who may manifest, at different times through speech, conduct, and bodily movement, intellectual capacity and moral character of different grades, must have these three areas intact, if he is to continue to evidence the highest attainment of which he is individually capable.

A question, often confusing, is frequently allowed to become involved with this psycho-physiological parallelism of increasing intellectual complexity and increasing integration of the cells of the central nervous system. On the one hand, the mere addition of neurones apparently forms a satisfactory explanation of the increased complexity of cortical reactions over that of the spinal reflexes. The psychical functions of the brain might therefore represent the result of a mere phylogenetic increase in nerve tissue, a product of cortical integration. On the other hand, in the human being and higher organisms, it is a common experience to find automatic actions developing from conscious actions, even becoming so set in the nervous system as to appear ineradicable reflexes. Many facts tend to suggest that conscious reaction has always presided over the phylogenetic development of reflex action; that psychical function thus preceded reflex function, and both helped to determine the course of organic evolution. This view was entertained by Cope, the eminent biologist, and is exploited as a fundamental philosophical hypothesis by Wundt, without doubt the leading psychologist of the day. Many difficulties present themselves to the acceptance of either theory. It is not necessary for us to take sides on this issue, when considering the localization of psychical function over the cortex of the cerebral convolutions; but it is desirable to keep this and similar psycho-physiological speculations from interfering with an acceptance of reported facts and conclusions.

It is not worth while to enter into a consideration of the various theories which have been propounded at different times to explain the specific nature of the nerve excitation which passes along the nerve fibres of a pathway of conduction. The crudest physical concepts have been called upon to do duty by way of explanation; thus the cell has been likened to a battery and the fibres to conducting wires; the nerve stimulus is frequently spoken of as a wave of nervous impulse, similar to but not identical with the electrical wave, propagated at an appreciable rate, flowing from nerve fibre to nerve fibre. Theories of electrical tension, of galvanism, of molecular vibrations, and of chemical explosions, are scientific fancies rather than hypotheses. When the nervous pathway was shown to be made up of unitary cellular elements, that were contiguous but not continuous, biological theory interpreted the conduction of the nerve stimulus as a series of amœboid movements. It may be said that no hypothesis has yet been formed that offers even the hope of becoming a sufficient explanation.

In addition to the original authorities, mentioned in the text, the writer has been much assisted by the critical abstracts of the literature to be found in the publications of Ferrier, Jackson, Macalister, Collins, Gordinier, and Barker, and especially by the "Sketches of the History of Reflex Action," by Hall and Hodge, in the *American Journal of Psychology*, from which have been drawn many statements of the established facts of the phenomena of reflex action.
Lightner Witmer.

BRAIN, GROWTH OF THE.—The following article aims to present a general account of the growth changes which occur in the human brain and cord, between the time of normal birth and the natural end of life, thus including those found in old age.

In dealing, as in this case, with data for the most part very incomplete, the danger of confusion arises from the tendency, on the one hand, to make a general application of special observations, and, on the other, to interpret the *absence* of positive as equal to the *presence* of negative evidence. With these words as a preface, however, we may spare ourselves the duty of showing in special instances the limitations of the observations cited.

In discussing the changes which occur in the neuraxis (brain and spinal cord = central nervous system), the following outline is employed:

A. Growth changes in the neuraxis and some of its divisions.

B. Growth changes in the neuraxis—considered as the resultant of changes in the cells which constitute it.

1. Number of neurones.
2. Size of neurones.
3. Changes in the cytoplasm of the cell bodies during growth.

C. Growth of the cerebral cortex.

A. GROWTH CHANGES IN THE NEURAXIS AND SOME OF ITS DIVISIONS.—The human encephalon varies widely in weight at maturity, even when members of the same race and the same social class are alone compared. Differences in the final weight must be looked upon as resulting from differences in the process of growth. The weight of the encephalon at maturity is illustrated by the accompanying table based on the observations of Dr. Boyd:[1]

TABLE I.—SHOWING IN GRAMS THE WEIGHT OF THE ENCEPHALON AND ITS SUBDIVISIONS IN SANE PERSONS, THE RECORDS BEING ARRANGED ACCORDING TO SEX, AGE, AND STATURE. (From Marshall's tables based on Boyd's records.)

SANE.

Males.					Females.				
Ages.	Encephalon.	Cerebrum.	Cerebellum.	Stem.	Stem.	Cerebellum.	Cerebrum.	Encephalon.	Ages.
Stature 175 cm. and upward.					Stature 163 cm. and upward.				
20–40	1409	1232	149	28	23	134	1108	1265	20–40
41–70	1363	1192	144	27	23	131	1055	1209	41–70
71–90	1330	1167	137	26	24	130	1012	1166	71–90
Stature 172–167 cm.					Stature 160–155 cm.				
20–40	1360	1188	144	28	26	137	1055	1218	20–40
41–70	1335	1164	144	27	26	131	1055	1212	41–70
71–90	1305	1135	142	28	24	128	969	1121	71–90
Stature 164 cm. and under.					Stature 152 cm. and under.				
20–40	1331	1168	138	25	24	130	1045	1199	20–40
41–70	1297	1123	139	25	25	129	1051	1205	41–70
71–90	1251	1095	131	25	25	123	974	1122	71–90

These records were obtained from 2,086 patients of the Marylebone Workhouse in London, representing, for the most part, the least favored class of persons native to Great Britain. For the purpose of weighing, the encephalon was divided into three portions: (1) The cerebrum, including all parts frontal to the midbrain; (2) the cerebellum, severed at the peduncles; and (3) the stem—the midbrain, pons, and bulb taken together.

Owing to the fact that these records are based on a workhouse population, it is probable that they represent brains less well grown and earlier subject to senile atrophy than would be the case among the more prosperous members of the community. The general relations to which we are about to call attention would, however, remain the same.

On comparing the sexes Table I. shows that the heavier brains belong to the males; on comparing those of different stature within each sex, that they belong to the tall individuals; and when those of the same sex and stature are compared, according to age, to those in the prime of life, *i.e.*, twenty to forty years of age. Sex and stature, then, are conditions which modify the weight which the brain will attain at maturity, and after the prime of life its weight diminishes.

Having indicated the weight at maturity under the conditions of the race and social class here chosen, we have next to determine the weight of the encephalon at birth, and the course of the changes by which it reaches its full size.

Vierordt has collected the most complete series of observations for the change in brain weight between birth and twenty-five years of age. The data are taken mainly from German records. They are printed in Table II.

TABLE II.—TO SHOW THE INCREASE IN BRAIN WEIGHT WITH AGE. ENCEPHALON WEIGHED ENTIRE WITH PIA. (Compiled by Vierordt.)

Age.	Males. Number of cases.	Males. Brain. Grams.	Females. Number of cases.	Females. Brain. Grams.
0 months	36	381	38	384
1 year	17	945	11	872
2 years	27	1025	28	961
3 "	19	1108	23	1040
4 "	19	1330	13	1139
5 "	16	1263	19	1221
6 "	10	1359	10	1265
7 "	14	1348	8	1296
8 "	4	1377	9	1150
9 "	3	1425	1	1243
10 "	8	1408	4	1284
11 "	7	1360	1	1238
12 "	5	1416	2	1245
13 "	8	**1487**	3	1256
14 "	12	1289	5	**1345**
15 "	3	**1490**	8	1238
16 "	7	1435	15	1273
17 "	15	1409	18	1237
18 "	18	1421	21	1325
19 "	21	1397	15	1234
20 "	14	1445	33	1228
21 "	29	1412	31	1320
22 "	26	1348	16	1283
23 "	22	1397	26	1278
24 "	30	1424	33	1249
25 "	25	1431	33	1224
Total	415		424	

When the data in Table II. are cast in the form of a curve representing the increase in weight according to age, we obtain the chart given below (Fig. 903).

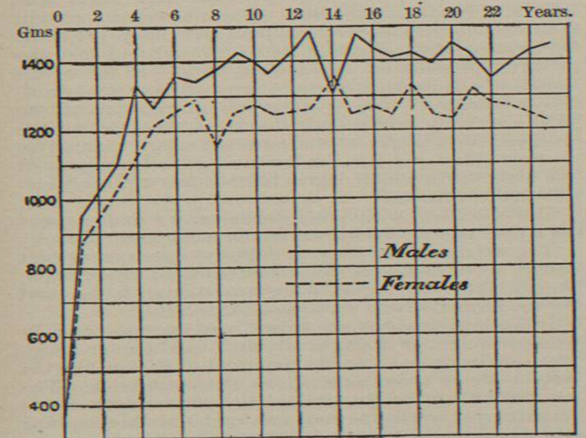

FIG. 903.—Curves Showing the Variations in Brain Weight During the First Twenty-Five Years of Life. Based on Table II.

In the records of Vierordt it appears that, except at birth and in the fourteenth year, the male has a greater brain weight than the female.*

In both sexes the most rapid increase in weight is during the first year; it continues to be rapid up to the fourth or fifth year, and then becomes slow till the seventh year, when the weight of the brain found in the adult is nearly attained. From this age on, there is a very slight and very slow growth up to maturity. At the time when nearly the final brain weight has been attained—namely, the seventh or eighth year—the full difference of 100 grams or more existing between the two sexes is evident. From this, it happens that the rapid growth of the brain has occurred while the body is still very immature, since boys of seven years weigh on the average only fifty pounds, and girls but forty-two pounds—this in both sexes being about one-third of the adult body weight; and that the differences characteristic of sex have been established before sexual maturity. The irregularities of the curve are to be explained as statistical mainly, and dependent on the comparative smallness of the number of cases available for each year. No significance is to be attached to the dip in the male curve at fourteen years. The very high averages for the males at twelve and fourteen years, and for the females at thirteen years, are to be noted, since they occur in other similar series.[5] These "premaxima" are most readily explained by assuming that an overgrowth of the brain during these years of beginning adolescence is one source of constitutional weakness, and hence the children dying at this period exhibit heavy brains. There is no reason to suppose that within the life cycle of the individual, the brain attains during these years a greater weight than that shown at maturity.

From the table of final weights (Table I.) as well as from that just presented on growth, it is plain that the difference in the weight of the encephalon according to sex is one exhibited at birth; that it increases during the growing period, and is maintained throughout life. In the first instance, this difference is most closely associated with the difference in the total body weight of the two sexes, and is so correlated in the mammalian series.

Table I. further shows us that the taller persons have the heavier brains, and this may probably be extended to mean the heavier persons, since when fairly compared, the taller are also probably the heavier. In old age in both sexes, the brain weight diminishes, as the result of shrinkage in the encephalon. There is some reason to think that this involutionary process is delayed in the more favored social classes.

It is an important fact that the differences in the weight of the encephalon according to sex, age, and stature are correlated with only very slight variations in the proportional development of the subdivisions of the encephalon as here examined. Table III. shows the percentage value of these subdivisions for different ages at all statures.

TABLE III.—SHOWING THE PERCENTAGE OF WEIGHT OF THE SUBDIVISIONS OF THE ENCEPHALON, THE RECORDS BEING GROUPED ACCORDING TO AGE. BASED ON TABLE I.

Males.					Females.				
Age.	Encephalon.	Cerebrum.	Cerebellum.	Stem.	Stem.	Cerebellum.	Cerebrum.	Encephalon.	Age.
20–40	100	87.52	10.49	1.91	1.96	10.9	87.13	100	20–40
41–70	100	87.00	10.6	1.94	2.02	10.8	87.14	100	41–70
71–90	100	87.33	10.6	1.98	2.11	11.16	86.4	100	71–90

Here there is a very slight falling off in the proportional value of the cerebrum in persons of advanced age. In general the value of the male cerebrum is slightly in excess. In the next table (IV.), where the comparison is made according to stature, there is a regular decrease in the value of the male encephalon with diminishing stature, and at all statures the male cerebrum is slightly in excess of the female.

* During the period of very rapid growth, a slight disparity in the average age of the cases compared easily reverses the weight relations according to sex. This is the probable cause of greater weight in the female at "birth," as reported by Vierordt. More careful determinations by Mies,[3] 1894, and Pfister,[4] 1897, show the male brain to be heavier.

TABLE IV.—SHOWING THE PERCENTAGE OF WEIGHT OF THE SUBDIVISIONS OF THE ENCEPHALON, THE RECORDS BEING GROUPED ACCORDING TO STATURE. BASED ON TABLE I.

MALES.					FEMALES.				
Stature.	Encephalon.	Cerebrum.	Cerebellum.	Stem.	Stem.	Cerebellum.	Cerebrum.	Encephalon.	Stature.
175 cm. and upward.	100	87.5	10.5	1.90	1.91	10.86	86.93	100	163 cm. and upward.
172–167 cm....	100	87.2	10.65	2.08	2.10	11.16	86.68	100	160–155 cm.
164 cm. and under.	100	87.17	10.6	1.86	2.09	10.83	87.06	100	152 cm. and under.

In Table V. it is possible to make the comparison of the proportional development of the several divisions from birth to old age.

TABLE V.—SHOWING THE PROPORTIONAL WEIGHT OF THE DIVISIONS OF THE ENCEPHALON AT DIFFERENT AGES. (Boyd.)

MALES.					FEMALES.				
Number of cases.	Age.	Cerebrum.	Cerebellum.	Stem.	Number of cases.	Age.	Cerebrum.	Cerebellum.	Stem.
45	New born.	92.4	5.8	1.60	45	New born.	92.1	6.2	1.50
22	7–14	87.8	10.3	1.61	18	7–14	87.9	10.5	1.50
99	30–40	87.3	10.6	1.98	80	30–40	87.0	10.8	2.01
95	70–80	87.0	10.7	2.09	128	70–80	86.9	10.9	2.15

We see here that the cerebellum is the portion least developed at birth, and that between birth and the seventh-year period, the proportions found at maturity are very nearly established. In this table, again, the percentage value of the cerebrum tends to be slightly greater for the male. During the active growing period the reduction in the percentage value of the cerebrum is due, of course, to the more active growth of the cerebellum and stem, while during the involutionary period—that is, between seventy and eighty years, in this table (V.)—the diminution in value is due to its more rapid shrinkage, as can be seen by examining the absolute weights exhibited in Table I.

As regards the subdivisions of the cerebrum, Franceschi[6] has some observations which are unique. He determined the weight of the thalamus and striatum for each half of the cerebrum, in a number of persons and at various ages. During the first five years, the records are too few and indefinite to be valuable. Beginning with twenty-one years, however, he has the following data to present:

TABLE VI.—GIVING THE WEIGHT OF THE BASAL GANGLIA IN THE TWO SEXES AT DIFFERENT AGES. WEIGHT IN GRAMS. (Franceschi.)

MALES (Basal ganglia).				FEMALES (Basal ganglia).			
Age.	Number of observations.	Mean weight.		Age.	Number of observations.	Mean weight.	
		Right.	Left.			Right.	Left.
21–40	16	41.2	40.8	21–40	20	36.0	36.0
41–70	38	41.6	42.3	41–70	45	37.7	38.0
71–87	22	42.4	42.4	71–87	21	37.7	41.0

This table shows no regular difference between the two halves of the brain. There is, however, a constant difference according to sex, these structures being about ten per cent. heavier in the male; and very curiously, an actual increase in weight in the last age group, when according to the other records the total weight of the cerebrum is *less* than that found during the prime of life. This peculiar relation must be confirmed before it can be regarded as significant.

In connection with the determination of the weight of the encephalon as the result of growth there are several problems arising from the effect of deformation of the skull during the growing period, and from the possibility of compensatory enlargement of the cranium along one or more axes when its normal growth is hindered. The winding of the child's head with a compressing bandage, so as to elongate it in the fronto-occipital axis, has for generations been practised about Toulouse, in France. The study of the brains of aged persons from this locality with skulls thus deformed has been made by Ambialet,[7] his investigation being the most important study along this line. As might be expected, the effects of this treatment are more pronounced if the deformation has been great than if moderate. Ambialet is able to show, first, that on the average the total weight of the encephalon was diminished, by this treatment, only from two to three per cent; further, that the relations between the cerebrum and the remainder of the encephalon were but slightly modified, the relative value of the cerebrum being reduced a fraction of a per cent., and, finally, that when the cerebrum is divided into lobes, after the method of Broca, the relative weights of these lobes are not significantly different from those found in the normal brain. Since the skulls in question are very evidently abnormal in shape, these results indicate that compensatory growth has occurred in the enclosed brain. This result would agree with those recently obtained from the study of crania by Boas,[8] which he formulates as follows: "Among skulls belonging to the same type, a breadth above the average is compensated by a height and a length below the average." This is probably only a special case representing a general tendency toward a final arrangement of cranial diameters which will result in the cranial capacity normal for the individual. The effects of bandaging the skull appear to cause a general nutritive disturbance rather than one limited by the boundaries of the bandage, and the results are not due to direct pressure on the enclosed brain. So far as this aspect of the problem is concerned, we have the beautiful researches of von Gudden[9] on the growth of the skull and brain, which show that while these two structures may to a slight extent mutually adapt themselves to each other, yet the fundamental growth changes in the brain are in a high degree independent of merely mechanical conditions.

In connection with the encephalon, we shall present such data as are available on the human spinal cord.

The weight of the cord at different ages can be best shown by a comprehensive tabulation of the results, though these are hardly numerous enough to be used for the formation of a curve (see Table VII.).

It thus appears that the spinal cord increases from an average weight of 3.42 gm. at birth to 27 gm. at maturity—an increase of nearly eightfold (7.8),—gaining in weight about twice as much as the encephalon. The encephalon has nearly attained its adult weight at the seventh year, while the cord (see table) at this time has less than two-thirds of its adult weight. So far as this table shows, the cord grows more rapidly than does the brain at *every period* succeeding birth. The final enlargement of the cord is correlated with the growth of the trunk and limbs that occurs during adolescence—a series of changes by which the cranial cavity is but slightly affected. The weight of the cord is therefore closely correlated with the length of the vertebral column. The proportion of the weight of the spinal cord to the weight of the brain is somewhat greater in men than in women, owing probably to the greater growth of the trunk in the male.

Since the central nervous system rapidly reaches nearly its full size while the remainder of the body is still quite small, it follows that the proportion of the weight of the entire body represented by it, decreases.

To show the relative development of the central nervous system, as represented by the brain at different ages, the percentages below are given from Vierordt:

TABLE VII.—WEIGHT OF THE HUMAN SPINAL CORD AT DIFFERENT AGES.

Observer.	Sex and number of cases.	Age.	BODY. Weight. Grams.	Length. Millimetres.	WEIGHT IN GRAMS. Brain.	Cord.	Grams of brain for each gram of cord.
Mies	21 male and female.	Birth to 11 days				3.42 Range 2–6	10 males, 116. 11 females, 113.
Danielbekof	200 " " "	Average age, 30 days			Males 415.3 Females 399.2	3.9 3.8	Males 106. Females 104.
Mies	1 female	One year six months	4,856	667	730	7.74	94
"	1 male	Six years		1,060	1,234	16.88	73
"	1 female	Ten years nine months		1,330	1,189	17.28	69
"	1 male	Eighteen years six months		1,750	1,349	27.50	49
"	13 "	Mature				27. Range 24–33.3 gm.	10 males, 51. 4 females, 49.

TABLE VIII.—PERCENTAGE VALUE OF THE BODY WEIGHT AS REPRESENTED BY THE ENCEPHALON AT THE AGES NAMED.

Age.	BRAIN WEIGHT.	
	Male.	Female.
Birth	12.29	12.81
One year	10.50	11.39
Five years	7.94	7.98
Ten years	5.59	5.56
Fifteen years	3.62	3.09
Twenty years	2.43	2.31
Twenty-five years	2.16	2.23

This table shows that the proportional value of the central nervous system falls off rapidly during the growing period and that the proportional value is greater in the female except in the ten, fifteen, and twenty year records. This greater proportional value in the female is the result of the smaller body weight, and the departure from this relation at the periods noted above is a statistical deviation, due most probably to the fact that during adolescent growth the increase in body weight occurs earlier in the female than in the male, and hence at these times the table compares the sexes at different phases of their growth.

In the growing neuraxis the changes in weight run nearly parallel to the changes in volume, but are a trifle more rapid, owing to the fact that with advancing age the specific gravity of the nerve substance increases and the percentage of water decreases.

Although there are numerous observations on the percentage of water in the human neuraxis at maturity, the changes occurring during growth have not been studied. To supplement this lack, a series of observations (not yet published) made on the white rat by Mr. Polkey and myself will be utilized.

From white rats at different ages the brain and spinal cord were removed separately, and the proportion of water in them was determined by drying, at about 97° C. A study of the results shows that at birth the brain contains about 87 per cent. of water and the cord 85 per cent., whereas in old age the brain contains about 78 per cent. and the cord 72 per cent. Thus a difference in the percentage of water exists between the brain and cord at birth, and this difference increases steadily throughout life.

In the case of both portions of the neuraxis, the curve representing the diminution in the percentage of water can be divided into three parts. The first part covers the first eight to ten days after birth. During this time the diminution in the percentage of water is slow. The second part comprises the next forty days of life. During this period it is very rapid. The third part is from the end of the second period to the termination of life, during which there is a very slow but steady diminution in the percentage of water.

The principal change in the central nervous system correlated with the proportional loss of water is the formation of medullary substance, and the two processes run very nearly parallel.

B. GROWTH CHANGES IN THE NEURAXIS CONSIDERED AS THE RESULTANT OF CHANGES IN THE CELLS WHICH CONSTITUTE IT.—The changes which occur in the central nervous system as a whole are but the resultant of all the changes taking place in the cells which compose it. An exhaustive list of these components would involve the cells forming the blood-vessels and the several sorts of supporting structures—ependyma, neuroglia, and connective tissue—in addition to the neurones proper. Lack of information concerning changes in the non-nervous structures will, however, preclude more than incidental mention of them, and we can turn our attention to the neurones, not, however, forgetting that the non-nervous structures are much more important constituents than this treatment of them would indicate.

1. *Number of the Neurones.*—It is first necessary to determine when the number of nucleated nerve cells (neurones, actual and potential) is fixed. The absence of karyokinetic figures in the human system at the time of birth is presumptive evidence that the number of nerve cells is not increased after that period. Other observations suggest that the production of new nerve cells has been completed in man by the end of the third month of fœtal life, and even if the production of new cells has not absolutely ceased at this time, our present evidence indicates that it has become very slow. It may be observed in passing, that in the white rat at birth cell division is still very active; but this has little bearing on the condition found in man, because the time of birth in different mammals does not furnish a base line for comparison, since the maturity of the animal at birth varies enormously with the species, and in this instance the new-born rat is to be compared with the human fœtus at least several months before birth. Granted that the number of nucleated nerve cells is formed early, we have next to inquire what happens to them after they have been formed. The studies of His[10] and others have shown that the first appearance of these elements is in the form of a neuroblast, which in some cases develops into the complete neurone, while in others it may remain undeveloped for years or even throughout life. When it does undergo development the order of the changes is in general that described by Cajal[11] for the cortical neurones (the pyramidal cells in the cortex of the rabbit). First, the formation of the axone, then the dendrites, and finally the collaterals; these portions being all well marked before the neurone as a whole has attained its full size. After this, the medullary sheath appears: first on the axone, and later on the collaterals. Nevertheless, even in those neuroblasts destined to undergo a complete development these changes do not occur at the same time in all the individuals. The fact that the sum of the nucleated cells which furnish both the permanent neuroblasts (granules of the authors) and the developed neurones is not increased after an early period in the fœtal development of man is the first important datum.

The second fact is that a number of these potential neurones begin to develop shortly after their formation, while others delay a longer or shorter time. Thirdly, all statements regarding the number of neurones (nerve cells) in any part of the nervous system are based on the number of fully characterized nerve elements there present, and leave unenumerated the potential nerve cells in the neuroblast stage. Since the well-characterized neurones are transformed from the neuroblasts only gradually and in series, it follows that during the earlier phases of growth the *number* of neurones will *increase;* but, as has just been explained, this increase is at the expense of neuroblasts already present in the locality, and does not depend on the *formation* of *new* cell elements.

From this it follows that in a given part of the nervous system there exists, after cell multiplication has ceased, the paradoxical conditions whereby an increase in the *number* of nerve cells may occur without any increase in the total number of neuroblasts and nerve cells taken together, since the latter arise by the transformation of the former.

In order to follow this increase in the number of neurones in the growing animal, it will be advantageous to use the following classification of the cell elements. By this classification, the neurones constituting the nervous system are arranged in three groups. Group I. The afferent neurones: Those furnishing the afferent pathways and having their cell bodies located in the spinal ganglia or their homologues. In this class the cell body lies outside the neuraxis. Group II. The central neurones—constituting the great mass of the central nervous system: All parts of these neurones lie within the wall of the original medullary tube, and all the neurones are concerned with the distribution of the impulses within these limits. Group III. The efferent neurones—concerned in distributing the impulses to the organs of expression. The type of the efferent neurone is the motor element of the ventral horn of the spinal cord, with its cell body within the wall of the medullary tube and its axone passing either to striped muscle tissue or to the peripheral neurones of the sympathetic system. To this last group the neurones of the sympathetic system also belong, but in this case both the cell bodies and the axones are found outside of the central system.

Since it is the mass of the central neurones which constitute the very great proportion of the central nervous system, and since this is the group which undergoes the greatest variation in the mammalian series, it has seemed desirable to separate this group from the other two, and this has been done by means of the foregoing classification. The studies of Birge [12] on the number of root fibres in frogs of different sizes and of Hardesty [13] on the growth of these fibres, show that in the afferent and efferent groups in the frog new axones are continually being formed, and we infer that this new formation follows from the development of neuroblasts which have remained latent for some time. The growth of the frog is so long continued that it is usually said to grow as long as it lives—a statement by no means demonstrated. The conditions are, however, very different from those found in mammals in which the period of growth is much more limited and the size of the body is fixed. In mammals, the available observations are very few. There are no observations on the increase of the neurones in the afferent system of the mammal (Group I.) except the recent study of the dorsal nerve root (fourth coccygeal of the cat) by Dale.[14] Here, the number of medullated fibres was found to be the same at different levels of the root, thus failing to show in the cat the outgrowing fibres revealed by Hardesty in the frog. It appears then that the number of dorsal root fibres in this locality is early fixed in the cat. Passing next to the efferent neurones, the records of Kaiser [15] on the "motor cells of the ventral horn" in the region of the human spinal cord, comprised between the fifth cervical and first thoracic segments, inclusive, are as follows:

TABLE IX.—SHOWING THE NUMBER OF DEVELOPED CELLS IN THE VENTRAL HORN IN THE CERVICAL ENLARGEMENT OF MAN AT DIFFERENT AGES. (Kaiser.)

Age.	Number of nerve cells.
Fœtus, sixteen weeks.	50,500
Fœtus, thirty-two weeks.	118,330
New-born child.	104,270
Boy, fifteen years.	211,800
Male, adult.	221,200

We assume, of course, in accordance with the explanation given above, that the additional neurones are derived from neuroblasts already present. If the numbers here given are interpreted literally, they mean that to the ventral roots of these segments there are added during the periods given the equivalent number of new fibres. Moreover, this addition, according to the table, would go on for a long period, and thus we might expect to find evidence of outgrowing axones in the ventral roots of persons more than fifteen years of age.

In the case of the ventral root of the fourth coccygeal of a cat, Dale was unable to find any evidence of outgrowing fibres; and, furthermore, the studies of Schiller [16] on the oculo-motor nerves of cats of different ages showed that at eighteen months the number of fibres present was hardly four per cent. greater than the number found at birth, indicating that here, at least, the number added between birth and maturity was small.

TABLE X.—SHOWING THE AVERAGE NUMBER OF FIBRES FOUND IN EACH OF THE OCULO-MOTOR NERVES OF CATS, FROM BIRTH TO EIGHTEEN MONTHS OF AGE. (Schiller.)

Age of specimen.	Mean number of fibres.	Extreme variation in number of fibres.
New born, A, B, C (average of three cases) ..	2,942	2,905–2,980
One month, D, E (average of two cases)	2,961	2,946–2,976
Four months, F	3,007	2,995–3,016
Twelve months, G (mother of A, B, F).......	3,013	3,002–3,019
Eighteen months, H	3,035	3,020–3,050

Using the observations of Schiller to control those of Kaiser, it may be argued that the number of efferent neurones in the cat is early completed. Probably the same is true for man; and if it is true for man then the great increase in the number of cell bodies found by Kaiser in the ventral horns of the spinal cord is due to the development of *central* rather than of *efferent neurones.*

Until more evidence on these points is available, however, further discussion would be useless.

The total number of neurones found in the brain and cord of man is doubtless variable, but for individuals of the same race the variability is probably not large. This is concluded from the constancy in the proportional development of the divisions of the encephalon. The closest determination of the number of neurones in the cerebral cortex of man has been made by Miss Thompson,[17] who employed as a basis the records of Hammarberg.[18] According to this computation, there are in the cerebral cortex 9,200,000,000 well-marked nerve cells. Using these results as a foundation, and estimating that in the remaining gray matter of the neuraxis the cells have an average frequency equal to that in the cortex, I have computed that the total number of nerve cells in the entire central nervous system is 11,200,000,000.

2. *Size of Neurones.*—In this connection it is important to remember that on passing down the mammalian series from larger to smaller forms, the nerve-cell bodies diminish much less rapidly in volume than does the entire animal or its central nervous system. From this it follows necessarily that in the nervous systems of small animals, with their small absolute weight and their comparatively large cell bodies, the number of the neurones must be far smaller than that found in man. To show the average size of the cell bodies in one locality in a

series of mammals, the following table from Kaiser is quoted:

TABLE XI.—SHOWING IN A SERIES OF MAMMALS THE MEAN DIAMETER OF CELLS FROM THE VENTRAL HORNS OF THE CERVICAL ENLARGEMENT. THE MEASUREMENTS FOR THE CHROMOPHOBIC AND CHROMOPHILIC CELLS ARE KEPT SEPARATE. (Kaiser.)

MEAN DIAMETER OF CELLS IN μ.

Chromophobe Cells.		Chromophile Cells.	
1 Plecotus auritus	28–53		
2 Talpa Europæa	36–54	1 Talpa Europæa	17–40
		2[1] Erinaceus Europæus....	25–45
3 Cercocebus sinicus	33–60	3 Cercocebus sinicus......	23–46
4 Cuniculus domesticus....	41–61	4 Cuniculus domesticus...	32–57.5
		5 Homo	23–59

1 Bat. 2 Mole. 2[1] Hedgehog. 3 Monkey. 4 Rabbit. 5 Man.

With this peculiarity of the cell bodies is to be contrasted the behavior of the axones. The calibre of the axones is most closely correlated with the volume of the cell bodies, and therefore is not more subject to diminution than the cell bodies themselves; but, on the other hand, the *length* of the axones necessarily varies with the size of the animal. From this it follows that the total volume of corresponding neurones is always diminished in the smaller animals, and this too despite the fact that the diameters of the cell bodies and the axones may be but little modified.

In man a notion of the volume of the average neurone at maturity can be obtained by dividing the volume of the central nervous system, so far as it is composed of neurones, by their estimated number. The volume obtained is 90,000 μ^3.*

The neuroblast, according to His,[10] has a volume of 700 cubic micra. According to this the average neurone would have increased only about one hundred and twenty-eight times in volume—whereas it can be shown that very many neurones increase more than a thousandfold.

Since a large number of neurones can be shown to increase many times more than the average enlargement, it follows that there must be a very large number of neuroblasts which develop either slightly or not at all. In support of this statement, attention is called to the fact that in the cerebral cortex the smallest neurones have diameters much smaller than that of the original neuroblasts; while in the cerebellar cortex, the granules with a mean diameter of about 7 μ appear still more reduced. There is at present no satisfactory explanation for these cases.

The only observations on the changes in the volumes of growing cell bodies in man are those by Kaiser,[15] made on the cell bodies of the ventral horns of the cervical enlargement of the spinal cord.

TABLE XII.—SHOWING THE VOLUMES OF THE LARGEST CELL BODIES IN THE VENTRAL HORN OF THE CERVICAL CORD OF MAN. (Based on Kaiser's records of the mean diameters.)

Subject.	Age.	Proportional volume of the cell bodies. $1 = 700\ \mu^3$.†	Time interval.
Fœtus	Four weeks	1	
"	Twenty weeks	17	
"	Twenty-four weeks.	31	36 weeks.
"	Twenty-eight weeks	67	
"	Thirty-six weeks ...	81	
Child at birth	....	124	15 years.
Boy, fifteen years.	....	124	
Man, adult.......	....	160	15 years.

† The volume 700 μ^3, in the fœtus of four weeks, is taken from His, and the figures represent multiples of that volume.

The proportional volumes given in Table XII. show that the rapid enlargement of these cell bodies occurs before birth. It gives, however, the same values for the child at birth and the youth at fifteen years, while in the mature man the size is somewhat greater. This is so peculiar a result that one is inclined to give greater weight to the statements of Marinesco,[19] who finds the cell bodies in question to increase in diameter from their formation up to twenty-five or thirty years, and the giant cells of the cerebral cortex to enlarge for a still longer time.

Opposed to Kaiser are also my own observations on the white rat, where the growth of the cell bodies continues, though at a diminishing rate, up to maturity. It appears from the white rat that the enlargement of the cell bodies is an event that takes place early, in the first half of the period of rapid growth of the neuraxis (first fifty days of life), and that it is mainly accomplished at a time when the axones are still increasing in all dimensions, and when medullation is yet very incomplete. The central nervous system in its first embryonic form is a mass of neuroblasts; in its completed form it is composed mainly of axones and their medullary sheaths. The condition at maturity was brought out by investigations of Miss Thompson,[17] on the proportion of the cerebral cortex occupied by the bodies of the neurones. The observations were made on material hardened in alcohol and stained with methylene blue (Hammarberg [18]). The cell bodies, under the conditions chosen, represented only 1.37 per cent. of the entire volume of the cortex. If we should increase this to 3 per cent. and include the dendrites with the cell bodies, there would still remain 97 per cent. of the cortex composed of other substances, and in a large measure this 97 per cent. would be represented by medullated axones. All the white substance of the nervous system is, in even a greater measure, composed of the same constituents, so that, taken all together, the medullated axones form the great proportion of the entire system. For this reason at least, this division of the neurone (the axone) requires special consideration. There is in the first place no reason to assume that the relative size of these structures is exactly the same in two brains otherwise comparable. But owing to their great preponderance a slight variation in the size of all the axones and their sheaths might alter very decidedly the gross weight of the encephalon without at the same time necessarily adding to its physiological complexity (Donaldson [20]). It is easy to see that even among the central neurones,—as, for example, the pyramidal cells of the cerebral cortex, the axone of which reaches to the lumbar enlargement of the spinal cord,—the axone with its sheath must be many times the volume of the cell body. The medullated axones of the large pyramidal cells are of such a diameter that a length of about 0.5 mm. of axone is equal in volume to the cell body. This gives twenty times the volume of the cell body for each centimetre of the medullated axone, and if it extended 40 cm. we should have the cell body with (20×40) 800 times its volume as represented by the medullated axone.

In the peripheral nervous system the relative mass of the axones is even greater than in the central system. Observations on the white rat show that in the case of the largest neurones belonging to the mid-lumbar spinal ganglia, there is a direct correlation between the increase in volume of the growing ganglion cell body and the area of the cross section of its axone; the ratios of enlargement being similar for both.[32] Further, from the time when the medullary sheath is formed on the axones of these cells up to maturity, this sheath exhibits in cross section a simple and constant relation to the enclosed axis—viz., the area of the enclosing medullary ring being very nearly equal to the area of the enclosed axis. This same relation between axis and sheath appears in the peripheral system of man, but the relation existing in the central nervous system has not yet been determined. As to the calibre of the medullated axones in the peripheral system, Westphal [21] reports in the peripheral nerves of man at birth the smallest fibres, including the sheath, 1.2 to 2 μ in diameter, and the largest 7 to 8 μ with an average diameter for all of 3 to 4 μ, while

* The estimated number of neurones—excluding the spinal and sympathetic ganglia—is 11,200,000,000. The volume of the central nervous system, composed of neurones = 1,005 c.c. The individual neurone, therefore, has the volume given above.