHTS	
		Weight in Grams	Length in Millimeters	Observed	Calculated	Deficiency	Excess
6	Male	5.02	93	62	65	...	4.8
8	Male	5.38	95	72	68	5.5	...
12	Male	11.37	125	108	106	1.8	...
13	Female	13.77	136	116	115	0.8	...
14	Female	16.03	145	122	125	...	2.4
15	Male	20.33	159	144	139	3.4	...
16	Male	27.33	167	153	155	...	1.3
17	Female	27.51	173	170	157	7.6	...
18	Male	32.95	184	165	168	...	1.8
19	Female	36.32	182	163	172	...	5.5
20	Female	37.46	188	185	175	5.4	...
21	Male	49.50	192	181	189	...	4.4
22	Female	49.82	202	187	192	...	2.6
23	Female	50.43	203	200	193	3.5	...
24	Male	51.77	200	201	193	3.4	...
25	Female	58.46	210	184	202	...	9.7
26	Female	60.12	211	205	203	1.9	...
27	Female	66.67	218	215	210	2.3	...
28	Female	73.05	231	212	218	...	2.8
29	Male	76.69	231	233	220	5.5	...
30	Male	87.05	231	223	227	...	1.7
31	Male	98.00	240	226	235	...	3.9
33	Male	144.50	280	255	265	...	3.9
35	Male	146.70	284	273	267	1.4	...
36	Female	146.90	275	279	265	5.0	...
38	Female	169.50	275	262	272	...	3.4
39	Male	184.60	284	287	275	4.1	...
41	Male	191.76	313	290	287	...	1.0
42	Male	199.10	312	299	290	3.0	...
44	Male	212.50	304	306	292	4.5	...
46	Female	225.20	303	305	294	3.6	...
50	Male	244.60	313	292	301	...	3.0
51	Female	272.10	340	306	314	. .	2.2
52	Male	313.00	343	321	322	...	0.3
Average..................................				212	211	3.8	3.0

Difference, 1 milligram; percentage, 0.4.

This table gives the original tabular number, sex, body-weight (without ovaries in the case of the females), length from tip of nose to tip of longest toe, observed and calculated weights of the central nervous system, together with the percentage by which the calculated departs from the observed weight; the observed weight being always considered as the standard. The conditions under which these measurements were made are given in full in an earlier paper (Donaldson, 1898, pp. 323 ff.). In the foregoing table the records in each case are for single observations. When the averages of the weights of the central nervous system, observed and calculated, are determined, it is seen that the average of the observed weights is 212, while that of the calculated is 211, thus giving a difference of only 0.4 per cent. That this small difference is the expression of discrepancies that are only slight is indicated by the fact that, if the entire series of records be divided into three groups, formed respectively by the first eleven, second eleven, and last twelve, and the difference in the average values of the observed and calculated weights be taken for each group, we obtain the percentage differences given in the following table:

TABLE II

To show the average percentage differences in the values of the observed and calculated weights of the central nervous system in three groups, formed from the records in Table I.

Group	Tabular Numbers	Number of Records	Percentage Difference; the Observed Values Being Taken as the Standard	
			Deficiency	Excess
A	6–21	11	...	1.0
B	22–33	11	0.6	...
C	35–52	12	...	0.8

It is thus seen that the percentage difference between the averages does not in any group exceed 1 per cent., and consequently we may infer that, if the records were based on averages of eleven or more individuals for each entry, the agreement of the observed and calculated values would be well within 1 per cent.

Another method of testing these results is by determining the relation of the percentage differences calculated for the individual cases. On enumerating the cases in which the calculated values are in excess, it is found that they are just seventeen, or one-half the total number of records, thus leaving seventeen cases where the calculated values are below those observed. Table I shows that the average value of the percentage deviations exhibiting deficiency is 3.8 per cent., while for those in excess it is 3.0 per cent. The plus and minus percentage deviations, therefore, nearly balance, as they should do if they depended on accidental causes.

We see, therefore, that the formula gives results very close to those observed. On looking at the curve (Fig. 1) we note that the calculated weights vary less from frog to frog than do those observed, and it thus happens that the line joining the dots which mark the calculated weights threads its way between the crosses which indicate the observed weights. Thus the weight of the central nervous system as calculated is less irregular than that directly observed.

Before commenting further on these results the observations on *Rana virescens* will be presented. In the case of *Rana virescens* the original table contained thirty-six records (Donaldson and Schoemaker, 1900, p. 120). Of these, Nos. 1, 2, 3 are at once excluded as being below the 5-gram limit. Of the remaining 33, one, No. 16, through some error, has a body-weight too small for its length (27.19 grams body-weight; 195 millimeters length), and four more, Nos. 33, 34, 35, 36, all of them spring frogs, have body weights which are manifestly too small, as is shown by the relation of these records in the curve already presented (Donaldson and Schoemaker, 1900, Chart I, p. 117). As there are no data for correcting these last four records, they are excluded from the series here used. After these removals there remain twenty-eight records taken at different times from April 14 to September 15. Some unpublished work on the seasonal change in the nervous system of the frog shows that in frogs of the same body-weight the weight of the central nervous system is subject to a rhythmic change, thus altering according to the season of the year.

During the past twelve months observations have been carried on in this laboratory with a view to following this change in some detail, and at present we have at hand data which enable us to correct the weight of the central nervous system in these frogs in the early and late season so as to make the observations taken at those times comparable with the records from midsummer frogs. To standardize these early and late records which appear in Table IV, corrections have been made in twelve instances in accordance with a fixed scale. This scale is based on the following observations: It appears that frogs of a given body weight, just after they emerge at the end of March or the first of April, have a relatively small weight of central nervous system.

TABLE III

Showing the corrections made in the spring and autumn frogs, the weight of whose central nervous system appears in Table IV.

No. in Table IV	Date	Percentage Correction	No. in Table IV	Date	Percentage Correction
31	April 14	+4	23	June 5	−5
17	April 19	+4	26	June 5	−5
13	May 21	−1	10	June 9	−5
28	May 21	−1	29	September 10	+3
5	May 31	−2	30	September 12	+3
9	June 3	−5	22	September 15	+3

This increases from 9 per cent. to 10 per cent. between the time of emergence and the first ten days of June, when it reaches a maximum. In undergoing this change the frog passes the midsummer weight about May 15. From this maximum the weight

TABLE IV

Containing twenty-eight records from leopard frogs (based on Table VII, Donaldson and Schoemaker, 1900). This table shows in successive columns the original tabular number, the sex, body-weight, length, and the observed and calculated weights of the central nervous system in milligrams. The last two columns show the percentage deviation of the calculated from the observed weights of the central nervous system; the percentages being computed on the observed values as the standard.

Tabular Number	Sex	Body		Weight of Central Nervous System in Milligrams		Percentage Deviation of Calculated from Observed Weights	
		Weight in Grams	Length in Millimeters	Observed	Calculated	Deficiency	Excess
4	Female	5.06	102	68	63	7.3	...
5	Female	7.85	124	82 (c)	84	...	2.4
6	Female	10.90	136	103	99	3.9	...
7	Female	11.41	139	99	102	...	3.0
8	Male	12.30	141	106	105	0.9	...
9	Female	14.85	153	116 (c)	115	0.8	...
10	Male	16.26	164	122 (c)	121	0.8	...
11	Male	16.31	160	121	121	0.0	0.0
12	Male	17.13	166	122	124	...	1.6
13	Male	19.91	160	131 (c)	129	1.5	...
14	Female	20.35	162	130	131	...	0.7
15	Male	23.45	168	134	138	...	2.9
17	Male	27.42	172	142 (c)	146	...	2.8
18	Female	29.40	185	143	152	...	6.2
19	Female	30.45	179	141	152	...	7.8
20	Female	33.96	172	152	155	...	1.9
21	Male	36.03	198	171	164	4.0	...
22	Male	38.16	200	161 (c)	166	...	3.1
23	Female	42.54	215	177 (c)	175	1.1	...
24	Female	44.75	208	188	175	6.9	...
25	Male	45.37	205	174	176	...	1.1
26	Female	46.00	216	179 (c)	178	0.5	...
27	Female	47.58	206	191	178	6.8	...
28	Female	48.33	220	174 (c)	182	...	4.6
29	Female	52.55	206	180 (c)	182	...	1.1
30	Female	55.25	215	186 (c)	187	...	0.5
31	Female	61.10	226	193 (c)	194	...	0.5
33	Female	70.98	239	213	204	4.2	..
Average				146	146	2.9	2.5

Difference, 0 milligram; percentage, 0.0.

drops rather rapidly, about 5 per cent., to the end of June. In July and August it remains, with slight fluctuations, comparatively constant, and at the beginning of September falls off from 2 per cent. to 4 per cent. as the frogs enter upon hibernation. These observations of course apply strictly only to frogs subjected to the climatic conditions found in Chicago and the neighborhood within a radius of one hundred miles.

In the preceding Table III we have indicated the tabular number of the frog, the weight of whose nervous system has been corrected, the date at which the initial observation was made, and the amount of the correction. The correction is entered in this table as a percentage of the observed weight, the + sign indicating that the amount was added and the sign — that it was subtracted.

In Table IV the observed weight of the nervous system which is there given for these cases is the *corrected weight*, and the fact that it is a corrected weight is indicated by the small letter (c) which follows the entry.

The other records in Table IV are from frogs killed in July and August, and are therefore classed as midsummer frogs. It will be recalled that in the case of *Rana virescens* the formula for calculating the weight of the central nervous system is the same as that for the bullfrog, except that the constant, C, is 28 instead of 30. The formula reads, therefore:

$$C.N.S. = (\text{Log } W \times \sqrt[4]{L})\, 28.$$

It is with this formula that the calculations appearing in Table IV have been made. The construction of Table IV is similar to that of Table I.

On applying to the records in Table IV the same tests as were used in the case of the bullfrog, Table I, we obtain results which are in some respects more satisfactory. It will be seen that the average weight of the central nervous system as calculated is exactly equal to the average weight observed. Further, if we divide the twenty-eight records into three groups of nine, nine, and ten, respectively, indicating the groups as A, B, and C, then the percentage differences for each group are seen to be also small — Table V.

TABLE V

To show the average percentage differences in the values of the observed and calculated weights of the central nervous system in three groups, formed from Table IV.

Group	Tabular Number	Number of Records	Percentage Difference; the Observed Values Being Taken as the Standard	
			Deficiency	Excess
A	4–12	9	0.5	...
B	13–22	9	...	2.0
C	23–33	10	1.3	...

This shows a maximum deviation for Group B of 2 per cent., but it seems probable that a series of records based on averages would coincide more closely than this. On examining in the leopard frog the percentage deviations, we find in one case (No. 11) exact coincidence, in twelve cases the calculated value is deficient, and in fifteen cases it is in excess. The average value of the deficiencies is 2.9 per cent., and of the excesses 2.5 per cent. These nearly balance, and point therefore to accidental causes as the source of the deviations.

These results for the leopard frog show that the curves fit somewhat better than in the case of the bullfrog, but the difference is not large nor significant. The statements that were made concerning the relations of the curves showing the observed and calculated weights in the bullfrog are also true for the corresponding curves based on the leopard frog.

It will be seen (Fig. 1) that in order to get the curves for the two species on the same chart, where they might be compared without being confused, the records for the leopard frog have been shifted 50 grams to the right. This enables us to see the approximate parallelism between the two curves, despite the fact that the leopard frog is differently shaped from the bullfrog, being somewhat more slender and having the relative weight of its trunk slightly less than that of the bullfrog (Donaldson, 1898, p. 334, Table IX; Donaldson and Schoemaker, 1900, p. 124, Table VIII). This slight difference in construction probably accounts for the necessity of using a smaller constant in the formula employed for the leopard frog, since the weight of the central nervous system would most probably be closely correlated with the development of the trunk. It is interesting to note, before leaving these records, that there is apparently no modification of the formula necessary for sex, in the case of either species. If we select the females from Table I, for the bullfrog, we find that they represent sixteen cases, or nearly one-half the number in the table. Arranging the records according to the tabular number, we have the percentage deviation for each case as given in Table I.

TABLE VI

Showing the percentage deviation for the female bullfrogs entered in Table I.

Tabular Number	Percentage Deviation		Tabular Number	Percentage Deviation	
	Deficiency, (7) Records	Excess, (9) Records		Deficiency, (7) Records	Excess, (9) Records
13	...	0.8	26	...	1.9
14	2.4	...	27	...	2.3
17	...	7.6	28	2.8	...
19	5.5	...	35	...	1.4
20	...	5.4	36	...	5.0
22	2.6	...	38	3.4	...
23	...	2.5	46	...	3.6
25	9.7	...	51	2.2	...

Average deficiency, 4.1 per cent.; average excess, 3.4 per cent.

On comparing the averages for the percentage deviations in these two columns we find the average for the excess 3.4 per cent., while that for the deficiencies is 4.1 per cent.—results practically the same as those obtained for both sexes in Table I.

TABLE VII

Showing the percentage deviation for the female leopard frogs entered in Table III.

Tabular Number	Percentage Deviation		Tabular Number	Percentage Deviation	
	Deficiency, (10) Records	Excess, (8) Records		Deficiency, (10) Records	Excess, (8) Records
4	...	7.3	23	...	1.1
5	2.4	...	24	...	6.9
6	...	3.9	26	...	0.5
7	3.0	...	27	...	6.8
9	...	0.8	28	4.6	...
14	0.7	...	29	1.1	...
18	6.2	...	30	0.5	...
19	7.8	...	31	0.5	...
20	1.9	...	33	...	4.2

Average deficiency, 2.9 per cent.; average excess, 3.9 per cent.

In this case the results are similar to those found in the female bullfrogs, except that the larger average percentage is on the excess side.

From these observations we conclude that in normal summer frogs of both sexes it is possible to calculate, with a high degree of accuracy, by the formulæ here employed, the absolute weights of the central nervous system.

Should others be inclined to test the correctness of these results by repeating the observations, it will be necessary carefully to avoid the sources of error which have been here enumerated, namely, the limitations of small size, the effect of season in the spring and autumn, and of the nutritive condition of the frog, as represented by starvation on the one hand, and the abnormal absorption of water or of drying on the other.

With these results in hand it is natural to seek for an interpretation of the formula which has been given in order to correlate it in detail with the changes which we know are going on in the central nervous system of the animals under examination. In the first place, the changes in the central nervous system, which the formula expresses, must take departure from the conditions which are present in the smallest frogs examined. In such a frog the central nervous system is composed of the supporting structures, neuroglia and ependyma, together with the blood and lymph vessels, and the nerve cells. These last form by far the greatest part of the substance. The nerve cells, or neurones, may be divided into those which are immature and those already matured, in the sense that these latter have sent out both kinds of branches, dendrites and axone, and that the axone has acquired a medullary sheath.

As the frog grows larger the nervous system increases in weight. Concerning the method of this increase the following statements can be made: First, there is no cell division in either the supporting tissues or the nervous tissues at this time; hence the increase in weight is due to the enlargement of cell elements which are already present in the system. In the case of the neurones already developed and functionally active, this enlargement means an increase in the volume of the cell bodies, in the number and size of the dendrites, and in the length and diameter of the axone and its medullary sheath. In the case of the undeveloped neurones, it means a rather rapid acquisition of the branches and medullary sheath, to be followed by the slower changes just described above. In general, these changes tend to increase the complexity of the entire system, but, so far as they represent a mere lengthening of the connecting axones and a mere increase in their diameter, the added weight does not necessarily imply the increase in complexity, but only a passive adaptation of the system to the increasing size of the cavities in which it is contained.

The formula which we have employed indicates that where the body-weight is expressed by numbers increasing in geometrical progression, the weight of the central nervous system is expressed by numbers increasing in arithmetical progression, these latter being multiplied by a factor derived from the length of the entire animal.

Certainly this factor, depending on the length of the frog, is to be associated with the increase in the length of the brain and cord, but no satisfactory interrelation between this factor and this part of the growth process has been established. We are compelled, therefore, at this time to be content with pointing out the entire series of events which the formula expresses, without attempting to correlate any portion of the formula with any special part of the growth change.

SUMMARY

The formulæ here presented apply to the two species of frog: *R. catesbiana*, the bullfrog, and *R. virescens*, the leopard frog. The best results are obtained when frogs taken in midsummer (months of July and August) are alone used. The frog must be in normal condition and have a body-weight of 5 grams or more. When these conditions are fulfilled, then the weight in milligrams of the central nervous system (*C.N.S.*) of the bullfrog can be determined with a high degree of accuracy by the formula

$$C.N.S. = (\text{Log}\ W \times \sqrt[4]{L})\ 30,$$

where W is the weight of the frog in grams, L the entire length in millimeters, and 30 a constant peculiar to the species.

In the same way the weight of the central nervous system (*C.N.S.*) in milligrams can be determined for the leopard frog by the formula

$$C.N.S. = (\text{Log } W \times \sqrt[4]{L})\, 28.$$

This formula is similar to that for the bullfrog, except as regards the constant, which for the leopard frog is 28.

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EXPLANATION OF FIGURE I

For this figure the data in Tables I and IV have been employed, and the accuracy of the figure can be tested by comparison with the tables.

The divisions on the base line indicate grams of body-weight; the divisions on the ordinates, milligrams of weight of the central nervous system. The observed weight of the central nervous system in milligrams is marked by + on the line of the ordinate above the point on the base line corresponding to the body-weight of the frog from which the central nervous system was taken. The calculated weight of the central nervous system is marked on the same ordinate line by a black dot (•). So far as it could be done without confusion, the (•) black dots indicating the calculated weights have been joined by a line, to better indicate their general relation to the observed records. The whole chart for the leopard frog has been shifted in the figure along the base line 50 grams to the right; hence all the body-weights in this chart are to be reduced by 50 grams from the weight indicated by their position.

In plotting the records, the indications (• and +) have been placed exactly where they belong except in those cases where exact placing would cause them to overlap. In such instances the displacement necessary for clearness has been distributed among the several records. In no case, however, does this displacement modify in any essential feature the character of the chart.

FIG. 1. WEIGHT OF BRAIN AND SPINAL CORD IN SUMMER FROGS