Neocortical Function in Behavior

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The important role of neocortical mechanisms in cognitive behavior has been a focus of scientific interest for the past century and a half. In the early 1800's, arguments raged between physiologists (e.g., Flourens [14]) and phrenologists, many of whom were good anatomists (e.g., Gall and Spurzheim [6]), as to whether the cerebral mantle functioned as a unit or whether a mosaic of cerebral suborgans determines complex psychological events. During the intervening period data have been subsumed under one or the other of these two views—almost always with the effect of strengthening one at the expense of the other. In the recent past, the accumulation of data has so markedly accelerated that a re-evaluation of the problem promises to prove fruitful. Specifically, the data obtained by the use of electronic amplifying devices to study neural events has raised questions concerning the validity of concepts generated by neuroanatomical techniques; the adaptation to subhuman primates of measures of choice behavior has stimulated discussion of the validity of concepts derived from clinical neurological material.

PROBLEMS OF NEURAL ORGANIZATION

First, let us take a look at some *neural* data and see how they fit current conceptualizations of cerebral organization. Explicitly or implicitly, most of us tend to think of the brain as being composed of receiving areas (sensory cortex) which function in some fairly simple fashion to transmit receptor events to adjacent areas of "association" cortex. Here, these neural events are "elaborated" and "associated" with other neural events before being transmitted to the motor areas of the brain; these motor areas are said to serve as the principal effector mechanism for all cerebral activity. This model was proposed some fifty years ago by Flechsig (13) on the basis of the then available anatomical information. As we shall see, the neural data available today make it necessary to modify this model considerably.

But, before we can come to grips with a new conception of brain organization, it is necessary to clarify some definitions. Over the years, many of the terms used in neurology have been imbued with multiple designa-

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tions. "Neocortex" is such a term. Comparative anatomists use this word to describe the dorsolateral portions of the cerebral mantle since these portions show a *differentially* maximum development in microsmatic mammals (such as primates) as compared with macrosmatic mammals (such as cats). In other branches of the neurological sciences (e.g., see Morgan and Stellar [30]), the term neocortex has come to cover *all* the cortical formations which reach maximum development in primates. The definition as used in these sciences subsumes portions of the cortex on the medial and basal surface of the cerebral hemisphere, which, though well developed in macrosmatic mammals, do show *some* additional development in primates. Since this mediobasal limbic cortex has been related (38, 45) to behavior rather different from that which concerns us in this paper, it seems worth while to find an unambiguous term which delimits the dorsolateral cortex. This purpose is served by a definition in consonance with the embryological development of the histological picture of the cerebral cortex. As reviewed in a recent publication (38), the cerebral cortex may be classified according to whether or not it passes through a six-layered embryonic stage. The medial and basal limbic structures do not pass through such a stage and are called "allo-" or "juxtallocortex"; the dorsolateral portions of the cerebral cortex do pass through such a stage and are called "isocortex."

It has been fashionable to subdivide isocortex according to cytoarchitectonic differences; difficulties in classification have been pointed out (3, 24, 35) which question the immediate usefulness of distinctions based solely on the histological picture of the cortex. I should prefer, therefore, to subdivide isocortex on the basis of thalamocortical relationships since these relationships are determined by the most reliable neurohistological technique available to us: namely, retrograde degeneration of neurons in the thalamus following cortical resection. But, if we are to use this criterion of subdivision of cortex because it is a reliable one, we are forced into looking at the organization of the thalamus as the key to the organization of the cortex. Recently, Rose and Woolsey (47) have divided thalamic nuclei into two classes: (1) those receiving large tracts of extrathalamic afferents and (2) those receiving the major portions of their direct afferents from within the thalamus. The former they called extrinsic and the latter, intrinsic nuclei. Thalamocortical connections, demonstrated by retrograde degeneration studies (7, 10, 37, 54), make possible the differentiation of isocortical sectors on the basis of their connections with extrinsic or with intrinsic thalamic nuclei (Figure 56).

It can be seen from Figure 57 that the portions of the cortex labeled as "extrinsic sectors" correspond essentially to those usually referred to
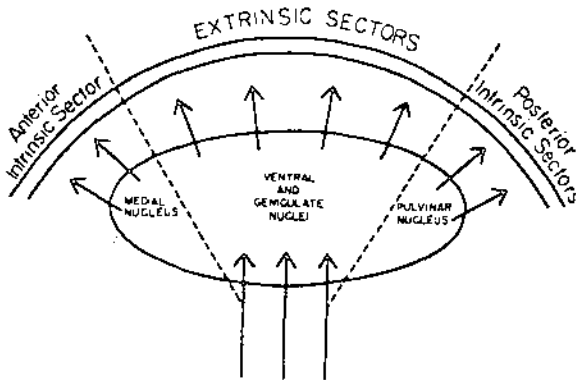
Fig. 56.—Diagrammatic scheme illustrating the division of isocortex into extrinsic and intrinsic sectors on the basis of thalamic afferent connectons. The ventral and geniculate thalamic nuclei which receives major direct afferents from extracerebral structures project to the extrinsic sectors; the medial and pulvinar thalamic nuclei do not receive such afferents and project to the intrinsic sectors.

as "primary projection areas," while those labeled "intrinsic sectors" correspond essentially to those usually referred to as "association areas." However, the terms "association cortex" and "primary projection areas" have their drawbacks: (1) "Association cortex" implies that in these portions of the cortex convergent tracts bring together excitations from the "receiving areas" of the brain. As we shall see, this implication has been unsupported by fact. (2) Electrophysiological experiments (which will be discussed below) have demonstrated a topographical complexity of organization which necessitated labels such as Areas I and II. Should the term "primary projection areas" be used to denote the Areas I only or should it cover such areas as II as well? Additional confusion arises since the intrinsic sectors *do* receive a thalamic projection, so that the term "secondary projection areas" has been suggested for these sectors (49). These considerations have led me to substitute the currently less loaded terms, "extrinsic" and "intrinsic."

Can the subdivision of cerebral isocortex into extrinsic and intrinsic sectors be validated when techniques other than retrograde thalamic degeneration are used? Figure 58 shows the extent of the cortical connections when myelinated fibers are traced by the Marchi (osmic-acid) staining technique from peripheral structures, such as optic tract and dorsal spinal roots, through the thalamus to the cortex. As can be seen by comparing Figures 57 and 58, there are, thus, at least two anatomical techniques
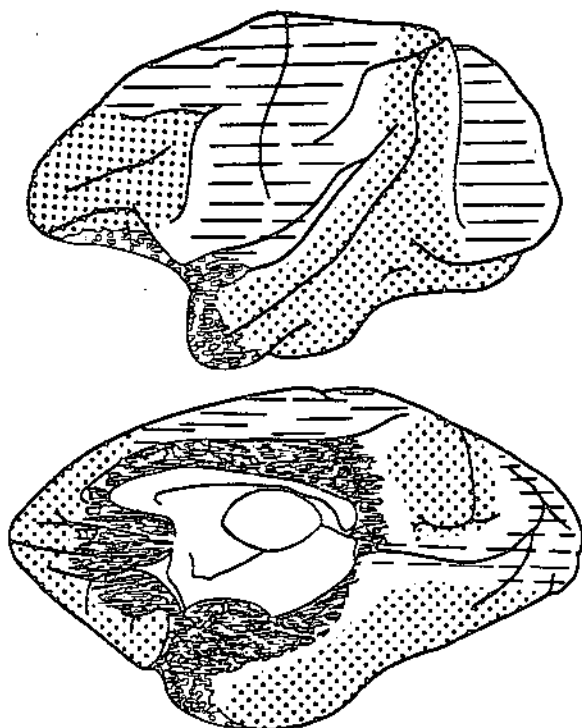
Fig. 57.—Diagrams of the lateral (above) and mediobasal (below) surfaces of the monkey's cerebral hemisphere showing the divisions discussed in the test. Shaded indicates allo-justallocortex; lined indicates extrinsic isocortex; dotted indicates intrinsic isocortex. Boundaries are not sharply delimited; this is, in part, due to minor discrepancies which result when different techniques are used and, in part, to difficulties in classification due to borderline instances and inadequate data (e.g., how should the projections of *n. ventralis anterior* and of *lateralis posterior* be classified?)

which permit approximately the same subdivision of isocortex: one derived from cell body stains; the second, from nerve fiber stains. Further support for the classification comes from electrophysiological data. When receptors are mechanically or electrically stimulated or when peripheral nerves are electrically stimulated, an abrupt change in electrical potential can be recorded from portions of the brain which are connected to these peripheral structures. Under appropriate conditions of anaesthesia, maps may be constructed on the basis of size of the potential changes evoked and the latency which intervenes between the time of stimulation and

the recording of the potential change (Fig. 59). As can be seen from the comparison of the maps made by the histological and electrophysiological techniques, there is considerable (though by no means complete) correspondence between various delineations of the extrinsic from the intrinsic sectors of the isocortex.°

Enough of definitions. I am sure you are convinced by now that the cerebral isocortex may usefully be divided according to whether its major input derives, via the thalamus, directly from the periphery or whether that input is largely intracerebral. But, have you noticed that, according to all of the techniques mentioned, input from extracerebral structures reaches the portions of the cortex usually referred to as "mo-
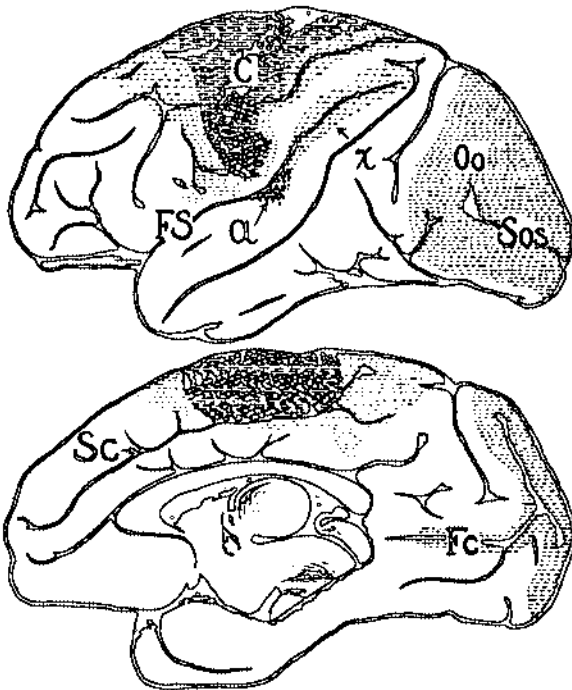

Fig. 58.—From Poliak (33). Extrinsic sectors as mapped by staining degenerating axons following thalamic lesions.

° The most glaring discrepancies between the electrophysiological maps and the anatomical maps are found along the boundaries of the various extrinsic areas. Thus, how are the projection areas of *n. ventralis anterior* and *n. lateralis posterior* (9) to be labeled? And, just where *do* the Areas II and III fit best? These problems are not solved by the proposed classification of isocortex into extrinsic and intrinsic sectors; however, clarification of nomenclature makes possible the posing of relevant questions.

tor" as well as those known as "sensory" areas? Electrophysiological experiments demonstrate that somatic afferents are distributed to both sides of the central fissure of primates. Since the *afferents* reaching the precentral "motor" areas as well as those reaching postcentral "sensory"
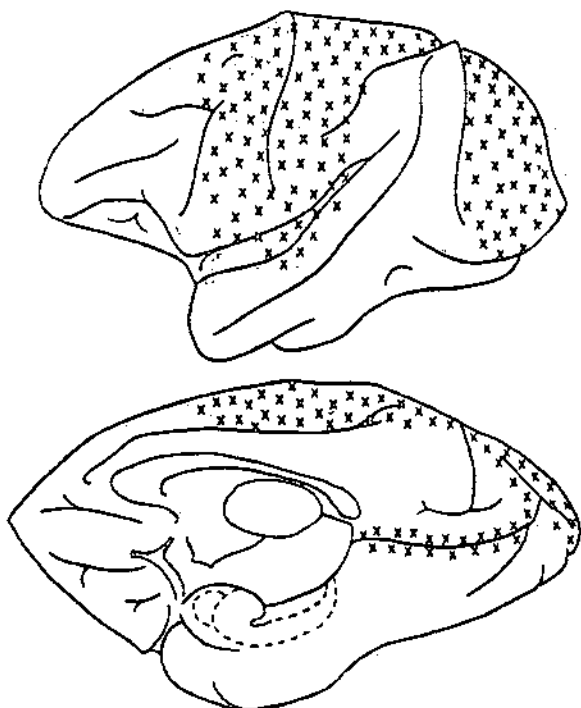

Fig. 59.—Diagrams of the monkey cerebral hemisphere as in Figures 57 and 58. This map of the abrupt electrical changes induced in cortex by peripheral stimulation was compiled from studies (20, 43, and an unpublished study) using animals sufficiently anesthetized with barbiturates to practically abolish the normally present spontaneous rhythms of potential changes recorded from the brain. Those potential changes were counted which were larger than 50 μv. and showed a latency within 3 sec. of the minimum latency of any abrupt potential change evoked in the particular afferent system investigated. These criteria were chosen as the most likely to indicate major direct afferents from periphery to cortex. The correspondences and minor discrepancies between this figure and Figure 58 indicate the approximate range of such similarities when different techniques and brain diagrams are used.

areas originate in both skin and muscle nerves, the critical differences between the input to the precentral and to the postcentral cortex must yet be determined if the differences in effect of resection of the pre- and postcentral cortex on behavior are to be explained in terms of input. What is important for us today is the fact that afferents from the periphery reach "motor" cortex relatively directly through thalamus, a fact which becomes more meaningful on consideration of the efferents leaving the isocortex.

It has been commonly held for the past 20 or 30 years that the pyramidal tract takes origin in the "motor" cortex, especially that portion close to the central fissure. A recent monograph by Lassek (25) documents thoroughly the evidence for a more extensive origin of the pyramidal tract from the entire extent of the precentral as well as from the postcentral cortex of primates: a return to an earlier held anatomical position which had become submerged during the first half of this century. Another conception held during this latter period, the distinction between pyramidal and extrapyramidal, has recently been questioned in the light of these and other data. Woolsey (57) has shown that the differences in movement brought about by electrical stimulation of the various parts of the precentral cortex may be ascribed to differences in somatotopic relationships rather than to differences in the complexity of organization of the movement. Thus, Woolsey finds that stimulations in the more forward portions of the precentral region, which had formerly been called premotor, activate the axial musculature, while those close to the central fissure activate appendicular musculature. Since axial muscles are larger, the movements they produce appear grosser than those produced by such discrete appendicular muscular units as those found in the hand—one need not invoke different orders of coördination or complexity to distinguish between the posterior and anterior portions of the motor cortex. Thus, the distinction between motor and premotor cortex fades and, as a result, makes unnecessary the classical distinction between the locus of origin of the pyramidal and extrapyramidal systems which has already been called into question by anatomical data.

On the other hand, evidence from ablation and stimulation experiments in both man and monkey indicates the continued necessity for differentiating precentral "motor" from postcentral "sensory" mechanisms (20). Certainly the distinction cannot be thought of simply in terms of afferents reaching the postcentral and efferents leaving the precentral cortex. Thus, with these data in mind, a thorough reinvestigation is needed of the organization of the input-output relationships of the extrinsic system related to somatic structures.

The marked overlap of input-output is not limited to the somatic extrinsic system. With respect to vision, eye movements can be elicited from stimulation of practically all the striate cortex (55); these eye movements can be elicited after ablation of the other cortical areas from which eye movements are obtained. With respect to audition, ear movements have been elicited from the auditory extrinsic system (4). From the portion of the cortex implicated in gustation, tongue and chewing movements may be elicited (2, 51); respiratory effects follow stimulation of the olfactory "receiving" areas (18, 38). Thus, an overlap of afferents and efferents is evident not only in the neural mechanisms related to somatic function but also in those related to the special senses. The overgeneralization to the brain of the law of (Bell and) Magendie (27), which defines sensory in terms of afferents in the dorsal-spinal and motor in terms of efferents in the ventral-spinal roots, must, therefore, give way to more precise investigation of the differences in internal organization of the afferent-efferent relationship between periphery and cortex in order to explain differences such as those between "sensory" and "motor" mechanisms. As yet, only a few experiments toward this end have been undertaken (1, 11, 46).

The afferent-efferent overlap in the *extrinsic* system suggests the possibility that the intrinsic systems need not be considered as association centers upon which pathways from the extrinsic sensory sectors converge to bring together neural events anticipatory to spewing them out via the motor pathways. Unfortunately, there are few reliable anatomical data concerning the connections of the intrinsic sectors so that our analysis of the organization of these systems relies largely on neuropsychological data. Let us turn, therefore, to experiments which manipulate cerebral isocortex either by stimulation or resection, and observe the effects of such manipulations on behavior.

PROBLEMS OF NEURAL ORGANIZATION IN COGNITIVE BEHAVIOR

For the purposes of this presentation, cognitive processes will be inferred from discriminative and problem-solving behavior since most of the recent relevant data stem from experiments in this area of investigation. The relation of the extrinsic sectors to such behavior has been extensively studied in the past, and I shall not dwell on recent contributions which elaborate usually held notions. It is worth mentioning, however, that, with the exception of the vestibular mechanisms, a different subdivision of the extrinsic sector (or an allocortical counterpart) has been related to each of the special senses (defined as those in which receptors

are aggregated in a discrete sense organ), whereas the search for a specific relationship between subdivisions of the extrinsic sectors and submodalities of sensation, such as touch versus cold or pattern versus color, has thus far proved unsuccessful. The problem of the organization of sensory function has hardly been posed in terms of current knowledge of receptor mechanisms and neural organization.

The classic prototype of the experiment relating extrinsic cortex to sensory behavior is that of Klüver (19), which shows that monkey deprived of its occipital lobes reacts visually only to total luminous flux; differential reactions to more complex visual events are absent. Regarding motor behavior, the classical prototype experiment is that of Lashley
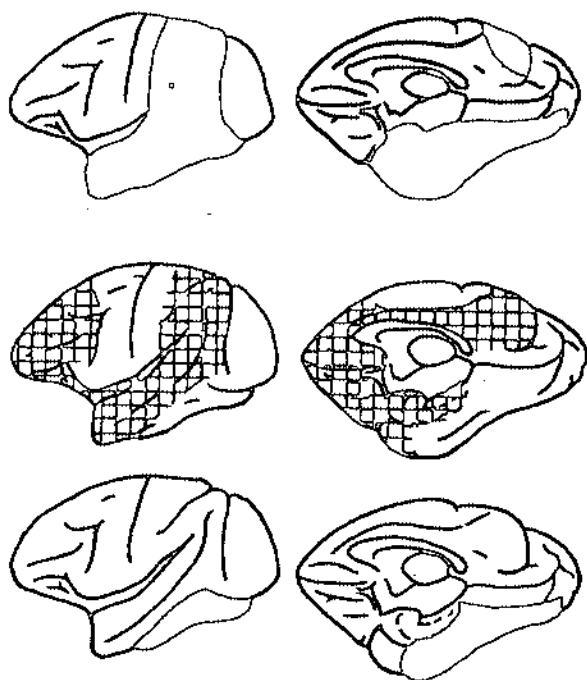

Fig. 60.—From Pribram (35). The upper diagrams represent the sum of the areas of resection of 15 subjects showing a decrement in the performance of a preoperatively learned visual discrimination task. The middle diagrams represent the sum of the areas of resection of 25 subjects showing no such decrement. The lower diagrams represent the intersect of the area shown in black in the upper and that *not* checkerboarded in the middle diagram. This intersect represents the area invariably implicated in visual choice behavior by these experiments.

(21): a monkey deprived of precentral cortex reacts only with grossly organized movements. More discretely organized patterns of movement are disturbed not in terms of the final solution of the problem presented, but rather in terms of increased time taken to complete the solution of the problem because of awkwardness. But, loss of occipital tissue does not completely destroy the organism's differential reaction to light, nor does loss of precentral tissue result in total loss of differentiated movements; rather, the impairment following invasion of the extrinsic cortical sectors may be characterized as a limit placed on the complexity of possible behavior. Interference with peripheral mechanisms imposes the greatest restriction. Interference with extrinsic cerebral mechanisms imposes a lesser, though still devastating restriction. I shall return to this point later.

With this background, let us turn to a large body of neuropsychological experiments made on monkey during the past ten years which delineate the organization of intrinsic cortex in choice behavior. There are two anatomically distinct intrinsic sectors: a posterior or parieto-temporopreoccipital, and an anterior or frontal. There are now several studies which suggest that the posterior sector may be subdivided into areas, each of which serves a separate sense modality. The following figures illustrate this point. Resections of most areas of the cerebral cortex are *not* followed by decrement in a monkey's performance of visual discrimination tasks (Fig. 60). However, when the inferotemporal area of the posterior intrinsic system is invaded, the animal is unable to make a great variety of visual choices even though it had learned to make them preoperatively. That this deficit in choice behavior is limited to the visual modality can be seen from Table 5. In the experiment illustrated here, the monkeys were taught somesthetic as well as visual choice problems. Occipitoparietal resections interfered with performance of the somesthetic problem but not with performance of the visual task; the converse finding

TABLE 5

Further behavioral analysis of the PTO cortex

	P48	P46	P49	T44	T45
Visual 10 (0–70)	0	0	0	(500)	(500)
Somatosensory 60 (0–100)	460	120	350	70	50
New Somatosensory	(1000)	(1000)	(1000)	320	260

was obtained following inferotemporal resections. In taste and olfaction, there is some evidence that the anterior temporal region (including allo-juxtallocortical structures) functions selectively (36): preliminary studies underway show promise of delineating a relationship between a portion of the posterior intrinsic sector and audition (56). Thus, portions of the *posterior intrinsic sector* have been related to discriminative behavior in one or another of the special senses or in somesthesis: Cognitive processes
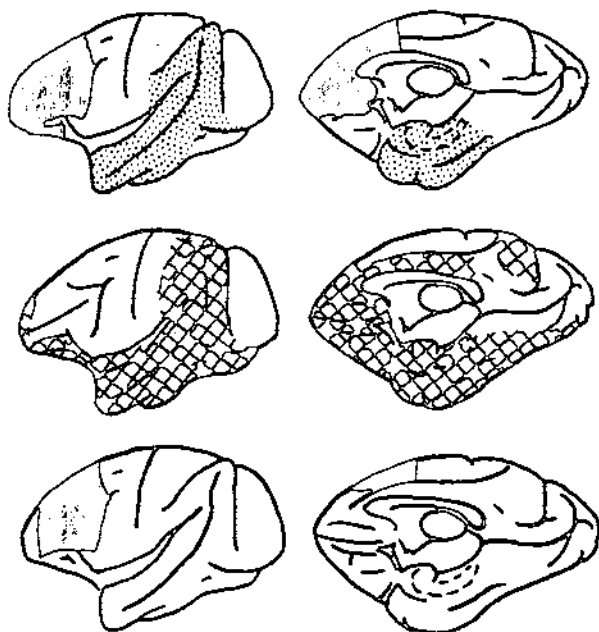

Fig. *61.*—From Pribram (35). The upper diagrams represent in black the sum of the areas of resection of 6 subjects that showed a decrement in the performance of delayed reaction preoperatively learned. The middle diagrams represent the sum of the areas of resection of 24 subjects that showed no such decrement. The lower diagrams represent the intersect of the area shown in the upper diagram and that *not* checkerboarded in the middle diagram. This intersect represents the area invariably implicated in delayed-reaction performance in these experiments. (Resection within the area stippled in the upper diagram occasionally results in "deficit"; however, a similar deficit occasionally appears in nonoperate controls. Such aberrant cases are not found when delayed alternation rather than delayed response is used. Alternation may, therefore, be considered a somewhat more reliable measure of frontal lobe deficit.)

are served, therefore, not only by modality-specific extrinsic mechanisms but by modality-specific intrinsic mechanisms as well.

No discussion of cerebral mechanisms in cognitive behavior is complete without reference to the *frontal intrinsic sector*. A series of experiments begun by Carlyle Jacobsen (16) has shown an invariant relationship between lesions of the frontal intrinsic system of monkey and decrements in performance of delayed reaction; no other resection of intrinsic isocortex has been found to alter reliably this class of behavioral events, and frontal resections fail to affect the many other types of choice behavior so far tested. Thus, since *completely separate* behavioral factors have been shown related to the posterior and to the frontal intrinsic sectors, any notion of the frontal lobes as a "higher" integrative mechanism is precluded (Fig. 61).

Further analysis has shown that the effects on choice behavior of frontal lesions extend to a variety of tasks of the delayed-reaction type; for instance, to those tasks in which monkeys are taught to alternately choose
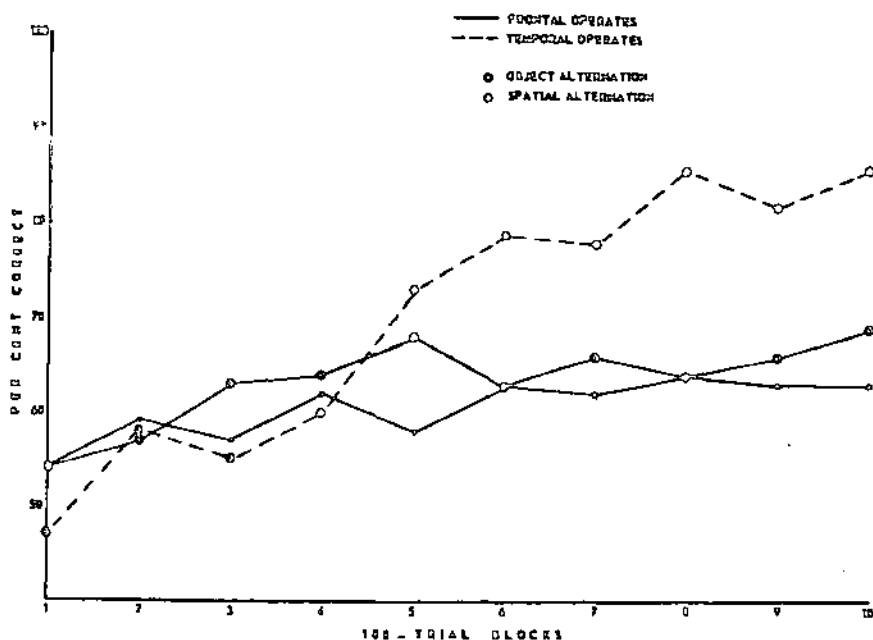

Fig. 62.—From Pribram and Mishkin (41). Performance curves of anterofrontal and control (inferotemporal) operates on spatial and object alternation. Note that anterofrontal operates are equally impaired in the performance of both tasks. On spatial alternation the control operates achieved a 90 per cent level of performance within 250 trials.
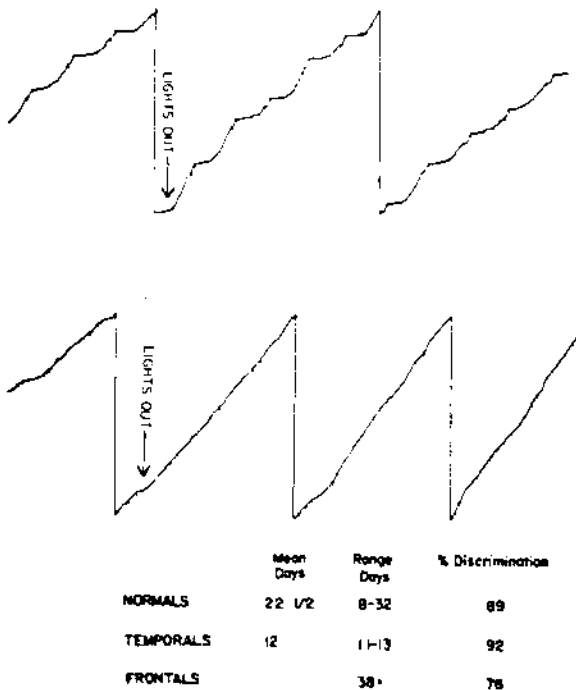
	Mean Days	Range Days	% Discrimination
NORMALS	22 1/2	8-32	89
TEMPORALS	12	1-13	92
FRONTALS		38 *	78

Fig. 63.—Examples of the rate of bar-pressing response of monkeys as cumulatively recorded. These curves were generated by an inferotemporal operate (above) and an anterofrontal operate (below) trained to respond differentially to different sequences of reward contingencies administered as a "multiple" schedule of reinforcement. This schedule consisted of a sequential alternation between two conditions, one in which 40 bar presses were rewarded by a peanut (fixed ratio) and the other in which 4 min. elapsed before reward, irrespective of the number of bar presses (fixed interval); initially, the ratio schedule was signaled by a red light, the interval schedule by a green light. During each 1½-hr. testing session the lights were turned off after 20 min. so that correct response rate was contingent solely on the animal's own prior behavior. Note the indiscriminate rate shown after "Lights Out" by the anterofrontal operate (lower curve). The numbers below the curves refer to the mean and range of the number of days taken to reach an 85 per cent criterion of discrimination between the fixed-ratio and the fixed-interval schedule in the absence of the light signal by four unoperated normal monkeys, two inferotemporal operates (Temporals), and two anterofrontal operates (Frontals). The subjects were considered to be making the discrimination whenever they took longer to make the first 40 bar presses while the interval schedule was in force. Note that the inferotemporal operates reached criterion in fewer days than most normals, which suggests that these operates relied more than did normals on nonvisual cues even when the signal was present. Note also that the anterofrontal operates failed to reach criterion.

one of two cups, spatial alternation (17, 42). Figure 62 describes the re-sults of an experiment in which the monkey must choose alternately one of two randomly placed objects (nonspatial, visual object alternation); resection of the frontal intrinsic system impairs performance when spa-tial cues are replaced by purely visual cues. Figure 63 graphs the results of another "alternation" experiment. In this, the alternation of two pat-terns of response rate is contingent on two schedules of reinforcement; the animal with a frontal resection is shown deficient when the alterna-tion is made dependent on its own prior behavior rather than on envir-onmental cues. Taken together, these experiments suggest that resections of the frontal intrinsic system impair performance *whenever* a correct choice depends exclusively on transient events not present at the time the. choice is made—irrespective of "modality."

As can be seen from these data, the basis for stating that different cortical areas serve different functions applies equally to the intrinsic and the extrinsic sectors; that is, manipulations of certain portions affect cer-tain classes of behavior while manipulations of other portions affect other classes. Such findings have given rise to "mosaic" conceptualizations of brain function in behavior. We must admit that these data are striking.
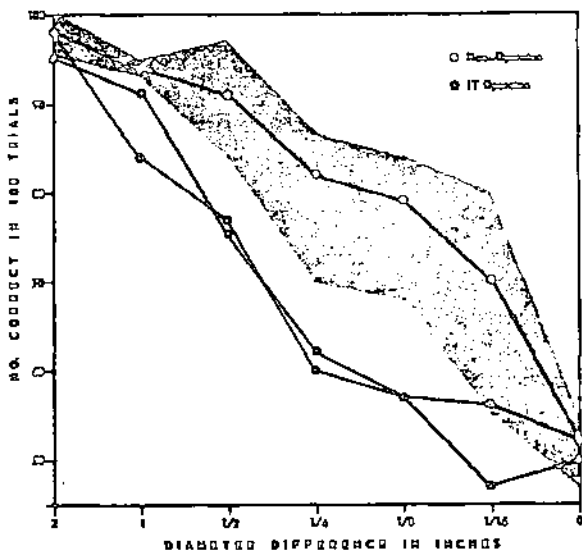

Fig. 64.—From Mishkin and Hall (28). Scores for two op-erates and four controls on the first run of size discrimina-tion. Shaded area indicates the range of performance of the four nonoperate controls.

It is easy to see, therefore, how the "localizationist" is impressed and how he may be satisfied with the conception that the cerebral isocortex (both intrinsic and extrinsic) can be subdivided further into units, each of which may serve a different function.

But this is not the whole story. A comparison of the effects of resection of the extrinsic and of the intrinsic systems involved in vision poses difficulties for the "mosaic" notion. As we have seen, the inferotemporal area of the posterior intrinsic system and only this portion of the intrinsic system is critically implicated in visual discrimination performance. Since similar and more drastic effects on visual choice behavior follow extensive lesions of the primate occipital lobe, how can we characterize the difference in function between the intrinsic and extrinsic "visual" systems? Two separate classes of visual behavior can be sought: one related to the extrinsic and the other, to the intrinsic system. However, no such separable relationships have been found to exist. Instead, any effect of resection of the intrinsic system may be duplicated by extensive resection of

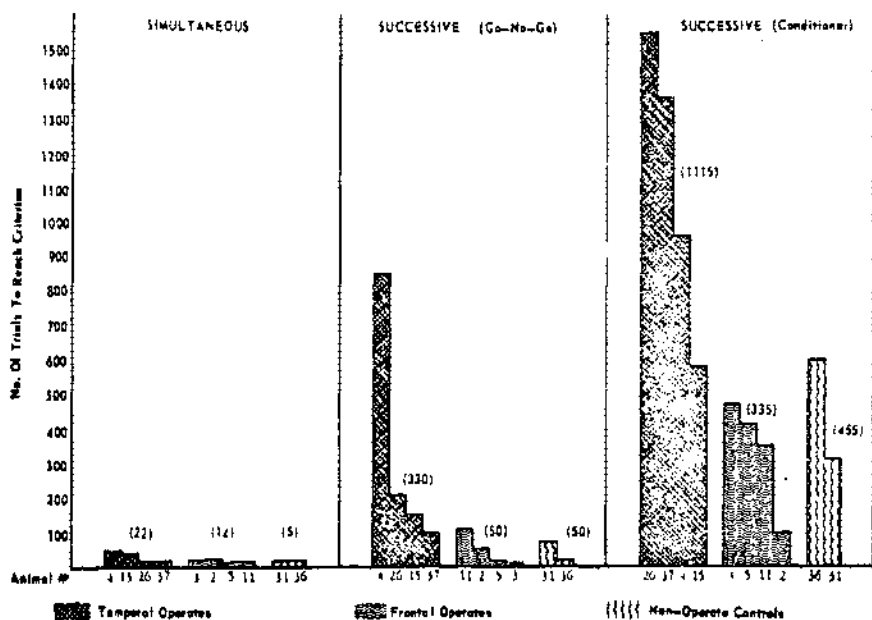*Fig. 65.*—From Pribram and Mishkin (40). Comparison of learning scores of three groups of animals (inferotemporal operates, anterofrontal operates, and nonoperate controls) in a simultaneous task and two types of successive tasks in which the *same* cues were used. The increment of impairment of the inferotemporal group, as compared with controls, appears roughly proportional to the increasing difficulty of the task for controls.

the extrinsic systems. Furthermore, the latter produces additional effects (e.g., field defects). Thus, the difference between the effects of resection of the intrinsic and of the extrinsic systems on vision is analogous to that which obtains between the effects of resection of the extrinsic system and of the sense organ: Resection of the intrinsic visual system limits the complexity of the organism's possible visual behavior but not so much as resection of the extrinsic visual system or that of the receptor. So far, independent measures of "complexity" are poor. One such measure has been the relative difficulty which normal animals have in learning visual problems. An analysis of "difficulty" has shown that the variables which must be taken into account include the physical parameters of the cue (Fig. 64), the situation in which cues are imbedded (Fig. 65), and the experience which the animal has had with this or with similar cues (44).

The fact that monkeys with inferotemporal resections show an impairment in visual behavior which is not as extreme as that found after total occipital lesions nor as severe as that which results when the sense organ itself is removed demonstrates that a hierarchical organization of neural systems exists in vision. Thus, functionally separable parts of the isocortex do not *necessarily* serve *different* functions. Do these findings presage the possibility of finding other hierarchical organizations of cerebral events when other categories of behavior are studied?

DISCUSSION: AN ALTERNATIVE TO THE TRANSCORTICAL REFLEX

Models of cerebral organization in cognitive processes have, heretofore, been based to a large extent on clinical neurological data and have been formulated with the "reflex" as prototype. Such models state that input is organized in the extrinsic "sensory," elaborated in the intrinsic "associative," and from there relayed to the extrinsic "motor" sectors. I have already pointed out that the afferent-efferent overlap in the extrinsic system makes such notions of cerebral organization suspect. A series of neuropsychological studies by Lashley (23), Sperry (49, 50), Chow (8), Evarts (12), and Wade (53), in which the extrinsic sectors were surgically crosshatched, circumsected, or isolated by large resections of their surround with little apparent effects on behavior, has cast further doubt on the usefulness of such a "transcortical" model. Additional difficulties are posed by the negative electrophysiological and anatomical findings whenever direct connections are sought between the extrinsic and intrinsic sectors (5, 39). These data focus anew our attention on the problem faced repeatedly by those interested in cerebral functions in cognitive behavior. Experimentalists who followed Flourens in dealing with the hierarchical

aspects of cerebral organization—e.g., Munk (31), Monakov (29), Goldstein (15), Loeb (26), and Lashley (22)—have invariably come to emphasize the importance of the *extrinsic* sectors not only in "sensorimotor" behavior but also in the more complex "cognitive" processes. Each investigator has had a slightly different approach to the functions of the *intrinsic* sectors, but the viewpoints share the proposition that the intrinsic sectors do not function independently of the extrinsic. The common difficulty has been the conceptualization of this interdependence between intrinsic and extrinsic systems in terms other than the transcortical "reflex" model—a model which became less cogent with each new experiment.

Is there an alternative which meets the objections levied against the transcortical "reflex" yet accounts for currently available data? I believe there is. The hierarchical relationship between intrinsic and extrinsic systems can be attributed to convergence of the *output* of the two systems at a subcortical locus rather than to a specific input from the extrinsic cortex to the intrinsic. Some evidence supporting this notion is already available. Data obtained by Whitlock and Nauta (57) using silver staining techniques, show that *both* the intrinsic and the extrinsic sectors implicated in vision by neuropsychological experiments are *efferently* connected with the superior colliculus. On the other hand, lesions of the intrinsic thalamic nuclei fail to interfere with discriminative behavior (9, 32). Thus, the specific effects in behavior of the intrinsic systems are explained on the basis of *output* to a subcortically located neural mechanism which functions specifically (e.g., superior colliculus in vision). This output, in turn, affects input to the extrinsic systems either directly or through the efferent control of the receptor (e.g., in vision, mechanisms of eye movement, accommodation). According to this conception, the "associative" functions of the central nervous system are to be sought at convergence points throughout the central nervous system, especially in the brain stem and spinal axis, and not solely in the intrinsic cerebral sectors.

What are the differences in the experimental approach suggested by these formulations? Let us return to the discussion of the relationship between frontal cortex and delayed reaction. According to the *old* model of the role of "association" cortex in behavior, we could conceive of the deficit in delayed-reaction–type behavior as a deficit in intersensory interaction, a possibility recently suggested by Teuber and Mishkin (52). Search for other intermodality "interactions" would follow. On the other hand, by taking into account the finding that the relationship between frontal and posterior intrinsic sectors to separate classes of behavior is distinct rather than hierarchical, a search would be instituted for a class or classes of variables distinct from those which have been found related

to the posterior (modality-specific) intrinsic systems: e.g., for a class "transient events not cotemporaneous with the response which they determine" such as predelay cue and reinforcement variables. Also, on the basis of analogy with the posterior intrinsic systems, we would predict the discovery of some "extrinsic" neural mechanism related to the anterior intrinsic sector. One possibility is that the limbic allo-juxtallocortical structures function in this manner. Experiments designed to discover a hierarchical relationship between the limbic and the anterior intrinsic cortex by neuropsychological experiment have been only partially successful. These experiments have shown that performance of tasks of the delayed-reaction type is *not* affected by limbic lesions (35); on the other hand, conditioned avoidance is affected by both frontal and limbic system ablations (45). Other forebrain structures, such as the neostriatum, must also be considered as possible "extrinsic" mates to the anterior intrinsic system since Rosvold and Delgado (48) were able to interfere with monkeys' performance of spatial alternation by stimulating with electrodes implanted in the caudate nucleus.

These, then, are some examples of the direction which the alternative to the transcortical reflex conception of the neural mechanisms serving cognitive processes can give experimenters. Apparently, the question as to whether a complex cognitive event is determined by the cerebral mantle as a unit or by a mosaic of cerebral suborgans continues to generate interest even when some old controversial issues are replaced by new ones.

SUMMARY

Conceptions concerning neocortical mechanisms in cognitive behavior have been re-evaluated in terms of recently accumulated data. Since the designation "neocortex" has become ambiguous, "isocortex" is substituted; relations to cognitive processes are inferred from discriminative and problem-solving behavior.

Isocortex has been classified according to the input it receives from the thalamus. When a sector of isocortex receives fibers from a thalamic "relay" nucleus which, in turn, receives its major afferents from outside the thalamus, the sector is called extrinsic. When a sector of isocortex receives fibers from a thalamic nucleus which receives no such extra-thalamic afferents, that cortex is classified as intrinsic.

Neurally distinct portions of the *extrinsic* isocortex are known to serve distinct classes of behavior. The distinctions are in part related to differences in input from different peripheral receptor mechanisms (e.g., sense organs). Other distinctions such as between "motor" and "sensory"

cortex *cannot* be attributed to such gross anatomical differences (e.g., that only afferents reach "sensory" and efferents leave "motor" cortex). Rather, differences in detail of the organization of the overlapping input to and output from *each* of the extrinsic sectors must be investigated.

Intrinsic isocortex can also be divided according to demonstrated relationships to one or another class of behavior. Discriminative behavior in specific modalities is affected when particular subdivisions of the posterior intrinsic cortex are removed. When the anterior intrinsic cortex is ablated, those discriminations are affected which are based primarily on transient events which are not cotemporaneous with the choice, irrespective of modality.

In several instances intrinsic and extrinsic systems are related to the *same* class of behavior. In these instances, the organism is limited in the possible complexity of cognitive behavior when the intrinsic cortex is resected—a limitation which is, however, not as severe as that resulting from extensive damage to the extrinsic system nor as that resulting from gross interference with receptor mechanisms. The hierarchical relationship described by these data has, heretofore, been attributed to specific afferents originating in subdivisions of extrinsic, and connecting to subdivisions of intrinsic, isocortex. Experiments have been quoted which make it unlikely that such *specific afferents* exist. Instead, the specificity of function of subdivisions of the intrinsic isocortex is, in this analysis, attributed to *convergence* on a common subcortical mechanism of *efferents* from hierarchically related intrinsic and extrinsic systems. The output from the intrinsic systems is, in this manner, conceived to influence the output from (and perhaps, via regulation of the peripheral sensory mechanism, the input to) the extrinsic systems. Thus, the primacy of the function of the extrinsic systems *and* the essential role of the intrinsic systems in cognitive behavior are accounted for without invoking the classical transcortical reflex to support a completely "mosaic" notion of cerebral function and without resorting to a non-localizationistic view of the intrinsic systems.

REFERENCES

1 Amassian, V. E. Interaction in the somatovisceral projection system. *Res. Publ. Ass. nerv. ment. Dis.*, 1952, *30:* 371–402.

2 Bagshaw, M., and K. H. Pribram. Cortical organization in gustation (*Macaca mulatta*). *J. Neurophysiol.*, 1953, *16:* 499–508.

3 Bailey, P., and G. Von Bonin. *The isocortex of man.* Urbana, Ill.: Univer. Illinois Press, 1951.

4 Bechterew, W. Von. *Die Funktionen der Nervencentra.* Vol. 3. Pp. 1859–64. Jena: Gustav Fischer, 1908–11. 3 Vols.

5   Bonin, G. V., H. W. Garol, and W. S. McCulloch. The functional organization of the occipital lobe. *Biol. Symp.*, 7.

6   Boring, E. G. *A history of experimental psychology.* (2nd ed.) New York: Appleton-Century-Crofts, 1950.

7   Chow, K. L. A retrograde cell degeneration study of the cortical projection field of the pulvinar in the monkey. *J. comp. Neurol.*, 1950, *93:* 313–40.

8   ———. Further studies on selective ablation of associative cortex in relation to visually mediated behavior. *J. comp. physiol. Psychol.*, 1952, *45:* 109–18.

9   ———. Lack of behavioral effects following destruction of some thalamic association nuclei in monkey. *Arch. Neurol. Psychiat.*, Chicago, 1954, *71:* 762–71.

10 Chow, K. L., and K. H. Pribram. Cortical projection of the thalamic ventrolateral nuclear group in monkey. *J. comp. Neurol.*, 1956, *104:* 57–75.

11 Dell, P. Corrélations entre le système végétatif et le système de la vie de relation: Mesencèphale diencéphale et cortex cérébral. *J. Physiol. Path. Gen.*, 1952, *44:* 471–557.

12 Evarts, E. V. Effect of ablation of prestriate cortex on auditory-visual association in monkey. *J. Neurophysiol.*, 1952, *15:* 191–200.

13 Flechsig, P. *Die Localisation der geistigen Vorgänge insbesondere der Sinnesempfindungen der Menschen.* Leipsig, 1896.

14 Flourens, P. *Recherches expérimentales sur les propriétés et les fonctions du système nerveux dans les animaux vertébrés.* Paris: Crevot, 1924, *26:* 332.

15 Goldstein, K. Die Topik der Grosshirnrinde in ihrer klinischen Bedeutung. *Dtsch. Z. Nervenheilk.*, 1923, *77:* 7–124.

16 Jacobsen, C. F. Studies of cerebral functions in primates: I. The functions of the frontal association areas in monkeys. *Comp. Psychol. Monogr.*, 1936, *13:* No. 3 (Whole No. 63), pp. 3–60.

17 Jacobsen, C. F., and H. W. Nissen. Studies of cerebral functions in primates. IV. The effects of frontal lobe lesions on the delayed alternation habit in monkeys. *J. comp. Psychol.*, 1937, *23:* 101–12.

18 Kaada, B. R., K. H. Pribram, and J. A. Epstein. Respiratory and vascular responses to monkeys from temporal pole, insula, orbital surface and cingulate gyrus: A preliminary report. *J. Neurophysiol.*, 1949, *12:* 347–56.

19 Klüver, H. Visual functions after removal of the occipital lobes. *J. Psychol.*, 1941, *11:* 23–45.

20 Kruger, L. Observations on the organization of the sensorimotor cerebral cortex. Unpublished doctor's dissertation, Yale Univer., 1954.

21 Lashley, K. S. Studies of cerebral function in learning: V. The retention of motor habits after destruction of the so-called motor areas in primates. *Arch. Neurol. Psychiat.*, Chicago, 1924, *12:* 249–76.

22 ———. *Brain mechanisms and intelligence.* Chicago: Univer. Chicago Press, 1929.

23 ———. The mechanism of vision: XVIII: Effects of destroying the visual "associative areas" of the monkey. *Genet. Psychol. Monogr.*, 1948, *37:* 107–66.

24 Lashley, K. S., and G. Clark. The cytoarchitecture of the cerebral cortex of

Ateles: A critical examination of architectonic studies. *J. comp. Neurol.*, 1946, *85:* 223–305.

25 Lassek, A. M. *The pyramidal tract. Its status in medicine.* Springfield, Ill.: Charles C Thomas, 1954.

26 Loeb, J. *Comparative physiology of the brain and comparative psychology.* London: J. Murray, 1901.

27 Magendie, F. Expériences sur les fonctions des racines des nerfs rachidiens. *J. Physiol. exp.*, 1822, *2:* 276–79.

28 Mishkin, M., and M. Hall. Discrimination along a size continuum following ablation of the inferior temporal convexity in monkeys. *J. comp. physiol. Psychol.*, 1955, *48:* 97–101.

29 Monakov, C. von. *Die Lokalisation im Grosshirn und der Abbau der Funktion durch Korticale Herde.* Wiesbaden: J. F. Bergmann, 1914.

30 Morgan, C. T., and E. Stellar. *Physiological psychology.* (2nd ed.), New York: McGraw-Hill, 1950.

31 Munk, H. *Uber die Funktionen der Grosshirnrinde: gesammelte Mitteilungen aus den Jahren.* Berlin: Hirschwald, 1881.

32 Peters, R. H., and H. E. Rosvold. The effect of thalamic lesions upon spatial delayed alternation performance in the rhesus monkey. Unpublished M. D. thesis, Yale Univer., 1955.

33 Poliak, S. *Main afferent fiber systems of the cerebral cortex in primates.* Berkeley, Calif.: Univer. California Press, 1932.

34 Pribram, H. and J. Barry. Further behavioral analysis of the parieto-temporo-preoccipital cortex. *J. Neurophysiol.*, 1956, *19:* 99–106.

35 Pribram, K. H. Toward a science of neuropsychology (method and data). In R. A. Patton (Ed.), *Current trends in psychology.* Pittsburgh: Univer. Pittsburgh Press, 1955, pp. 115–42.

36 Pribram, K. H., and M. Bagshaw. Further analysis of the temporal lobe syndrome utilizing fronto-temporal ablations. *J. comp. Neurol.*, 1953, *99:* 347–75.

37 Pribram, K. H., K. L. Chow, and J. Semmes. Limit and organization of the cortical projection from the medial thalamic nucleus in monkey. *J. comp. Neurol.*, 1953, *98:* 433–48.

38 Pribram, K. H., and L. Kruger. Functions of the "olfactory brain." *Ann. N. Y. Acad. Sci.*, 1954, *58:* 109–38.

39 Pribram, K. H., and P. D. MacLean. Neuronographic analysis of medial and basal cerebral cortex: II. Monkey. *J. Neurophysiol.*, 1953, *16:* 324–40.

40 Pribram, K. H., and M. Mishkin. Simultaneous and successive visual discrimination by monkeys with inferotemporal lesions. *J. comp. physiol. Psychol.*, 1955, *48:* 198–202.

41 ———. Analysis of the effects of frontal lesions in monkey: III. Object alternation. *J. comp. physiol. Psychol.*, 1956, *49:* 41–45.

42 Pribram, K. H., M. Mishkin, H. E. Rosvold, and S. J. Kaplan. Effects on delayed-response performance of lesions of dorsolateral and ventromedial frontal cortex of baboons. *J. comp. physiol. Psychol.*, 1952, *45:* 565–75.

43   Pribram, K. H., B. S. Rosner, and W. A. Rosenblith. Electrical responses to
     acoustic clicks in monkey: Extent of neocortex activated. *J. Neurophysiol.*,
     1954, *17*: 336–44.
44   Pribram, K. H., and M. Varley. Further analysis of the effect of variations
     of delayed reaction on the performance of monkeys with frontal lesions.
     See Pribram, K. H. The intrinsic systems of the forebrain: an alternative to
     the concept of cortical association areas, Fig. 14 in *Handbook of Physiology.*
     New York: McGraw-Hill, in press.
45   Pribram, K. H., and L. Weiskrantz. Comparison of the effects of medial and
     lateral cerebral resections on conditioned avoidance behavior of monkeys.
     J. comp. physiol. Psychol., 1957, *50*: 74–80.
46   Rose, J. E., and V. B. Mountcastle. Activity of single neurons in the tactile
     thalamic region of the cat in response to a transient peripheral stimulus.
     Johns Hopk. Hosp. Bull., 1954, *94*: 238–82.
47   Rose, J. E., and C. N. Woolsey. Organization of the mammalian thalamus
     and its relationships to the cerebral cortex. *Electroencyph. clin. Neuro-
     physiol.*, 1949, *1*: 391–404.
48   Rosvold, H. E., and J. M. R. Delgado. The effect on the behavior of mon-
     keys of electrically stimulating or destroying small areas within the frontal
     lobes. *Amer. Psychologist*, 1953, *8*: 425–26.
49   Sperry, R. W. Cerebral regulation of motor coordination in monkeys fol-
     lowing multiple transection of sensorimotor cortex. *J. Neurophysiol.*, 1947,
     10: 275–94.
50   Sperry, R. W., N. Miner, and R. E. Meyers. Visual pattern perception fol-
     lowing subpial slicing and tantalum wire implantations in the visual cortex.
     J. Comp. physiol. Psychol., 1955, *48*: 50–58.
51   Sugar, O., J. G. Chusid, and J. D. French. A second motor cortex in the
     monkey (Macaca mulatta). *J. Neuropath.*, 1948, *7*: 182–89.
52   Teuber, H. L., and M. Mishkin. Judgment of visual and postural vertical
     after brain injury. *J. Psychol.*, 1954, *38*: 161–75.
53   Wade, M. Behavioral effects of prefrontal lobectomy, lobotomy and circum-
     section in the monkey (Macaca mulatta). *J. comp. Neurol.*, 1952, *96*: 179–
     207.
54   Walker, A. E. *The primate thalamus.* Chicago: Univer. Chicago Press, 1938.
55   Walker, A. E., and T. A. Weaver, Jr. Ocular movements from the occipital
     lobe in the monkey. *J. Neurophysiol.*, 1940, *3*: 353–57.
56   Weiskrantz, L., and M. Mishkin. Effect of various cortical lesions on audi-
     tory discrimination in the rhesus monkey. In preparation.
57   Whitlock, D. G., and W. J. H. Nauta. Subcortical projections from the tem-
     poral neocortex in Macaca Mulatta. *J. comp. Neurol.*, 1956, *106*: 185–212.
58   Woolsey, C. N., P. H. Settlage, D. R. Meyer, W. Spencer, T. Hamuy, and
     A. M. Travis. Patterns of localization in precentral and "supplementary"
     motor areas and their relation to the concept of a premotor area. *Res. Publ.
     Ass. nerv. ment. Dis.*, 1952, *30*: 238–64.