Critical Review.

THE LOCALIZATION OF FUNCTION IN THE CENTRAL NERVOUS SYSTEM: A REVIEW OF SOME RECENT STUDIES OF ANIMAL BEHAVIOUR.

BY C. P. SYMONDS, LONDON.

IN recent years there have appeared many valuable contributions to the study of function in the central nervous system and the correlation between function and structure. Many of these papers have dealt with problems of cerebral localization: the work of Liepmann and Wilson upon apraxia in relation to lesions of the cortex cerebri and corpus callosum; Head's studies upon sensation and the cerebral cortex; the observations of Holmes upon disturbances of the higher visual functions in patients with lesions of the parietal lobes; and the vast mass of literature which has grown up around the classical work of the Vogts and Wilson upon the basal ganglia, may be mentioned in illustration. Nor have problems of functional localization at lower levels failed to receive a fair share of attention, as witnessed by the careful studies of the midbrain, cerebellum, and spinal cord, which, in the hands of the clinician and experimental physiologist, have thrown considerable light upon the functional importance of these structures, and on the respective physiological value of the various cell stations and fibre tracts contained therein. Inspired by the writings of Hughlings Jackson, and approaching the study of modern researches in an attitude of mind determined in some degree by the tradition of his genius, the British school of neurology shows a tendency to a somewhat rigid belief in the exclusive localization of separate functions at set levels in the nervous hierarchy.

Thus it is assumed that there are in man at least three such levels where certain neurones are grouped together, so that the cerebral hemispheres alone are responsible for the execution of phasic movements of the so-called conscious order, the basal ganglia and midbrain nuclei deal with the maintenance of posture, equilibration, and rhythmic movements of progression, while in the spinal cord there

are ordained special conjunctions of neurones for the performance of mass-reflexes of a protective or excretory nature.

It has been generally held in this respect that the centres and pathways, through which are mediated the various functions specified, are laid down at birth or develop shortly after it in accordance with a definite plan, which is an inheritance of the ages evolved through countless generations in accordance with the laws of natural selection. According to this view, individual variations in the function of the nervous system depend wholly on variations in its structure, and, in the gradual course of the process of evolution, progressive diversity of function has been achieved by the preservation to the species of variations with a high survival value.

These beliefs have driven neurologists persistently to seek light upon obscure problems of function in theories of their phylogenetic origin, often with illuminating results. There are, however, dangers in the way of those who follow this path of thought too closely, lest they become so enamoured of the theory that they find in it a place for each new observation, with never a pause for analysis and a fresh survey of the facts.

THE STUDY OF BEHAVIOUR.

Upon the nervous system with its dominant function of integration the living organism depends for its ability to adapt itself to varying conditions in its environment, and the adaptations so made are summed up in the word behaviour.

Glancing briefly at the phylogeny of the nervous system, we see that at a certain point in its evolution there has been a divergence of the ways. In the primitive organism the modes of response to environmental factors are few in number and strictly limited in character. In the further course of development the adaptive mechanisms become more numerous, but are still innate and invariable, and continue to be so throughout the whole of the insecta. With the development of the vertebrate phylum, however, there appears, in addition to the innate invariable characteristics of behaviour, an increasingly larger number of individually acquired and variable modes of response, reaching a high degree of importance in mammals and culminating in man.

An impetus has been given to the study of these variable factors in behaviour by the formulation of laws governing the acquirement of conditioned reflexes. It has been shown that the exhibition of food to a hungry dog excites the secretion of saliva; if now a bell be rung at the same time as the food is exhibited and this conjunction of stimuli be repeated a number of times, the sound of the bell alone will become an adequate stimulus for the reflex secretion of saliva. In

other words a stimulus—the ringing of the bell—which previously produced no response, becomes capable of initiating a definite bodily reaction: the animal has acquired a new mode of response to a factor in its environment.

Much work has now been done to prove that a very large proportion of all human behaviour is made up of conditioned reflexes acquired on similar lines, and this has led to careful objective studies of behaviour in the human infant.

J. B. Watson, in a series of experiments upon new-born babies, has demonstrated that many reactions popularly supposed to be innate or instinctive are really acquired as conditioned reflexes, and that the stock of inherited invariable modes of response is smaller than was formerly held. He has proved, for instance, that the human infant does not show the reactions characteristic of fear in response to contact with or sight of animals, but that such a reaction may be conditioned by making use of the innate fear response to a sudden loud noise. He has further shown that the blinking reflex which occurs in adults when a threatening movement is made towards the eye is not present at birth, and is not observed before the fifty-fifth day. Observations such as these are of the highest importance, and it would seem that purely objective studies of behaviour reactions in the newly-born may lead to more critical views of the theories at present held concerning the nature of reflex phenomena in decerebrate and spinal man.

In the case of other bodily systems the establishment of a new function is accompanied by corresponding structural adaptation: when a man learns the trade of blacksmith the muscles of his arms hypertrophy, as we say, to meet the demands of his new work. In the nervous system, however, as far as we know, there is no possibility of such a new growth of cells and fibres, so that we are forced to the conclusion that newly-acquired habits must be mediated by pre-existing neurones.

In the formation of a habit we are tempted to believe that some change in the structural formation of the neurones must take place, some knitting of synaptic connections in one direction and loosening in others; but of what actually does occur we know nothing.

Many questions naturally arise in this connection, some of which have been answered by experimental work upon animals, others by observations of disorders of nervous function in disease with correlation of the structural lesions found post mortem. As an instance of the latter we may take the researches which have shown that the acquired habit of speech in man depends upon the integrity of certain fairly well-defined areas of the cortex cerebri, which in right-handed persons are always in the left hemisphere. Destruction of these

areas results in loss of the habit acquired. In such studies of the structures involved in the process of learning, chief attention has naturally been paid to the cerebrum, on account of its steadily increasing predominance in size and complexity of structure, as compared with the rest of the nervous system, in the higher mammalia and man. And with the advance of our knowledge there has arisen a tendency to the belief that a great many acquired functions are localizable in the cerebrum—that centres and pathways lie ready for their use in the inherited structure of the brain, which are the same for all men, and that we may in time be able to map out the cortex in a veritable mosaic of functional topography.

THE EXPERIMENTAL WORK OF FRANZ AND LASHLEY.

Some recent experimental work in America throws a new light upon the old problems in which there appear certain novel features of startling importance.

FIG. 1.—THE SIMPLE MAZE.
a, Starting compartment; b, Middle alley; c, Cul de sac; d, Alley leading to food, e.

S. I. Franz and K. S. Lashley, having been for some time past at work upon the training of rats to acquire various habits of a more or less complex nature, were led to the investigation of the following questions in relation to these animals:—

1. Is any one part of the brain essential for the learning of habits, or the learning of a particular habit?
2. When such a habit has been learned, is there any one area, the destruction of which will lead to the loss of that habit?
3. If a habit can be lost as the result of such a destructive lesion, may it be re-acquired?

The authors commenced their researches by endeavouring to ascertain the results of destruction of the frontal lobes in rats which had been trained in a simple maze. The maze was built of wood with a wire cover in the pattern shown in the accompanying figure (Fig. 1). The rat when hungry was placed in the starting compartment (a), and the sliding door was then lifted. When first introduced into the starting compartment the rat would sniff at the wire cover and at the sides and corners of the compartment, paying no particular attention to the door. When the door was raised he would stand erect and sniff at its lower edge before venturing into the first alley. With practice his reactions became centred on the door; on being introduced into the starting compartment he would try to push it up, or sniff at the crack under it.

Now the moment the experimenter touched the door to open it, the rat would turn with his head in the right front corner of the compartment, ready to crawl out as soon as he had sufficient space. In first trials the rat would spend much time in sniffing at the cover, walls, and corners of the maze. After training he would go from starting compartment to food in 1.2 second. The minimum time spent on the first trial by any of sixty rats trained was 8 seconds, and the mean time 30 seconds, most of which time was spent in exploratory sniffing. With practice these exploratory movements disappeared, and the animal would run to the food without a pause. Many of them came to follow the path marked by the dotted line in *Fig. 1*, being the shortest possible route to the food.

Each rat was given a fixed number of trials each day until ten successive trials had been completed without error, and this was taken as evidence of completion of learning. (It was found that, after this point was reached, rarely more than six errors were made in the next consecutive hundred trials.)

The total time consumed in the course of learning was recorded for each animal for the first trial, and for the first fifteen trials. In a number of rats so trained the frontal lobes were destroyed through trephine openings under anæsthesia, and the animals tested in the maze within twenty-four hours of the operation; the total time and number of errors for the first trial, and for the first fifteen trials, were again determined, and being compared with the original figures showed that in no case was the habit lost. For instance, in the case of the rat first tested the results were as follows :—

				In Learning	After Operation
First 15 trials	Total time	..	..	188 seconds	54 seconds
	Errors	..	..	5 „	1 (?) „
First trial	Time	..	..	15 seconds	2.6 seconds
	Errors	..	..	0 „	0 „

When the experimental part of the work was complete the animals were killed, and the brains hardened and cut in serial horizontal sections, from which the exact extent of the lesions in each case was mapped out and recorded in a diagram.

The results showed that the entire frontal pole of each hemisphere was destroyed in one or another of the animals, and that no one part of the frontal pole remained undestroyed in all. The conclusion reached therefore was that no particular part of the frontal pole of the rat's cortex is necessary for the retention of the simple maze habit.

The technique of the first series of experiments has been fully described for purposes of illustration. As the result of further studies with the simple maze it was found: (1) That the habit may be retained after the destruction of any part or all of the cortex lying in front of and above the knee of the corpus callosum, and after the destruction of any part of the temporal or parietal regions; (2) That the *maze habit may be acquired* after the destruction of all the cortex included within these areas, and after the destruction of one, perhaps both, of the striate nuclei.

In a further series of experiments rats were trained to a more complex habit. Within a wire cage was set a problem box containing food, the door of which could be unlatched only by pressure upon

FIG. 2.—THE INCLINED-PLANE BOX.

A, Door of restraining cage; B, Inclined plane; C, Catch extending down to upper edge of door; D, Door leading into food-box.

the free end of an inclined plane set upon the roof of the box (*Fig. 2*). In order to gain the food, therefore, the rat had first to depress the inclined plane, then jump down and enter the box through the open door. The frontal lobes were destroyed in trained animals, and the results of post-operative tests compared with the original trials as in previous experiments. It was found that some of the animals retained the habit, while others lost it, and comparison with the post-mortem sections showed that whereas retention had been observed in several cases with *partial* destruction of the frontal lobes, in no case in which these lobes had been *completely* destroyed was the habit retained.

Partial destruction of the frontal pole did not always result in

loss of the habit, but an attempt to find a correlation between the part destroyed and the retention or loss of the habit revealed the further fact that no single part of the frontal pole escaped destruction in the animals which *retained* the habit (i.e., if a map were made to show the *combined extent* of the lesions in these animals the whole frontal pole was included).

"It follows that although some part of the frontal region must remain intact if the plane-box habit acquired by the normal animals is to be retained, the particular part preserved is immaterial. The different parts of the frontal region are, to adopt a term from experimental embryology, 'equipotential in the functioning of the habit'."

FIG. 3.—THE DOUBLE-PLATFORM BOX.
a, b, Platforms which must be pushed down in the order a-b, in order to open the door, d, to the food-box.

A further series of experiments was now carried out to determine the ability of rats, with various parts of the cerebrum destroyed, to learn more complex habits. For this a new problem box was devised (Fig. 3), the door of which was opened inwards by a strong spring, but was held shut by two latches. These were released by pressure upon two platforms, one on either side of the box; in order to open the door it was necessary for the animal to press first upon the right then upon the left-hand platform. Failure to perform these movements in the correct order resulted in failure to open the door.

As a measure of learning, the following arbitrary criterion was employed. The animal must go directly from the door of the outer

cage to the right-hand platform and push it down : he must then go by some constant path to the other platform and, after pushing it down, must go directly to the open door and enter the problem box. Any deviation from the direct path, or pause to sniff at the door or other part of the problem box, was counted as an error. Three trials were given daily, and three successive trials without error had to be made in one day before learning was considered perfect.

In this series of experiments the animal was given an hour for each trial, and if it had then failed to solve the problem it was removed from the box. The 'learning time' was recorded in terms of the number of trials required.

As a preliminary, ten normal animals were trained (*Group 1*), and then five groups of animals in which various portions of the cerebrum had been removed at operation. In *Group 2* one or other hemisphere was removed as completely as possible ; in *Group 3* both occipital lobes were removed : in *Group 4* the parietal lobes were destroyed on both sides ; in *Group 5* both frontal lobes were removed ; and in *Group 6* the frontal and parietal lobes were destroyed in both hemispheres.

The combined lesions in these animals therefore covered the whole cerebral substance. The results of these experiments are shown in the following table :—

THE AVERAGE NUMBER OF TRIALS REQUIRED FOR LEARNING THE DOUBLE-PLATFORM BOX BY NORMAL AND OPERATED GROUPS.

Group	Lesion	Average Trials	Range of Variation
1	Normal	142.6	63-204
2	Hemidecerebrate ..	87.2	49-141
3	Occipital injury ..	68.8	45-107
4	Parietal injury ..	80.0	41-101
5	Frontal injury ..	90.0	90
6	Frontoparietal ..	39.0	27-51
	All operated ..	79.0	27-141

From this table it appears that the operated animals were not at all inferior to normal ones trained under the same conditions. In fact the animals with cerebral lesions appeared to learn more quickly, which was shown to be due to the tendency of the normal rat in the earlier trials to leap over the platforms, whereas the paretic animal was more likely to trip over it, and in the process of trial and error to arrive at the solution more rapidly.

The functions of deeper structures in learning were next called in question, and it was shown that the rate of learning was unaffected by destruction of the hippocampal lobes and striate nuclei.

J Neurol Psychopathol: first published as 10.1136/jnnp.s1-1.4.329 on 1 February 1921. Downloaded from <http://jnnp.bmj.com/> on April 26, 2023 by guest. Protected by copyright.

These experiments showed that no single part of the cerebrum was necessary for the learning of the double-platform-box habit, and no single part was proved to be significantly more efficient in learning than any other part. For the acquirement of the habit the various parts of the cerebrum seemed to be absolutely equipotential. "Moreover, at best 50 per cent of the cortex can be dispensed with without marked deterioration, and there seems to be no relation between the absolute quantity of cerebral cortex functional and the ability to learn."

A number of rats were now trained in a habit involving visual discrimination. The problem box used offered a choice between two alleys, and at the end of each alley a circular translucent plate was fixed. One of these was illuminated, the other dark. It was found in animals so trained that destruction of the frontal or parietal regions did not affect the habit. But in three animals in which both occipital lobes were destroyed the habit was completely lost. That this was not due merely to the shock of the operation was proved by a control experiment. Close observation showed that vision was not lost in these animals, and in the case of two of them in which the attempt was made *the habit was relearned in normal time*. This shows that in normal animals the visual habit is mediated in some way by the occipital region and by the occipital region alone, but that in the absence of this region *other parts of the nervous system are able to take on their function*.

THE SIGNIFICANCE OF FRANZ AND LASHLEY'S WORK.

Lashley expresses his conclusions in the following words :—

The point most clearly demonstrated is the complete vicarious functioning of all parts of the cerebrum in learning. Not only are areas to which associative function might be ascribed unnecessary for the acquirement of habits, but even projection areas, which have been considered as hereditarily organized relay stations for impulses to or from the cortex, may be dispensed with without any discoverable loss in ability to learn a difficult reaction which is normally mediated by those areas. This capacity for vicarious functioning seems to hold true both for the cortex and for the underlying structures making up the archipallium. Such a fact can only be explained by the assumption of a fan-like distribution of fibres from the lower centres to all parts of the cerebrum, permitting incoming impulses to reach any part of the cortex, which happens to be intact, with equal ease.

Yet, if this is the case, it is not clear why any particular part of the cortex should function to the exclusion of other parts in the formation of a habit under normal conditions, unless we can further assume a somewhat greater concentration of fibres from given lower centres in given cerebral areas. Probably this represents the true state of affairs, for it is evident, from the fact that destruction of the frontal or occipital regions abolishes

corresponding habits, that under normal conditions the various parts of the cerebrum have specialized functions. Nevertheless, this specialization is only relative, and is of such little practical consequence that learning may go on with equal speed in the presence or absence of the specialized areas.

The results further form a strong argument against the existence of any cerebral areas which have a directive influence over learning, whether it be by 'attention' mediated through the frontal lobes or by the 'conscious action' of the brain as a whole. On the contrary, they suggest that the only essential condition for learning is the simultaneous activity of two reaction systems which are in anatomical connection by association fibres.

SUMMARY OF OTHER EXPERIMENTAL DATA.

Some attempts had been made previously to train animals with experimental lesions of the cerebrum. In the course of his studies of the decerebrate dog, Goltz (1892) made no definite attempts at training, and, apart from the improvement in walking shown after recovery from shock, reported the acquisition of one function only. He noted that at first the swallowing reflex could be elicited only by placing food in contact with the pharynx. Gradually the reflex came to be called out by more distal stimuli to the tongue, chewing movements appeared, and on the twenty-fourth day after operation food was first taken when placed against the lips. A similar improvement in a dog after decerebration was noted by Rothmann (1912), who also trained his animal to walk upon its hind legs with the fore feet supported. Burnett (1912), in a careful series of experiments, failed to obtain the maze habit in decerebrate frogs.

Franz (1902, 1907) showed that destruction of the frontal lobes in cats and monkeys is attended by loss of recently-acquired habits, but that these habits may be re-acquired in normal time.

Leyton and Sherrington (1917), in the course of studies upon the excitable cortex in anthropoid apes, performed certain ablation experiments which they summarize in the following words :—

Ablation of the cortex of the larger part of an arm or leg area in gyrus centralis anterior produced heavy paresis of the corresponding limb ; but this paresis quickly lessened and the limb soon regained in large measure its volitional mobility, and became successfully used for climbing, picking up food, picking the teeth, etc. Ablation further of the greater part of the arm area of the second hemisphere induced no recrudescence of paresis in the already paretic and partly recovered arm. After the double lesion, considerable recovery of the volitional use of both limbs somewhat rapidly ensued, the hands, for instance, being used freely in climbing, picking up food, etc.

Ogden and Franz (1917) performed experiments in which hemiplegia was produced in monkeys by the application of the electro-cautery to the motor cortex, which was previously delimited by

electrical stimulation. They found that if the monkey were untreated very little recovery took place in the course of six months; if ordinary massage were used there was very little improvement. But if the sound side of the animal were restrained so that movements of climbing and feeding must be made if at all by the use of the paralyzed segments, improvement was rapid and recovery practically complete.

AN APPLICATION OF THESE RESULTS TO CLINICAL NEUROLOGY.

The question naturally arises, "How far are we justified in applying to man the experimental data obtained from rats?"

Lashley considers that there is no justification for assuming any fundamental difference between the cerebral mechanism in the rat and man. The differences between the rat and the ape are scarcely greater than those between the ape and man, and in both cases are differences of degree:—

Both the sensory and intellectual capacities of the adult man are the result of years of training which have led to the establishment of countless habits having a definite structural basis. Cerebral injury may destroy a very great number of these instead of the few which such an animal as the rat has formed, and the apparent loss of function will therefore be greater. Further, the rate of learning in the human adult depends largely upon the number and complexity of the habits already formed. When the latter are abolished, the entire system must be built up slowly *de novo* before anything like an approach to adult performance is attained. . . . The rat loses less than higher forms after cerebral injury because he has less to lose, and he seems to recover more rapidly chiefly because a little improvement brings him relatively nearer the standard of comparison (normality) than does the same amount of impairment in man.

It follows from Lashley's arguments that he submits the possibility of complete vicarious function in the human brain. Even in the rat, however, he is forced to admit the existence in normal animals of inherited structural peculiarities favouring the localization of certain habits in particular areas of the cortex. And it seems probable that such specialized pathways are more numerous in higher mammals. In relation to this point, clinical experience so far is entirely opposed to the possibility of re-acquisition of the faculty of speech when once the centres normally mediating this function have been completely destroyed.

The observations of Leyton and Sherrington, already referred to, support his view that vicarious function in relation to simple motor habits may be possible in the anthropoid apes.

The possibility of some degree of vicarious function in the central nervous system is obviously of the highest importance in the treatment of cases of organic nervous disease. The knowledge that within

the brain and spinal cord neurones once destroyed can never be repaired, and the assumption of specific localization of function in these neurones, have led the practitioner to a somewhat hopeless view of these cases.

Franz was inspired by his earlier work to turn his attention in 1915 to the possibility of retraining patients suffering from paralyses due to old cerebral lesions. He attempted the re-education of five hemiplegics whose lesions were of many years' standing (the most recent dated back to an apoplexy eight years before). By means of the employment of stereotyped methods of training and estimation of the learning times required, he was able to show that a great deal of improvement could be effected even after this length of time, but that the process of re-education was comparatively slow and required much patience and energy on the part of the teacher. He concludes his paper with the remark, "We should probably not speak of permanent paralyses or of residual paralyses, but of uncared-for paralyses."

Attention has been widely called of late to the so-called hysterical element in organic nervous disease. The theory advanced to explain this condition is that the original disturbance of function produced by transient damage to nerve-fibres is perpetuated by a process of auto-suggestion. This is doubtless true in a number of cases.

But is it not possible that the methods of *re-education* which prove so successful in the hands of the exponents of the theory are *truly* educative, in that the results represent a process of re-learning, by means of other structures, of functions lost by destruction of the original pathways—a true instance of vicarious function? If we could accept this view, we should be able to differentiate such cases and exclude them from the heterogeneous mass of clinical material generally labelled 'hysterical', a procedure which might help us towards a clearer view of hysteria as a nosological entity.

To the student of neurophysiology these researches afford problems of fascinating interest. We have been accustomed to regard the reflex phenomena in decerebrate and spinal man as examples of inherited pattern-reactions released from inhibition by cerebral centres—reactions old in the history of the phylum—and we have looked for constant and invariable laws governing these phenomena.

Yet in clinical practice we frequently meet variations which are difficult to explain on the basis of any such rigid formula. The evidence quoted in this paper suggests that some of the reflexes mediated by subcerebral centres may after all be acquired habits, in which such variations might naturally be expected to occur. We may perhaps seek in the history of the *individual* the explanation of the fact that in some cases of undoubted transection of the spinal

cord, contrary to rule, there appear in the lower limbs those reflexes classified by Riddoch as extensor phenomena.

BIBLIOGRAPHY.

- BURNETT, T. C., "Some Observations on Decerebrate Frogs, with especial Reference to the Formation of Associations", *Amer. Jour. Physiol.*, 1912, xxx, 80.
- FRANZ, S. I., "On the Functions of the Cerebrum : I. The Frontal Lobes in Relation to the Production and Retention of Simple Sensory Habits", *Amer. Jour. Physiol.*, 1902, viii, 1.
- FRANZ, S. I., "Recovery of Function in Hemiplegia", *Jour. Amer. Med. Assoc.* 1915, lxxv, 2150.
- FRANZ, S. I., "On the Functions of the Cerebrum : The Frontal Lobes", *Arch. of Psychol.*, 1907, No. 2, 64.
- FRANZ, S. I., and LASHLEY, K. S., "The Retention of Habits by the Rat after Destruction of the Frontal Portion of the Cerebrum", *Psychobiology*, 1917, i, 3.
- GOLTZ, F., "Der Hund ohne Grosshirn", *Arch. f. d. g. Physiol.*, 1892, li, 570.
- LASHLEY, K. S., and FRANZ, S. I., "The Effects of Cerebral Destruction upon Habit Formation and Retention in the Albino Rat", *Psychobiology*, 1917, i, 71.
- LASHLEY, K. S., "Studies of Cerebral Function in Learning", *Psychobiology*, 1920, ii, 55.
- LEYTON, A. S. F., and SHERRINGTON, C. S., "Observations on the Excitable Cortex of the Chimpanzee, Orang-utan, and Gorilla", *Quart. Jour. Exper. Physiol.*, 1917, xi, 135.
- ROTHMAN, M., "Demonstration des Hundes ohne Grosshirn", *Ber. über d. V. Kongress f. exper. Psychol.*, 1912, 256. Leipzig : Barth.
- WATSON, J. B., *Psychology from the Standpoint of a Behaviorist*, Philadelphia, 1919.