In the simplest case of learning by "trial and error," the learner tries successive responses to a given situation until he finds the correct one. Even in this simple type of learning there are at least two different components which contribute to the efficiency of the learning process: the degree to which the search is conducted systematically—for instance, not making the same wrong response twice—and the degree to which the correct response is fixed, so that no further mistakes will follow. If, in a later, different problem, a different response is correct, there is a third component—namely, the efficiency of unlearning or re-learning.

The present study shows how ablations of different portions of the forebrain in monkeys affect the different components of trial and error learning, and the implications of these findings are discussed for the character of the neurological bases of the "active uncertainty" called thought.

ON THE NEUROLOGY OF THINKING

by Karl Pribram

Stanford University

"The man in the street, when asked what he thinks about a certain matter, often replies that he does not think at all; he knows. The suggestion is that thinking is a case of active uncertainty set over against conviction or unquestioning assurance."

—John Dewey in "The Natural History of Thinking"

INTRODUCTION

A discussion of the "Neurology of Thinking" appears, at first glance, to engender insurmountable difficulties. However, on closer examination, the task seems less formidable and unapproachable, and holds a particularly fascinating challenge. Following Dewey's suggestion that thinking is "active uncertainty set over against conviction or unquestioning assurance," the problem of the neurology of thinking can be approached by way of behavioristic psychology. "Active uncertainty" is manifest during "problem solving behavior." Admittedly "problem solving behavior" and "thought" are not synonymous, nor even at the same level of discourse; however an analysis of the neural mechanisms serving problem solving behavior permits an initial and time honored approach to an increased understanding of the thought process.

Superficially such a discussion is more manageable than a discussion of the neurology of thinking. As we shall see, however, from the neurobehavioral experiment to be described, what constitutes a "problem" and its "solution" for the behaving organism turns out to be as complexly determined as the thought process itself.

The argument may conveniently be initiated by Sherrington's analysis of the relatively simple neurobehavioral relations designated by him as "reflex." In the *Integrative Action of the Nervous System* (1906), several of the chapters are devoted to the interaction between reflexes. Sherrington's analysis begins: "A reflex detached from the general nervous condition is hardly realizable. The compounding together of reflexes is therefore a main problem in nervous co-ordination. . . . If we regard the nervous system of any higher organism from the broad point of view, a salient feature in its scheme of construction is the following."

"At the termination of every reflex-arc we find a final neurone, the ultimate conductive link to an effector organ (muscle or gland). This last link in the chain, e.g., the motor neurone, differs obviously in one important respect from the first link of the chain. It does not subserve exclusively impulses

generated at one single receptive source, but receives impulses from many receptive sources situate in many and various regions of the body. It is the sole path which all impulses, no matter whence they come, must travel if they are to act on the muscle-fibers to which it leads. . . . The singleness of action from moment to moment thus assured is a keystone in the construction of the individual whose unity it is the specific office of the nervous system to perfect.

"Certain consequences result from this arrangement. One of these seems the preclusion of essential qualitative difference between nerve-impulses arising in different afferent nerves. . . . A second consequence is that each receptor being dependent for final communication with its effector organ upon a path not exclusively its own but common to it with certain other receptors, such nexus necessitates successive and not simultaneous use of the common path by various receptors using it to *different or opposed* effect. When two receptors are stimulated simultaneously, each of the receptors tending to evoke reflex action that for its end-effect employs the same final common path but employs it in a different way from the other, one reflex appears without the other. The result is *this* reflex or *that* reflex, but not the two together. . . . These reflexes may in regard to one another be termed *antagonistic*."

But this is not the only possible manner of interaction between reflexes. "We note an orderly sequence of actions in the movement of animals, even in cases where every observer admits that the co-ordination is merely reflex. We see one act succeed another without confusion. Yet, tracing this sequence to its external causes, we recognize that the usual thing in nature is not for one exciting stimulus to begin immediately after another ceases, but for an array of environmental agents acting concurrently on the animal at any moment to exhibit correlative change in regard to it, so that one or another group of them becomes—generally by increase in intensity—temporarily prepotent. Thus there dominates now this group, now that group in turn. It may happen that one stimulus ceases coincidently as another begins, but as a rule one stimulus *overlaps* another in regard to time. *Thus each reflex*

breaks in upon a condition of relative equilibrium, which latter is itself reflex. In the simultaneous correlation of reflexes some reflexes combine harmoniously, being reactions that mutually reinforce. These may be termed *allied reflexes*, and the neural arcs which they employ *allied arcs*."

The differences between the co-ordination of antagonistic and allied reflexes are summed up in the following statement: "Unlike reflexes have successive but not simultaneous use of the common path; like reflexes mutually reinforce each other on their common path. Expressed teleologically, the common path, although economically subservient for many and various purposes, is adapted to serve but one purpose at a time."

The role of antagonism between reflexes is perhaps most clearly stated in Sherrington's discussion of some of the conditions "influencing the issue of competition in the determination of successive combinations of reflexes; factors such as 'fatigue,' 'intensity,' 'successive spinal induction'." "The organism, to be successful in a million-sided environment, must in its reactions be many-sided. Were it not for such so-called fatigue, an organism might, in regard to its receptivity, develop an eye, or an ear, or a mouth, or a hand or leg, but it would hardly develop the marvelous congeries of all those various sense-organs which it is actually found to possess. . . . *As a tap to a kaleidoscope, so a new stimulus that strikes the receptive surface causes in the central organ a shift of functional pattern at various synapses.*"

By contrast, combinations of allied reflexes "*reinforce* one another in their action on the final common paths they possess in common. . . . This reinforcement is significant of the solidarity of the whole spinal mechanism. . . . But the same principle extends to the reactions of the great arcs arising in the projicient receptor organs of the head. . . . *Thus at any single phase of the creature's reaction a simultaneous combination of reflexes is in existence.* In this combination the positive element . . . exhibits a harmonious discharge directed by the dominant reflex-arc reinforced by a number of arcs in alliance with it."

Conceptualizations of the neurobehavioral

relations represented by combinations of antagonistic and of allied reflexes have been repeatedly but variously restated over the past half century. Rarely, however, has the scope of data that was analyzed allowed the comparison of the two types of relationships. Most of the conceptualizations have been models phrased in neural, electrical and chemical terms: Sherrington's inhibitory and excitatory states, successive and simultaneous spinal induction are examples; others are direct current fields, interference patterns, phase sequences, reverberatory and negative feedback circuits. These models have the virtue that a direct empirical test of the inferred mechanisms should ultimately prove possible; unfortunately, the techniques and data are not often at hand to permit the precision in model construction which comes from such empirical testing. Precise models of psychological processes are available, however; these have not as yet been applied to neurobehavioral analyses. In such models castings of dice are used as paradigm rather than taps to a kaleidoscope; moves in a chess game rather than homeostats, which were Cannon's (1941) and Wiener's (1949) development of the conception of "reflexes breaking in upon conditions of equilibrium, themselves reflex." But the basic conceptions have not changed. Thus stochastic, statistical methods are invoked when behavior involves "the marvellous congeries of all those various sense-organs" by means of which organisms display their "many-sided reactions" in a "million-sided environment." And, combinatorial, equilibratory mathematics serves when "any single phase of the creature's reaction ... although economically subservient for many and various purposes" is "harmoniously" adapted to "the positive element ... reinforced" by a number of elements "in alliance" with it. For convenience, the two types of processes will hereafter be referred to as "differentiative" and "intentional"; differentiative when the many sided reactions of the organism are functionally related to the million-sided aspect of the environment; intentional when harmonious reactions result from adaptations to a number of mutually reinforcing positive elements.

Considerable progress has been made in the specification of neural mechanisms that determine differentiations and intentions. Only a few examples warrant mention here and these only briefly. The rapidity with which receptors adapt (one determinant of Sherrington's "so-called fatigue") has been related to the ability to differentiate between positions of tactile and visual stimuli. Large afferent and efferent tracts in the central nervous system (the "primary projection" or "extrinsic" systems) maintain receptor modality, specific topological correspondence between receptor-effector tissues, and the cerebral mantle—disruptions of these tracts, of the nuclear discontinuities intercalated in their course, or of their cortical station, drastically interferes with such differentiative processes as motor skill, differentiation between visual, auditory, gustatory or somesthetic stimuli. Other neural mechanisms are so constituted that a collation of signals from receptor surfaces results from convergence upon diffusely and replicatively interconnected neuronal pools—excitation or destruction of these mechanisms alters the intentional processes that determine sequences of action, e.g., feeding, fighting, maternal behavior and certain types of performance such as alternation.

Neurobehavioral analysis has shown that those neural mechanisms which subserve differentiation are related to one aspect of the problem solving process; that those mechanisms which subserve intention are related to another aspect. The portions of the problem solving process that are related to neural mechanisms of differentiation will, for convenience, be referred to as "delineations of problems"; those portions that are related to neural mechanisms of intention, "economic solutions of problems." "Economic" distinguishes this type of solution from haphazard "vicarious trial and error" solutions. Perhaps the most readily comprehensible introduction to this neurobehavioral analysis of the problem solving process will come from the description of an experiment undertaken to clarify some of the issues raised in earlier drafts of this attempt.[1]

---

[1] Whatever the merit of this manuscript, much is due George Miller who led me by the hand through the formidably formal gardens of mathematics and who instigated not only the experiment

DELINEATIONS OF PROBLEMS

On the basis of comparative neuroanatomical and electrophysiological data the forebrain can be divided into two major portions: a dorsolateroposterior and an anteromediobasal. In primates each of these major portions contains intrinsic sectors: posterior intrinsic sectors (the classical sensory association areas, [Pribram, 1954; Pribram, 1958b]), and a frontal intrinsic sector (the classical frontal association area, [Pribram, 1958a]). Neurobehavioral experiments performed during the past twenty-five years have shown these intrinsic sectors to be especially related to problem solving processes (Harlow, 1953; Pribram, 1954). The aim of this, and of the following section, is to specify in detail this relationship.

An experiment.

Procedure. A modified Wisconsin General Testing Apparatus (Harlow, 1942) is used to test twelve rhesus monkeys on a complex problem. The monkeys are divided into three groups, two operated and one control, each containing four animals. The animals in one operated group had received bilateral cortical resections in the posterior intrinsic cortex and those in the other operated group, bilateral cortical resections in the frontal intrinsic cortex some two and a half years prior to the onset of the experiment (Fig. 1); those in the control group are unoperated. In the testing situation these animals are initially confronted with two junk objects placed over two holes (on a board containing twelve holes in all) with a peanut under one of the objects. An opaque screen is lowered between the monkey and the objects as soon

but also many of the ideas reported; Jerome Bruner who initially posed the problem of the neurology of thinking to me and who gave encouragement through the difficulties of solution; Eugene Galanter who has acted as indispensable interpreter and critic; the several others who at one time or another provided ideas and support to the effort: Elizabeth Connor, Jane Connors, Edward Green, Hellmuth Kaiser, Harriett Knapp, Judy and Walter Rosenblith; W. S. Battersby and Ernest R. Hilgard for their helpful comments on earlier drafts of this attempt; and the twelve little rhesus monkeys who skillfully, patiently and impatiently played the multiple object game with me daily for six months.
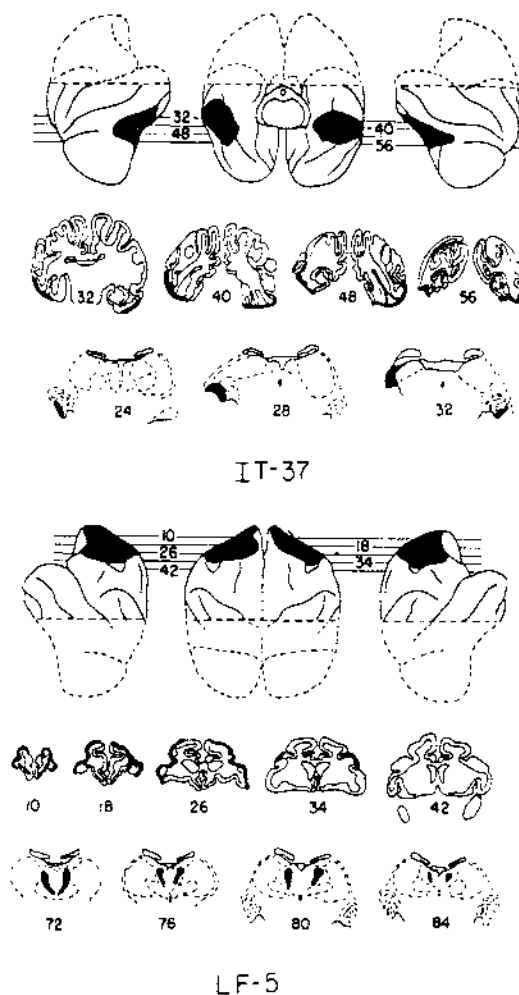

IT-37

LF-5

Fig. 1. Representative reconstructions and cross sections through cortex and thalamus showing extent of the lesions in the posterior (upper figure) and frontal (lower figure) intrinsic systems. Cortical lesions and resulting thalamic degeneration shown in black.

as the monkey has displaced one of the objects from its hole (a trial). When the screen is lowered, separating the monkey from the twelve hole board, the objects are moved (according to a random number table) to two different holes on the board. The screen is then raised and the animal again confronted with the problem. The peanut remains under the same object until the animal finds the peanut five consecutive times (criterion). After a monkey reaches criterion performance, the peanut is shifted to the second object and testing continues (dis-

crimination reversal). After an animal again reaches criterion performance a third object is added (Fig. 2). Each of the three objects in turn becomes the positive cue; testing proceeds as before—the screen separates the animal from the twelve hole board, the objects are placed randomly over three out of the twelve holes (with a peanut concealed under one of the objects), the screen is raised, the animal allowed to pick an object (one response per trial), the screen is lowered and the objects moved to different holes. The testing continues in this fashion until the animal reaches criterion performance with each of the objects positive, in turn. Then a fourth object is added and the entire procedure repeated. As the animal progresses the number of objects is increased serially through a total of twelve (Fig. 3). The testing procedure is the same for all animals throughout the experiment; however, the order of the introduction of objects is balanced—the order being the same for only one monkey in each group.

Analysis of the problem posed by this experiment indicates that solution is facilitated when a monkey attains two strategies: (1) during search, moving, on successive trials, each of the objects until the peanut is found; (2) after search, selecting, on successive trials, the object under which the peanut had been found on the preceding trial. During a portion of the experiment, searching is restricted for animals with posterior intrinsic sector ablations; and selection of the object under which the peanut had been found on the previous trial is impaired by frontal intrinsic sector ablations. The effects of the posterior intrinsic sector lesions will be dealt with first.

Figure 4 graphs the averages of the total number of repetitive errors made by each of the groups in each situation in the multiple object experiment. Comparison of Figure 4 with Figure 5, representing the repetitive errors made by each group in each situation during search, illustrates that the deficit of the frontally operated group is not associated with search (a result that is discussed below); however, the peak and general shape of the error curves describing the performance of the control and posteriorly operated groups are similar whether total repetitive errors (Fig. 4) or search errors (Fig. 5) are plotted. In spite of the increasing complexity of the succeeding situations, the curves appear little different from those previously reported to describe the formation of a discrimination in complex situations (Bush & Mosteller, 1951; Skinner,
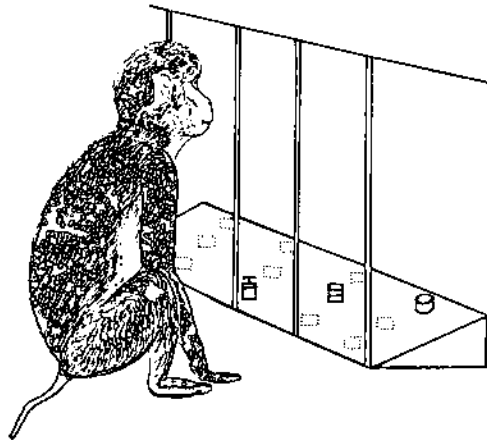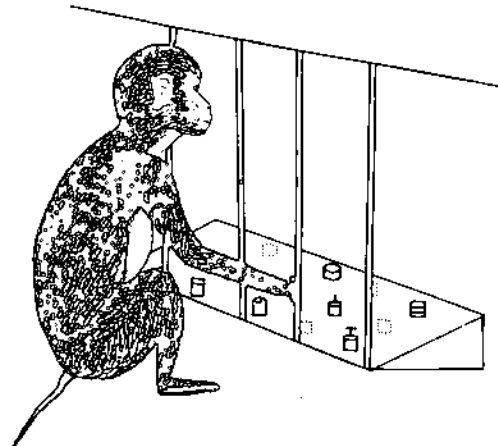

FIG. 2   FIG. 3

FIG. 2 and 3. Diagram of the multiple object problem showing examples of the three and the seven object situations. Food wells are indicated by dashed circles, each of which is assigned a number. The placement of each object over a food well was shifted from trial to trial according to a random number table. A record was kept of the object moved by the monkey on each trial, only one move being allowed per trial. Trials were separated by lowering an opaque screen to hide, from the monkey, the objects as they were repositioned.
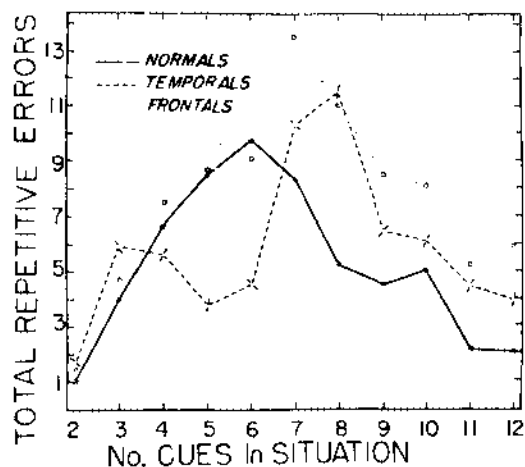
Fig. 4. Graph showing the average of the total number of repetitive errors made in the multiple object experiment by each of the groups (Controls = Normals; Posterior Intrinsic Sector Lesions = Temporals; Frontal Intrinsic Sector Lesions = Frontals) in each of the situations. A situation is defined by the number of objects in the problem and includes successions of trials. During each succession the peanut is consistently placed under one of the objects (cues). The succession is terminated when the monkey has moved, on five consecutive trials, the object under which the peanut is placed (criterion). (See also the legends to Figures 2, 3, and 8.) A repetitive error is made by a monkey when he moves more than once, during a succession of trials, an object *other* than the one under which the peanut is placed.
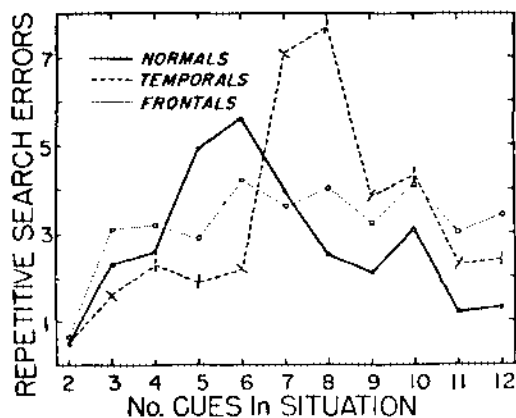

Fig. 5. Graph of the average of the number of repetitive errors made in the multiple object experiment by each of the groups during search (see legend to Figure 4). Search trials are those anteceding the first "correct" reponse in a succession of trials, i.e., those anteceding the movement of the object (cue) under which a peanut has been placed. Note the difference between the location of the "hump" in the graph of the normal controls and in that of the posteriorly lesioned group (temporals).

1938). Though one might, a priori, expect the number of repetitive responses to increase monotonically as a function of the number of objects in the situation, this does not happen. Rather, during one or another phase of the discrimination, the number of such responses increases to a peak and then declines to some asymptotic level (Bush & Mosteller, 1951; Skinner, 1938). Analysis of the data of the present experiment has shown that these peaks or "humps" can be attributed to the performance of the control and posteriorly operated groups during the initial trials given in any particular (e.g., 2, 3, 4 ⋯ cue) situation—i.e., when the monkey encounters a *novel* object. The period during which the novel and familiar objects are confused is reflected in the "hump" (Fig. 6). The importance of experience as a determinant of the discriminability of objects has been emphasized by Lawrence (1949; 1950). His formulation of the "acquired distinctiveness" of cues is applicable here. In a progressively more complex situation, sufficient familiarity with *all* of the objects must be acquired before a novel object is sufficiently distinctive to be readily differentiated.

But there is a difference between the control and the posteriorly operated groups as to when the confusion between novel and familiar objects occurs. The peak in errors for the posteriorly operated group lags behind that for the controls—a result which forced attention because of the paradoxically "better performance" of the posteriorly operated group throughout the five and six cue situations (in an experiment which was originally undertaken to demonstrate a relation between number of objects in the situation and the discrimination "deficit" previously shown by this group).

These paradoxical results are accounted for by a formal treatment based on mathematical learning theory: on successive trials the monkeys had to "learn" which of the objects now covered the peanut and which objects did not. At the same time they had to "unlearn," i.e., extinguish, what they had previously learned—under which object the peanut had been and under which objects it had not been. Both neural and formal models have been invoked to explain the results
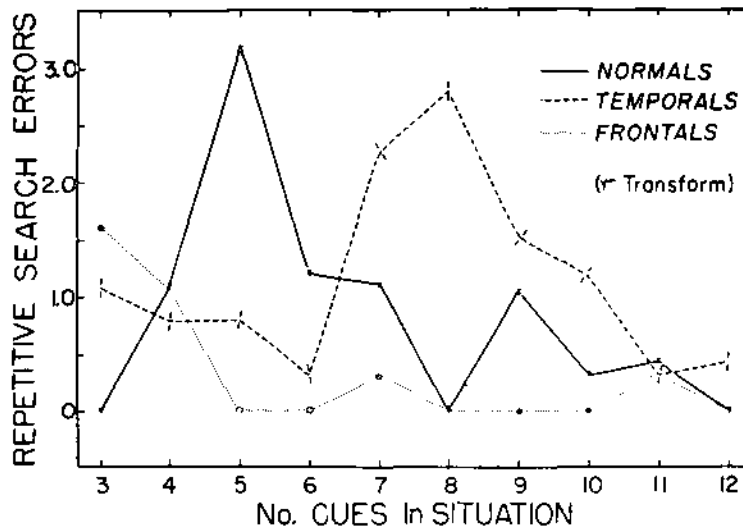
Fig. 6. Graph of the average of the number of repetitive errors made in the multiple object experiment during those search trials in each situation when the additional, i.e., the novel, cue is first added. Note that the peaks in errors shown in Fig. 5 are accounted for by the monkeys' confusion between novel and familiar objects as graphed here.

obtained in such complex discrimination situations. Skinner (1938) postulated a process of neural induction to account for the peak in errors, much as Sherrington had postulated "successive spinal induction" to account for the augmentation of a crossed extension reflex by precurrent antagonistic reflexes (such as the flexion reflex). Several of Skinner's pupils (Estes, 1950; Green, 1958) have developed formal models. These models are based on the idea that both "learning" (or "conditioning") and "unlearning" (or "extinction") involve antagonistic response classes—that in both conditioning and extinction there occurs a transfer of response probabilities between response classes. This conception is, of course, similar to Sherrington's "this reflex or that reflex but not the two together." The resulting equations that constitute the model contain a constant which is defined as the probability of sampling a particular stimulus element (Green, 1958), i.e., object, in the discrimination experiment presented here. This constant is further defined (Estes) as the ratio between the number of stimulus elements sampled and the total number of such elements that could possibly be sampled. This definition of the constant postulates that it is dependent for its determination upon both environmental and organismic

factors. According to the model the rapidity of increase in errors in a discrimination series depends on this sampling ratio—the fewer objects sampled, the more delayed the peak in recorded errors. The paradox that for a portion of the experiment the posteriorly lesioned group performs better than the control group stems from the relative delay in the peak of the recorded errors of the operated group.[2] The model predicts, therefore, that this operated group has sampled fewer objects during the early

[2] The actual model used to interpret the data analyzed here was developed by Green (1958) and is patterned after a model of discrimination of learning proposed by Bush and Mosteller (1951). The Green model takes its roots from a parallel model originated by Estes (1955). The general form of the model is derived from Estes' equations describing the conditioning and extinction processes:

$\bar{p}_n(S - I) = 1 - (1 - \bar{p}_0)(1 - \phi_1)^{rn}$ for conditioning to those elements which constitute occasions for reinforcement.

$\bar{p}_n(S' - I) = \bar{p}_0(1 - \phi_2)^{rn}$ for extinction to those elements which are never occasions for reinforcement

and

$$\bar{p}_n(I) = \frac{\pi\phi_1}{\pi\phi_1 + \pi\phi_2} - \left[\frac{\pi\phi_1}{\pi\phi_1 + \pi\phi_2} - \bar{p}_n \right]$$

$\cdot (1 - \pi\phi_1 - \pi\phi_2)^n$ for the changes associated

portions of the experiment. This prediction is tested as shown in Fig. 7.

The prediction is confirmed. The posterior intrinsic sector is thus established as one of the organismic variables that determine the constant of the model. As postulated by the model, the ratio of objects sampled turns out to be more basic than the number of objects in the situation, per se.

Mechanisms of invariance

Monkeys with posterior intrinsic sector lesions show a lag in attaining the strategy to sample extensively; is this impairment correlated with other deficiencies in differentiation that follow such lesions? These deficiencies differ in some respects from those produced by lesions of the extrinsic systems, but the differences are subtle and have repeatedly eluded precise specification
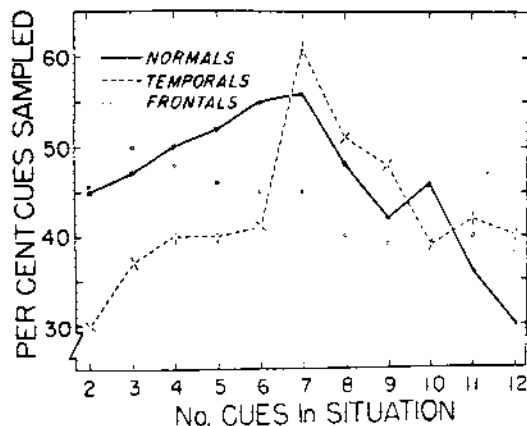

Fig. 7. Graph of the average of the per cent of the total number of objects (cues) that are sampled by each of the groups in each of the situations (see legend to Figure 4). To sample, a monkey had to move an object until the content or lack of content of the food well was clearly visible to the experimenter. As was predicted (see text), during the first half of the experiment the curve representing the sampling ratio of the posteriorly lesioned group differs significantly from the others at the .024 level (according to the non-parametric Mann-Whitney U procedure, [Mann & Whitney, 1947]).

with intercept elements, i.e., those present on both reinforced and unreinforced occasions.

where

$\bar{p}_0$ is the initial probability of response (operant level).

π is the relative frequency of reinforced trials in the discrimination series.

ϕ_1 and ϕ_2 are sampling ratios for reinforced and non-reinforced stimulus sets, respectively.

n denotes the number of trials.

It is assumed that the above equations are weighted directly as a function of the proportion of elements within the intercept and non-intercept subsets, such that

$$\bar{p}_n(S') = k'\bar{p}_n(S' - I) + (1 - k')\bar{p}_n(I).$$

In these experiments, then,

S' is the set of unreinforced stimulus elements (objects under which no peanut is located) and

I includes among the subset of elements common to both reinforced and unreinforced trials those objects which "recently" have had a peanut under them.

k' is the proportion of stimulus elements not common to both reinforced and unreinforced trials.

$\bar{p}_n(S')$ is the mean probability of response on non-reinforced trials (probability of error responses) on the nth trial.

In the present experiment only the objects with no peanuts under them are considered since only one object at a time had a peanut under it. Thus the set of reinforced objects reduces to one, and the sampling ratio associated with it ϕ_1 is maximized with respect to the sampling ratio associated with the unreinforced sets, ϕ_2.

(Pribram & Mishkin, 1955). The available data may therefore be briefly reviewed in a renewed attempt at such specification. (1) As already noted, drastic bilateral removal of an *extrinsic* sector severely limits differentiative behavior in the modality and only in modality served by that sector. The limitation affects practically all differentiations in the mode: e.g., a monkey whose occipital lobes have been removed reacts only to the grossest changes in the environment that affect the visual receptors—changes that can be ascribed to variations in total luminous flux (Klüver, 1942). Comparably, drastic bilateral removal of a posterior *intrinsic* sector restricts differentiative behavior within the mode served by that sector, and only within that mode, but the limitation is not as severe as that produced by drastic removal of the extrinsic sector serving that mode (Chow & Hutt, 1953; Pribram, 1954). (2) Under some conditions, differentiation is unimpaired after drastic resection of the posterior *intrinsic* sector: e.g., after such a removal, a monkey can catch a flying gnat in midair and can pull in

a peanut which is beyond reach but attached to an available fine silk thread (0000 surgical). In these situations as in situations that necessitate the opening of a single box or depressing of a single lever, the operated animal is indistinguishable from an unoperated control animal (Pribram, 1958b). (3) Under other conditions, such as those in the experiment described above, differentiation is impaired after posterior *intrinsic* sector ablations. These conditions have in common the requirement that two or more separate responses be systematically related to the differences between the environmental events that determine the stimulus; i.e., alternatives are available to the organism, alternatives that are specified by environmentally determined stimuli. Such stimuli, for convenience, will hereafter be referred to as "input" variables. Examples of the problems where impairment is found (in the visual mode) are: brightness, color, form, pattern, size, and flicker discriminations (Mishkin, 1954; Mishkin & Hall, 1955; Mishkin & Pribram, 1954); successive and simultaneous discriminations (Pribram & Mishkin, 1955); successions of discriminations ("learning set") (Chow, 1954; Riopelle, Alper, Strong, & Ades, 1953); oddity discriminations (Harlow, Davis, Settlage & Meyer, 1952); and matching from sample (Harlow et al., 1952). Though the operated animals may perform "normally" on particular problems within a problem group, decrement is found on other more "difficult" problems in that group. Difficulty of problem is independently defined by the number of trials taken by naive unoperated animals to learn the problem. In most instances problem difficulty has also been related to differences between the physical dimensions of the objects, e.g., size discrimination (Mishkin & Hall, 1955), and to other determinants of the alternatives in the situation, e.g., situational differences (Pribram & Mishkin, 1955), sampling in the multiple object problem.

These then are the data. Extensive bilateral ablations of both extrinsic and posterior intrinsic sector resections impair differentiative behavior but differences between the impairments exist. Attempts to portray these differences are familiar. Neurologists have spoken of "defective sensibility" and of "agnosia" (Freud, 1953; Head, 1920), the latter often conceived as a disorder of memory. In so far as this distinction assumes an associationistic model of the functions of the intrinsic sectors, it gains little support from neurological or neuropsychological evidence (Pribram, 1958b). An alternate view can be proposed. Psychologists have spoken of "existential discriminations" and "differential discriminations" (James, 1950), or of "sensibility" and "intelligibility" (Miller, Heise & Lichten, 1951), distinctions that are made on the basis of whether the organism's actions are determined by "simple presence or absence" of input variables or by "some more complex relationship" between these variables, such as the number of "contextual alternatives" in the situation (Miller, 1951). The results of the multiple object experiment warrant an attempt to pursue this conceptualization of the distinction by proposing a formal model of the interaction between the functions of the intrinsic sectors in differentiative behavior.

The defect in differentiative behavior that results from lesions of the extrinsic and posterior intrinsic sectors of the forebrain can be characterized by stating the variety of transformations of descriptions of the input under which behavior remains invariant. Following extensive bilateral resections of the extrinsic sectors, behavior remains invariant under a great variety of transformations of the input. For instance, for these preparations, even brightness and size of luminant are multiplicatively interchangeable quantities (Klüver, 1942), whereas differentiative behavior by organisms with intact extrinsic sectors is invariant under much more restricted ranges of transformations of the input—e.g., differentiation in the case of contrast and contour (Mach, 1897), texture and acuity (Gibson, 1950); continuous (orthogonal) projective in the case of position, distance, form and rigid motion (Gibson, 1950, Ch. 8; Gibson, 1956; Gibson & Gibson, 1956).

The effects of lesions of the posterior intrinsic sectors can also be usefully charac-

terized in this way. Differentiative behavior which remains invariant under still fewer transformations of the input is interfered with by such lesions. In the extreme, unique responses, i.e., "absolute" differentiations, would be most affected.

Unique responses can occur only when both an "absolute" unit and an "absolute" reference point have been fixed. As indicated in the discussion of the results of the multiple object experiment, mathematical learning theory provides an approach to the specification of these units and their referents. The fact that this mathematical device has proved so powerful a tool in the analysis of some completely unexpected effects of posterior intrinsic sector lesions lends support to its usefulness in the development of the model.

Partitioning

By what neural mechanism could the posterior intrinsic sectors effect a restriction of the systems of transformations of the input under which differentiative behavior remains invariant? On the basis of neurological and neurobehavioral data, the suggestion has been forwarded that the intrinsic sectors operate, via efferents, on the events occurring in the extrinsic mechanisms (Pribram, 1958b). These efferents can be conceived to partition the afferent activity that results in the events in the extrinsic sectors, events initiated by and corresponding to inputs. Partitioning determines the extent of the range of possibilities to which an element or a set of elements can be assigned. Partitioning results in patterns of information, information given by the elements of the subsets resulting from the partition (von Neumann & Morgenstern, 1953). The posterior intrinsic sector mechanism is thus conceived to provide both referent and units though *not* the elements to be specified. The effect of continued intrinsic sector activity will, according to this model, result in a sequence of patterns of information (partitions) of increasing complexity, which in turn allow more and more precise specification of particular elements in the set (or subsets) of events occurring in the extrinsic systems. Thus, through continued posterior

intrinsic sector activity, more and more information can be conveyed by any given input. As a result, the organism's differentiative behavior remains invariant under a progressively narrower range of systems of transformations of the input—differentiations become more "absolute."

The programming of the activities of the posterior intrinsic sectors remains in question. Some things are clear, however. The advantage of this model is that the program is not composed solely by the events upon which the program operates. In this respect the model is in accord with neural and neurobehavioral facts (Pribram, 1958b). Other models, whether associationistic or match-mismatch (Bruner, 1957), demand the *storage* of an ever increasing number of "bits" of information. The evidence is overwhelmingly against the presence in the intrinsic systems of such minutely specific engrams (Lashley, 1950). In the model here presented, engrams consist of encoded programs; these operate on the neural events that are initiated by the input, transforming them into other neural events which can lead to an ever increasingly finer, i.e., appropriate, differential response (Gibson & Gibson, 1955; Werner, 1940). In this formulation the posterior intrinsic sectors are conceived as programming mechanisms that function to partition events initiated by the input, not as the loci of association of such events, nor as the loci of storage of an ever increasing number of minutely specific engrams.

ECONOMIC SOLUTIONS OF PROBLEMS

The mechanism by which the posterior intrinsic sectors is conceived to affect differentiative behavior finds a parallel in the mechanism by which the frontal intrinsic sector can affect intentional behavior. Intentions, as noted earlier, are defined as the result of the "harmonious interactions" that result from adaptations to "a number of mutually reinforcing positive elements." The demonstration of this parallel is most effectively initiated by some further analyses of the data obtained in the multiple object discrimination experiment.

Some experiments

Returning to the multiple object experiment, Figure 8 graphs the average of the total number of trials taken by each group of monkeys in each situation to reach the criterion of five consecutive errorless responses. The peculiarities of the shape of the curve representing the performance of the posteriorly operated animals have already been analyzed above. The difficulties in performance encountered by the frontally operated group are more clearly demonstrated by comparing the graph of the total number of trials (Fig. 8) with one that portrays performance following completion of search, i.e., after the first response on which the peanut is found (Fig. 9). Note that the lag shown by the frontally operated group in reducing the number of trials taken to reach criterion (or the number of repetitive errors made) occurs *after* the peanut has been found. This group of monkeys experiences difficulty in attaining the strategy of

FIG. 9. Graph of the average of the number of trials to criterion taken in the multiple object experiment by each of the groups in each of the situations after search was completed, i.e., after the first correct response. (See legends to Figures 5 and 8.) Note the difference between the curves for the controls and for the frontally operated group, a difference which is significant at the .05 level by an analysis of variance (F = 8.19 for 2 and 6 df) according to McNemar's (1955) procedure performed on normalized (by square root transformation) raw scores.
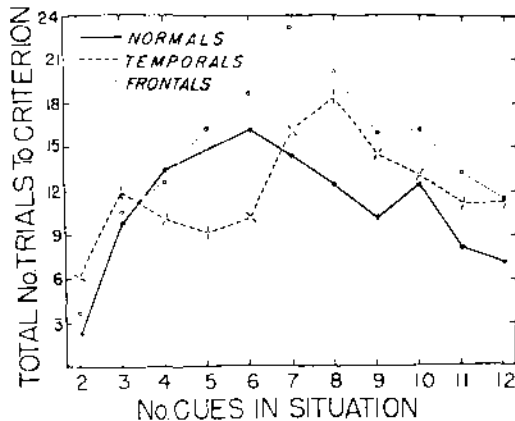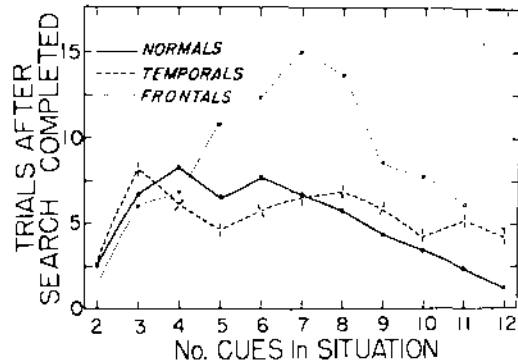

FIG. 8. Graph of the average total number of trials taken in the multiple object experiment by each of the groups (Control = Normal; Posterior Intrinsic Lesion = Temporal; Frontal Intrinsic Lesion = Frontal) to reach, in each of the situations, a criterion of performance of five consecutive correct responses. A correct response occurred when the monkey moved the object under which a peanut had been placed for that trial. In a succession of trials, the peanut remained under one of the objects until criterion performance was reached. Then the peanut was shifted to one of the other objects in the situation and the trials resumed; this procedure was repeated until each of the objects in each of the situations had been the correct one. (See also the legends to Figures 2, 3, and 4.)

returning on successive trials to the object under which they have, on the previous trial, found the peanut. Whatever may be the explanation of this difficulty, a precise description can be given: for the frontally operated group "finding the peanut" does not determine subsequent behavior to the extent that "finding the peanut" determines the subsequent behavior of the normal group. In Sherrington's and in behavioristic terms the "positive element," response to the object is, for the frontal group, inadequately reinforced by the "alliance with it" of the action, finding the peanut. More generally, response probabilities of the frontal group are less affected by the outcomes of their actions (e.g., finding a peanut).

Interestingly, before the frontally operated group begins to attain the necessary strategy (after the seven cue situation), performance of this group reflects the number of alternatives in the situation. This finding suggests a parallel with analyses of the effects of outcomes developed in the theory of games and economic behavior. The effects of outcome are determined by two classes of variables: (1) the dispositions of the organism, and (2) an estimate about the

actions of other parts of the system. The finding that performance of the frontally operated group is related to the number of alternatives in the situation suggests that this group is deficient in evaluating the second class of variables—but this is only suggested by these results. Support for the hypothesis that frontal lesions do not affect the dispositional variables that determine the effect of an outcome of an action comes from the results of another experiment.

In a constant (fixed) interval experiment, ten rhesus monkeys are tested in an "operant conditioning" (Skinner, 1938) situation which consists of an enclosure (discarded icebox) in which a lever is available to the monkey. Occasionally, immediately after a depression of the lever, a pellet of food also becomes available to the monkey. The experimenter schedules the occasions on which the action of pressing the lever has the outcome that a food pellet becomes available. In this experiment, these occasions recurred regularly at a constant (fixed) interval of two minutes. The conditioning procedure, as a rule, results in performance curves (scallops) which reflect, during the early portions of the interval, a slow rate of response, and during the latter portions an accelerating rate which nears maximum just prior to the end of the interval. All of the monkeys used in this experiment were trained every other day for two hour sessions until their performance curves remained stable (as determined by superimposition of records and visual inspection) for at least ten consecutive hours.

Two experimental conditions were then imposed, one at a time: (1) deprivation of food for 72 and 110 hours; (2) resection of frontal and posterior intrinsic cortex. Food deprivation increases the total rate of response of all animals markedly but does not alter the proportion of responses made during portions of the interval (Fig. 10). Resection of the frontal intrinsic sector does not change the total number of responses but does alter the distribution of responses through the interval—there is a marked decrease in the difference between the proportion of responses made during the various portions of the interval. Monkeys with
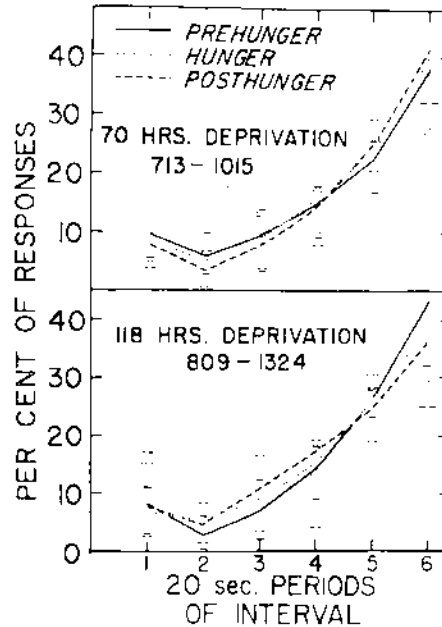

Fig. 10. Graph showing the effect of food deprivation on monkeys' rate of lever pressing response to food (a small pellet of laboratory chow) which became available every two minutes. The *change in total rate* is indicated by numbers under the deprivation label. The *lack of change in the distribution of responses* is shown by the curves. Each curve represents the average of the responses of ten monkeys; each point represents the average rate during a period of the interval over ten hours of testing. Variance is indicated by the short horizontal bars. Dr. Nathan Azrin made this experiment possible by constructing apparatus and by suggesting that separate counters be used to record performance during each period of the interval. Mr. David Nowel, Mr. Thomas Tighe and Miss Libby Fleisher helped carry out this and the experiment reported in Figure 11.

lesions of the posterior intrinsic sectors and unoperated controls show no such changes (Fig. 11).

The results of the constant interval experiment support the contention that the effect of an outcome of an action is influenced by variables which can be separately classified. Deprivation influences total rate of response; frontal lesion, the distribution of that rate. Deprivation variables are akin to those which have in the past been assigned to influence the disposition of the organism. The frontal intrinsic sector lesion appears to influence the monkey's estimates about the situation. This finding is thus in accord with that obtained in the multiple
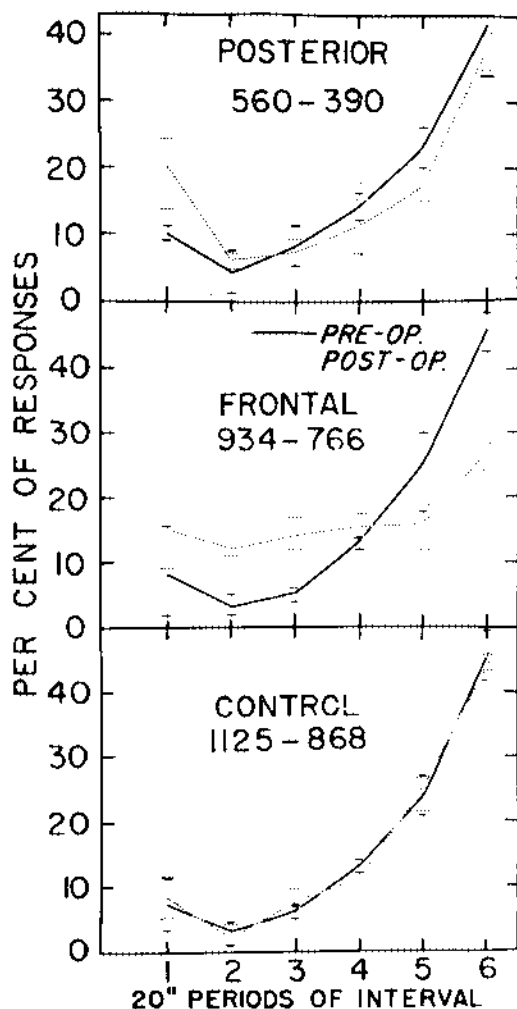
FIG. 11. Graph showing the change in distribution on monkeys' response rate following frontal intrinsic sector ablation (three monkeys). Note that the distribution of rate over the interval is not affected in the controls (four monkeys) and after posterior intrinsic sector ablations (three monkeys). Also note that the total rate of response did not increase; rather rate was somewhat decreased, probably due to the ad libitum feeding period which all groups were given prior to operation—approximately two weeks before postoperative testing. (Compare with Figure 10 and see legend to that figure.)

object problem. Both experimental findings can be formally treated by the device of "mathematical expectation" (von Neumann & Morgenstern, 1953, Ch. 1). The distribution of response probabilities in the constant interval experiment can be considered a function of the temporal "distance" from the outcome; distribution of response probabilities in the multiple object experiment is a function of the number of objects in the situation. Frontal intrinsic sector lesions interfere with those aspects of intention that depend on an estimation of the effects that an outcome of an action has in terms of the total set of possible outcomes that are available. The effects of frontal intrinsic sector lesions on behavior related to outcomes thus parallels the effects of posterior intrinsic sector ablations on behavior related to inputs. A general model of intrinsic sector mechanisms seems therefore to be possible. As a step towards such a model a brief review of available data follows.

The effect of frontal intrinsic sector resection on the distribution of responses in the multiple object and constant interval problems is correlated with other deficiencies in preferential behavior that follow such resections. The most clear-cut deficiency is in the performance of delayed reaction and of alternation by subhuman primates. These problems are usually classified with those used primarily to study differentiative behavior, although differences between the two are recognized. These differences have been conceptualized in terms of one-trial learning (Nissen, Riesen, & Nowles, 1938), immediate memory (Jacobsen, 1936), and retroactive inhibition (Malmo, 1942), conceptions which are insufficiently distinctive to account for recently reported experimental findings (Mishkin & Pribram, 1956). More penetrating analyses have been accomplished for the effects of frontal intrinsic sector lesions on the performance of the double alternation problem (Leary, Harlow, Settlage, & Greenwood, 1952) and for the simple alternation problem per se. These analyses emphasize the recurrent regularities which constitute the alternation problems and suggest that such problems be considered examples of a larger class which can be distinguished from problems that require differentiation (Galanter & Gerstenhaber, 1956). Delayed reaction may also belong to the class of problems specified by recurring regularities: the recurrence, at the time response is permitted, of some of the events present in the predelay situation,

constitutes an essential aspect of the delay problem (Mishkin & Pribram, 1956).

The reasons for classifying the delayed reaction and alternation problems with those related to systematic variations of outcomes remain somewhat obscure. The results of the following experiment provide some clarification. Under special conditions, monkeys with lesions of the frontal intrinsic sectors perform remarkably well the delayed reaction and alternation problems (Mishkin & Pribram, 1955; Mishkin & Pribram, 1956). Adequate performance is established, however, at the cost of a great number of repetitive errors (though not of initial errors, Fig. 12). These results can be described as a failure in performance due to the relative inefficacy of the outcome of the frontally operated animals' actions in determining subsequent action. This descrip-
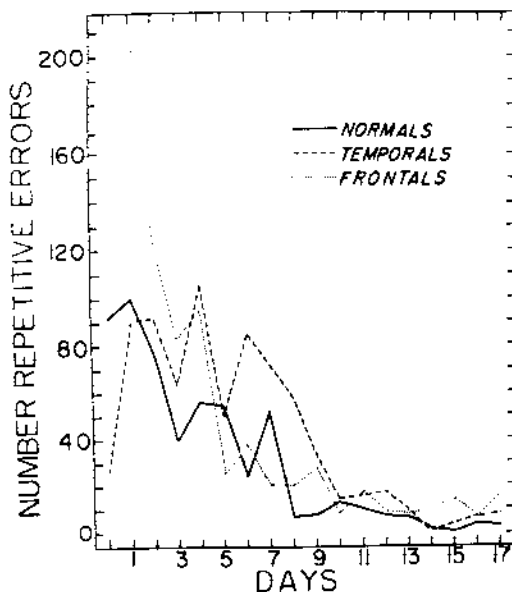

Fig. 12. Graph showing the differences in the number of repetitive errors made by groups of monkeys in a "go-no-go" type of delayed reaction experiment. Especially during the initial trials, frontally operated animals repeatedly return to the food well after exposure to the "nonrewarded" predelay cue. Note, however, that this variation of the delay problem is mastered easily by the frontally operated group. The twelve rhesus monkeys used in the multiple object experiment (Figures 4–9) served as subjects some two years earlier in the delayed response experiment portrayed here. Dr. Margaret Varley assisted in the performance of the earlier experiment.

tion is compatible with the finding that, in delayed reaction, the important determinant of performance is the outcome of the animal's reaction in the predelay situation (Mishkin & Pribram, 1956), the outcome having "acquired distinctiveness" during the earlier phases of the experiment.

From these data, a formal model of the neural mechanism that underlies the effect of frontal intrinsic sector resections on intentional behavior can be proposed. This model takes into account the neural relationship between the frontal intrinsic sector and the mediobasal structures of the forebrain (Pribram, 1958a), and is based on the finding that two classes of variables determine the effects of the outcome of an action. A large body of data has been accumulated in the last twenty years as a result of studies which made use of surgical ablation and electrical stimulation (Olds, 1956; Pribram, 1958a; Pribram & Kruger, 1954). These data demonstrate the special relation of the mediobasal systems of the forebrain to the class of variables subsumed under the rubric "disposition."

Mechanisms of disposition

Changes in the following types of behavior are reported to result from mediobasal forebrain ablations and stimulations: fighting (dominance, reaction to frustration); fleeing (escape and avoidance); feeding (appetitive, such as hoarding, and consummatory); and mating and maternal (nest building and care of the young). Stimulation or ablation which affects one of these behavior patterns is likely also to affect the other (though not necessarily to the same extent). On the other hand, the performance of discrimination tasks remains unaffected (Pribram, 1958a; Pribram & Kruger, 1954).

Typically, the damage or stimulation of mediobasal forebrain sectors affects intentional behavior by disrupting the more or less orderly recurring sequences of actions which constitute feeding, fighting, fleeing, mating and maternal behavior. None of the elements of the sequence drop out; rather the duration of any one such element of action is altered. The outcome of an action appears, in these damaged animals, to be

an ineffective terminant or maintainant of acts in the sequence (Deutsch, 1953). Specifically, animals with mediobasal forebrain sector resections continue feeding long after control subjects (with the same amount of deprivation and in the same situation) have stopped eating (Fuller, Rosvold, & Pribram, 1957; Pribram & Bagshaw, 1953). The duration of avoidance behavior is shortened: e.g., a monkey will repeatedly grasp a flaming match even though he is burned each time (Fulton, Pribram, Stevenson, & Wall, 1949). A fighting reaction is not maintained. An animal with a mediobasal forebrain sector lesion may draw blood or have a finger bitten off and within a few seconds sit unconcernedly munching peanuts. This effect, as that on avoidance, is especially easy to discern in measures of extinction (Pribram & Weiskrantz, 1957). Reactions to a "frustrating situation" are also altered along this dimension: the intensity of an animal's reaction to frustration is unimpaired, but the duration of the reaction is shorter than that of a control subject (Pribram & Fulton, 1954). When closely examined, the effects of mediobasal forebrain sector ablation on hoarding (Stamm, 1954), mating (Schreiner & Kling, 1953) and maternal (Stamm, 1955) behavior, are on the duration of a particular element of the sequence, e.g., food or an infant are dropped before the nest is reached, or occasionally, carried to the nest and then taken out again to be dropped elsewhere.

The neural mechanisms whereby the mediobasal forebrain sectors affect the outcome determinants of behavior are only beginning to be detailed (Pribram, in press). Essentially, the mediobasal forebrain sectors are especially related afferently and efferently to medial and mesencephalic and diencephalic structures in which are located receptors surrounding the 3rd and 4th cerebral ventricles (such as osmo- and temperature sensitive elements) as well as the non-specific diffuse systems (Scheibel, Scheibel, Amollica, & Moruzzi, 1955). The latter are characterized by networks of short, fine-fiber neurons (Segundo, 1956). In such networks synaptic, dendritic and electrotonic phenomena, especially sensitive to neurochemical influences, are most likely of greater total significance than are rapidly propagated patterns of neural impulses. In fact, the connections between the mediobasal forebrain and medial mesencephalic and diencephalic structures are so arranged that even when propagated signals are transmitted, the effect on the target site is more often a change in the local excitability than the firing of neurons (Gloor, 1955).

Characteristic interactions between the functions of the mediobasal forebrain sectors and those of the diffuse non-specific systems are thus beginning to be established at the neural level, interactions which can account for the findings that intentional behavior is affected when mediobasal forebrain structures are ablated or electrically excited. Analysis of the effects of these interactions can therefore be undertaken. Changes in the excitability of these neural mechanisms have been correlated with changes in activation, such as sleep-wakefulness, which, in the intact organism, are cyclic processes. The effect of an outcome of any particular action depends on the state of the organism and this state is a cyclic function, e.g., a heaping plate of food is most desirable at the peak of the appetitive cycle but slightly nauseating just after consumption of a large meal. The differences in the effects of outcomes depend therefore on the dispositions of the organism that are only partially (and inadequately) described by the differences that can be found to occur during any one cycle (Finger, 1951; Finger & Reid, 1952; Hall & Hanford, 1954; Lawrence & Mason, 1955; Richter, 1955). More complete description takes into account cyclicly recurring regularities.

The cycles of activation (or deactivation) in behavior that occur with changes in the excitability of the central and peripheral nervous system are analogous to conversions between potential and kinetic energy in physical systems—the activity of water at the base of a fall is not properly described in terms of the differences between the "amount" of energy which exists in the limpid pool at the top of the falls and that which characterizes the excited turbulence at the base. Rather, the difference is between reciprocally related quantities—e.g., kinetic and potential, in the case of physical

systems (e.g., the waterfall); anabolic and catabolic, in biological descriptions. Thus, a "need-reduction" formulation, in which the referent against which changes are specified is considered to be some basal (i.e., minimal) activity level, is found inadequate. This conceptualization, by insistence on "amount" of need as the basic variable, easily falls into the trap of confusing the reciprocally related potential and kinetic manifestations of the energic process with quantitative differences in the total amount of energy in the system.

An added argument against simple need "reduction," based on the notion of "physiological need," is that such a notion does violence to physiological fact. Oxygen deprivation produces little increase in respiratory rate provided a constant partial pressure of CO_2 surrounds the respiratory receptor mechanisms in the carotid body and brain stem (Meyer, 1957). Food deprivation, as in starvation, is insufficient *per se* in increasing appetite. Long term deprivation of mating leads as often to continence as to frustration—these examples suffice to suggest that physiological need is not invariably produced by deprivation. And, of course, the converse also holds: that "need" (e.g., measured by the rate or amount of movement related to an outcome) may actually *increase* when recurrently "satisfied" (Lawrence & Mason, 1955).

On the other hand, the more complete specification that takes into account the reciprocally related recurring changes between excitability and rest is supported by physiological fact. The electrical activity of totally isolated neural tissue is cyclical (Burns, Grafstein, & Olszewski, 1957). The period of cyclical activity can be specified and any changes imposed on the normal periodicity can be described. The advantages of such description are: that the "amount of excitability" is not confused with "amount of energy"; that a particular event can increase excitability at one time and decrease it at another; thus, the effect of an outcome of an action can be conceived to depend on the phase of the excitability cycle at the moment of action. The disposition of an organism is therefore a basic determinant of intentional behavior. Dispositions are conceived to be dependent on changes in the periods of neural excitability cycles.

Expectation

By analogy with the model describing the functions of the extrinsic and posterior intrinsic mechanisms, the proposal of a model of the frontal intrinsic and mediobasal forebrain mechanisms begins with a statement of the variety of transformations of the outcomes of actions under which behavior remains invariant. Following extensive bilateral resections of the mediobasal forebrain systems, behavior remains invariant over a wide variety of transformations of outcome, e.g., even gross changes in the amount of food deprivation minimally alter rate of response to food (Weiskrantz, 1953).

Frontal intrinsic sector lesions affect intentional behavior that remains invariant only under the more restricted ranges of transformations of the outcome, transformations which, in controls, can be shown to affect the distribution of intentional responses.

Unique distributions can occur only when both the units of intention and their referent have been fixed. Difficulties in defining such units and their referent stem from the cyclical variations which describe the dispositions of organisms—difficulties already discussed from the neuro-behavioral standpoint. The formal device "mathematical expectation," which is so usefully applied to the analysis of the effects of frontal intrinsic sector lesions, is designed to overcome the difficulties encountered in analyzing the solution of problems characterized by cyclic phenomena (von Neumann & Morgenstern, 1953). This device, based on combinatorial (equilibratory) and set theoretical methods, attempts to meet the difficulties by the suggestion that the solution of such problems is described, not by the single elements that define the problem, but by sets (and subsets) of such elements. Unfortunately, the mathematics falls somewhat short of accomplishment in this area and only some rudimentary approaches to the task are possible at this time (von Neumann & Morgenstern, 1953).

Nevertheless, the relevance of the device, mathematical expectation, in the analysis of the results of the multiple object and constant interval experiments, suggests the formal model of the frontal intrinsic mechanism. This model conceives of the frontal intrinsic mechanism to partition the events in the mediobasal forebrain systems, dispositional events that determine the effect of outcome variables. Partitioning thus results in distributions of intentions, intentions determined by the elements of the subset resulting from the partition. The frontal intrinsic mechanism is therefore conceived to provide both referent and units, though *not* the elements that specify intentional behavior. The effect of continued frontal intrinsic sector activity will, according to this model, result in an increasingly complex sequence of intentions which, in turn, allow more and more precise specifications of intent that can be conveyed for any given outcome. As a result, the organism's intentional behavior remains invariant under a progressively narrower range of systems of transformations of outcomes—intentions become more precise.

The programming of the activities of the frontal intrinsic sector remains in question. Some things are clear, however. The advantage of the model is that the program is not composed by the events upon which the program operates. Thus, as in the case of the posterior intrinsic mechanisms, storage of encoded programs is demanded—not storage of an ever-increasing number of discrete intentions. In this formulation, the frontal intrinsic sector is conceived as a programming mechanism that maps intentions—a conception that is in accord both with experimental finding and much clinical observation (Elithorn, Piercy, & Crosskey, 1955; Freeman & Watts, 1951; Penfield, 1948; Rylander, 1948).

THOUGHT

The argument has been forwarded, on the basis of an analysis of neurobehavioral data, that two major classes of behavior can be distinguished: differentiative and intentional. Both classes are observed when an organism solves a problem. The multiple object experiment provides a paradigm of the relation between each of these classes and problem solution. Differentiation determines the strategy that facilitates search; intentions determine the strategy that facilitates performance. In more general terms, differentiative behavior delineates the problem through the acquisition of information; economic solution of the problem depends on intentional behavior that utilizes the information already acquired (Kochen & Galanter, 1958).

Still more precise systematic definitions of the organismic variables that determine differentiation and intention may profitably lead to further empirical inquiry and may aid in unravelling the terminological gobbledygook that accompanies an effort of this sort. The particular words chosen to denote the distinctions made are not too important; that the distinctions be made in some way is often helpful. The concept of "stimulus" is crucial to psychological inquiry (Stevens, 1951); thus definition starts logically with this concept. Behavior theory often begins with the statement that a response is a function of certain organismic variables (e.g., drive, habit) and of a "stimulus" which is conceived as some environmental event or constellation of environmental events. This classical behaviorist position has been challenged by those investigators primarily interested in psychophysical and perceptual problems (Allport, 1955; Stevens, 1951). These investigators are concerned with the more precise specification of the category "stimulus" as including "distal" (e.g., environmental) and "proximal" (organismic, i.e., receptor) events. This concern must be shared by the neuropsychologist who is interested in the relationships between central processes and behavior, since complex interactions between receptor and central mechanisms preclude an understanding of the one without an appreciation of the other. The importance of central regulation of receptor events is attested by the findings of recent physiological experiments which demonstrate mechanisms that allow the regulation of afferent activity through efferents from the central nervous system: the effect of electrical excitation of efferents

(⅓ of the fibers in the ventral spinal root) in modifying the activity of afferents originating in muscle spindles (Eccles, Fatt, & Landgren, 1956; Eldred & Hagbarth, 1954; Kuffler & Gerard, 1947; Kuffler & Hunt, 1952); the influence of excitation of efferents in the otic system on afferent activity initiated by auditory stimulation (Galambos, 1956), and similar effects in the optic (Dodt, 1956; Granit, 1955), somatic (Hagbarth & Kerr, 1954; Hernandez-Peon & Scherrer, 1955) and olfactory (Kerr & Hagbarth, 1955) systems.

"Stimuli" are thus conceived as centrally regulated receptor events. To avoid confusion, the term "input" is reserved for those receptor events which can be shown to be systematically related to an ensemble of environmental events. Inputs are specified either by direct observation of the effects of environmental events on receptor events, or indirectly from such effects on the behavioral responses of the organism.

As with the term "stimulus," several uses of the term "response" are also often confounded. As used in this presentation, "response" denotes any dependent variable which is selected as representative of an action—i.e., a repertoire of responses which can be shown to be systematically related. Movements or smooth muscle and endocrine events comprise the effector components of action; those components that modify receptor activity (i.e., the stimulus components) are referred to as the "outcome" of the actions. Actions are specified either by direct observations of the outcomes of muscular or endocrine events (e.g., the changes in the activity of afferents from muscle spindles) or indirectly from some behavioral response (e.g., the record of depressions of a lever) made by the organism.

Behavior observed to be a function of systematic variations of input is referred to as differentiative; behavior observed to be a function of systematic variations of outcome is referred to as intentional. The obviously circular relation between all of these definitions is tolerable since each term is independently, as well as circularly, definable: the environmental terms by physical methods, the organismic terms by biological methods.

The experiments presented show that the delineation and economic solution of a problem begin more or less haphazardly. Haphazard problem solving behavior is described by the relatively wide range of systems of transformations of the inputs and the outcomes of actions under which the behavior remains invariant. Strategic problem solution, on the other hand, occurs with restriction of the range of such systems of transformations. The experiment is interpreted to indicate that restriction, in this instance, results from the operation of a mechanism (the intrinsic) that partitions the neural events (in the extrinsic and mediobasal systems) determined by inputs and outcomes. By providing both a referent and units, partitioning defines the range of possibilities to which an input or outcome is assigned by the organism.

Is not the range of possibilities to which an input or an outcome is assigned by an organism the amount of "active uncertainty" shown by that organism in the situation? And is it not this active uncertainty that Dewey suggests is referred to by the man in the street as "thinking"? The delineation of a problem and its economic solution have been shown to be dependent on the range of possibilities to which input or outcome is assigned; establishing this range is characteristic of the thought process. A partitioning mechanism can be conceived to accomplish this characteristic; such a mechanism has been posited to describe the functions of the intrinsic systems of the forebrain. On the basis of clinical neurological data, thought has classically been a suggested result of the function of these systems. The data and analysis here reported support the suggestion and give a more precise description of both the mechanism and the thought process than had heretofore been possible. As a corollary, some better understanding has been obtained of what constitutes a problem and its solution for the behaving organism: delineation of the problem by differentiation amongst a set of possible inputs; economic solution of the problem by intentional choice amongst a set of possible outcomes. This understanding places a somewhat greater emphasis on, and details more ex-

plicitly, the organismic variables that determine problem and solution than many of the more recent conceptions and thus comes closer to attempts made in earlier psychologies.[3]

[3] The neural mechanism of thinking proposed here is similar in several respects to others already formulated. The neurobehavioral data presented, and their formal analysis, suggest that the events in the extrinsic and mediobasal forebrain systems are indeed the important determinants of moment to-moment behavior, as in Lashley's (1952) and in Köhler's formulation (Köhler, 1938; Köhler & Held, 1949; Köhler, Neff, & Wegener, 1955; Köhler & Wegener, 1955). However, these events are acted upon by others which provide the contextual matrix that sets limits on the moment-to-moment behavior, as proposed by Freud (1953), by Duncker ("functional fixedness," 1945), and, more recently, by Forgus (1954, 1956, in press). The resultant of the interaction of these two classes of neural events is described more formally, though less picturesquely, by the mechanism, 'partitioning of sets,' than this resultant is described by Lashley's largely nativistic or Hebb's largely empiricistic conceptions: reduplicated neural loops (Lashley, 1942) or phase sequences (Hebb, 1949). Yet all three share the essential characteristic that, in continued problem solving behavior, increasingly complex patterns of neural events occur, patterns that allow more and more precise differentiations and intentions to take place.

The argument forwarded is in other respects similar to earlier neuropsychological formulations, in particular, those that have emphasized *attitudinal* factors. The analysis of the neurobehavioral data here presented makes the distinction between partitions of (attitudes towards) those sets of events determined by inputs and those determined by outcome. This distinction allows greater precision in the description of attitudinal factors: those related to differentiation (e.g., Lashley's comparison attitude [1952]), can be redefined as a capacity to acquire information—to search through a large number of possible inputs (especially "negative instances"); those related to intention (e.g., Goldstein's abstract attitude [1948]), can be redefined as the capacity to choose one outcome (a "positive instance") in the face of a large number of possible outcomes. Such redefinition, though at first startling, takes substance from the recent demonstration of the importance of the outcome of action in the determination of the reorganization of the visual field after experimental inversion (Hein & Held, 1957; Köhler, 1951; Werner & Wapner, 1952; Werner & Wapner, 1955).

Parallels with other, more recent neuropsychological analyses can also be drawn. Denny-Brown (1956) has distinguished between cortical resections that affect patterns of approaching (grasping, hopping, placing) and those that affect pat-

"Thinking" has, for the most part, been the province of philosophers. But, as Fromm has emphasized, philosophies of thought have been of two sorts: those that originate

terns of avoiding (withdrawing). Although the cortical resections made by Denny-Brown and those described here are only roughly comparable, enough correspondence exists to permit the suggestion that the "patterns of approaching" and "sampling" as described here, may reflect some common mechanism; that the "patterns of avoiding" may be manifestations (in untamed animals subjected to laboratory routines) of the behavior described here as guided by outcomes.

Nor is the distinction between the delineative and the economic aspects of problem solution a new one in the behavioral sciences. The contributions of the Würzburg school (Humphrey, 1951) and their Gestalt oriented successors (Allport, 1955; Lewin, 1936; Maier, 1930; Wertheimer, 1945) have consistently emphasized the distinction between the "content" of thought and its "direction" or "motor," between knowledge and intention (Lewin, 1936). These formulations, however, have frequently confounded two of the pairs of distinctions made in this presentation: the distinction between the delineative and the economic aspects of problem solution on the one hand, and, on the other, that between the attitudinal (partitioning) factors and the events upon which those attitudes operate. Piaget (1955) comes somewhat closer to maintaining separate these distinctions. This correspondence between Piaget's analysis of the results of his observations and that presented here may be due to the similarity of the formal devices used: Piaget's "groups of displacements" are included in the "systems of transformations" referred to throughout this presentation.

Psychoanalytic formulations have suffered from some confusions similar to those of the Gestalt schools. The psychoanalytic formulations have, for the most part, been concerned with intentional behavior, but they have been couched in vocabulary devised to describe differentiation. As a result, distinctions between the "attitudinal" ("expectational," "should") determinants of intentional behavior and the "affective" ("dispositional," "want") determinants have been spoken of as differences between "conscious" (differentiated) and "unconscious" determinants. A more precise statement is made possible by the argument here presented. The attitudinal and affective determinants of intentional behavior are inexorably mixed; distinguishing between them is a problem in its own right. This problem has its economic aspects: the patient must "want" solution of the problem, and he must "expect," i.e., be willing to "pay for," solution. The problem also has its delineative aspects: a differentiation must be made between attitudinal factors (expectations, plans, programs) which determine the patient's intentions and which are "empty" *per se*,

in Aristotelian logic and those more interested in logical paradox (Fromm, 1956). Epistemologies (e.g., the empiricist writings of Locke and of Hume) have delineated the problem acutely—for problem solution they have, almost invariably, resorted ultimately to intuition or nihilism. Philosophies more concerned with solutions of problems than with their delineation (e.g., in the Occidental tradition, the economic writings of Locke

and those factors which constitute dispositions. This is one of the tasks of therapy. Neither the attitudinal factors (expectations) nor the dispositions (wants) are "unconscious"; the distinction between them *is* unconscious, and it is this distinction that must therefore be delineated. Only when delineation has been accomplished can economic solution be attempted. Intentions can be altered by a change in action, and so in the outcomes that determine future intentions; or they can be altered by a change in expectations, and so in the specifications of the intentions.

Social scientists have also made use of the distinction between the delineative and the economic aspects of problem solution. Thus, Parsons distinguishes between determinants of "interest" in a problem and those "which provide the standards of what constitute satisfactory solutions of these problems" (Parsons, 1951). Basic to this distinction is the difference, as yet grasped only vaguely, between the acquisition of information (Shannon & Weaver, 1949) and its utilization (von Neumann & Morgenstern, 1953). The development of this distinction in the social, as well as in the biological (and in the physical), sciences is hampered by the fact that in connotative use the language of Occidental cultures fails to separate clearly the differences brought out by the neurobehavioral analysis made here: differences between attitudinal factors and the events upon which these attitudes operate on the one hand; and between the delineative and the economic aspects of problem solution on the other. Recently there has been, in North America, a shift in popular connotation away from attitudinal determinants: e.g., the term "honesty" no longer refers exclusively to "telling the truth," "respecting others' property" and such, but also to "behaving according to *how* one 'feels' and 'sees' the situation," even if this entails occasional lying or stealing (Riesman, Glazer, & Denny, 1950). Such confusion in connotative meaning creates special difficulties for a science that must obtain data almost exclusively from verbal reports. The results of analyses such as this one of neurobehavioral data may be most usefully applied to the social sciences as keys that open avenues of conceptualization common to all sciences, conceptualizations now locked behind the intricacies of verbal behavior.

and Adam Smith and of Marx; the philosophies of Spinoza and Hegel) have faced the paradoxical aspects of problem solution. The statement that, in an open market place, a maximum competitive self-interest leads not to destruction but to an increased standard of living is the result of an attempt to deal with paradoxes; paradoxes similar to those encountered here in the analyses of fluctuations in disposition and of combinations of expectations with respect to the outcome of actions. The psychological distance between the primates' neural mechanisms of differentiation and intention and systems of philosophy is still awesome; yet,

"Before the connection of thought and brain can be explained, it must at least be stated in an elementary form; and there are great difficulties about stating it. . . . Many would find relief at this point in celebrating the mystery of the unknowable and the "awe" which we should feel. . . . It may be constitutional infirmity, but I can take no comfort in such devices for making a luxury of intellectual defeat. . . . Better live on the ragged edge, better gnaw the file forever!" (James, 1950, pp. 177-179).

REFERENCES

Allport, F. A. *Theories of perception and the concept of structure.* New York: John Wiley & Sons, Inc., 1955. pp. 14–57.

Bruner, J. S. On perceptual readiness. *Psychol. Rev.,* 1957, 64, 123–152.

Bruner, J. S., Wallach, M. A., & Galanter, E. H. The identification of recurrent regularity. *Am. J. Psychol.,* 1959, LXXII, 200–209.

Burns, B. D., Grafstein, B., & Olszewski, J. Identification of neurones giving burst response in isolated cerebral cortex. *J. Neurophysiol.,* 1957, 20, 200-210.

Bush, R. R. & Mosteller, F. A model for stimulus generalization and discrimination. *Psychol. Rev.,* 1951, 58, 413-423.

Cannon, W. B. The body physiologic and the body politic. *Science,* 1941, 93, 1–10.

Chow, K. L. Effects of temporal neocortical ablation on visual discrimination learning sets in monkeys. *J. comp. physiol. Psychol.,* 1954, 47, 194–198.

Chow, K. L. & Hutt, P. J. The association cortex of Macaca mulatta: a review of recent contributions to its anatomy and functions. *Brain,* 1953, 76, 625-677.

Denny-Brown, D. Positive and negative aspects of cerebral cortical functions. *N. Carolina Med. J.,* 1956, 17, 295-303.

Deutsch, J. A. A new type of behavior theory. *British J. Psychol.*, 1953, XLIV (Part 4), 304–317.

Dewey, J. *Essays in experimental logic.* Chicago: Univ. of Chicago Press, 1916, pp. 183–216.

Dodt, E. Centrifugal impulses in rabbit's retina. *J. Neurophysiol.*, 1956, 19, 301–307.

Duncker, K. On problem solving. *Psychological Monographs* (Amer. Psychol. Assoc., Washington, D. C.), 1945, 58.

Eccles, J. C., Fatt, P., & Landgren, S. Central pathway for direct inhibitory action of impulses in largest afferent nerve fibres to muscle. *J. Neurophysiol.*, 1956, 19, 75–98.

Eldred, E. & Hagbarth, K. E. Facilitation and inhibition of gamma efferents by stimulation of certain skin areas. *J. Neurophysiol.*, 1954, 17, 59–65.

Elithorn, A., Piercy, M. F., & Crosskey, Margaret. Prefrontal leucotomy and the anticipation of pain. *J. Neurol., Neurosurg., & Psychiat.*, 1955, 18, 34–43.

Estes, W. K. Toward a statistical theory of learning. *Psychol. Rev.*, 1950, 57, 94–107.

Estes, W. K. Theory of elementary predictive behavior: an exercise in the behavioral interpretation of a mathematical model. *Mathematical Models of Human Behavior, Proceedings of a Symposium.* Stamford, Conn.: Dunlap and Associates, Inc., 1955.

Finger, F. W. The effect of food deprivation and subsequent satiation upon general activity in the rat. *J. comp. physiol. Psychol.*, 1951, 44, 557–564.

Finger, F. W. & Reid, L. S. The effect of water deprivation and subsequent satiation upon general activity in the rat. *J. comp. physiol. Psychol.*, 1952, 45, 368–372.

Forgus, R. H. The effect of early perceptual learning on the behavioral organization of adult rats. *J. comp. physiol. Psychol.*, 1954, 47, 331–336.

Forgus, R. H. Advantage of early over late perceptual experience in improving form discrimination. *Canad. J. Psychol.*, 1956, 10, 147–155.

Forgus, R. H. The effect of different kinds of form pre-exposure on form discrimination in learning. *J. comp. physiol. Psychol.*, in press.

Freeman, W. & Watts, J. W. Intelligence, emotion and social behavior following prefrontal lobotomy for mental disorders. *Psychosurgery.* Springfield, Ill.: Charles C Thomas, 1951 (2nd ed.), XXVIII.

Freud, S. *On aphasia.* New York: International Universities Press, Inc., 1953, pp. 48–105.

Fromm, E. *The art of loving.* New York: Harper & Brothers, 1956, pp. 72–82.

Fuller, J. L., Rosvold, H. E., & Pribram, K. H. The effect of affective and cognitive behavior in the dog of lesions of the pyriform-amygdala-hippocampal complex. *J. comp. physiol. Psychol.*, 1957, 50, 89–96.

Fulton, J. F., Pribram, K. H., Stevenson, J. A. F.,

& Wall, P. D. Interrelations between orbital gyrus, insula, temporal tip and anterior cingulate. *Trans. Amer. Neurol. Assoc.*, 1949, p. 175.

Galambos, R. Suppression of auditory nerve activity by stimulation of efferent fibers to cochlea. *J. Neurophysiol.*, 1956, 19, 424–437.

Galanter, E. H. & Gerstenhaber, M. On thought: the extrinsic theory. *Psychol. Rev.*, 1956, 63, 218–227.

Gibson, J. J. *The perception of the visual world.* New York: Houghton Mifflin Co., 1950, pp. 110–114, 152–154.

Gibson, J. J. & Gibson, Eleanor J. Perceptual learning: differentiation or enrichment. *Psychol. Rev.*, 1955, 62, 32–41.

Gibson, J. J. & Gibson, Eleanor J. *Continuous perspective transformations and the perception of rigid motion.* Research Report under Office of Naval Research Contract and Cornell University on the Visual Perception of Motion and Space, September 1956.

Gloor, P. Electrophysiological studies on the connections of the amygdaloid nucleus in the cat. *EEG Clin. Neurophysiol.*, 1955, 7, 223–242 (Part I), 243–264 (Part II).

Goldstein, K. *Language and language disturbances.* New York: Grune & Stratton, 1948, pp. 5–8.

Granit, R. Centrifugal and antidromic effects of ganglion cells of retina. *J. Neurophysiol.*, 1955, 18, 388–411.

Green, E. J. A simplified model for stimulus discrimination. *Psychol. Rev.*, 1958, 65, 56–63.

Hagbarth, K. E. & Kerr, D. I. B. Central influences on spinal afferent conduction. *J. Neurophysiol.*, 1954, 17, 295–307.

Hall, J. F. & Hanford, P. V. Activity as a function of a restricted feeding schedule. *J. comp. physiol. Psychol.*, 1954, 47, 362–363.

Harlow, H. F. Responses by rhesus monkeys to stimuli having multiple sign values. *Studies in Personality.* New York: McGraw-Hill, 1942, pp. 105–123.

Harlow, H. F. Higher function of the nervous system. *Ann. Rev. Psychol.*, 1953, 15, 493–514.

Harlow, H. F., Davis, R. T., Settlage, P. H. & Meyer, D. R. Analysis of frontal and posterior association syndromes in brain-damaged monkeys. *J. comp. physiol. Psychol.*, 1952, 45, 419–429.

Head, H. *Studies in neurology.* Oxford Medical Publications, 1920, Vol. 2, Part IV, Chap. 5, pp. 577–608.

Hebb, D. O. *The organization of behavior.* New York: John Wiley & Sons, 1949.

Hein, A. V. & Held, R. M. Correction of errors in hand-eye coordination after distortion of the retinal image. (Abstract of presentation at Eastern Psychol. Assoc., 28th Annual Meeting, 1957), p. 33.

Hernandez-Peon, R. & Scherrer, H. Central mechanisms controlling conduction along

central sensory pathways. *Acta Neural. Latino. Amer.*, 1955, 1, 256–264.

Humphrey, G. *Thinking.* London: Methuen Press, 1951.

Jacobsen, C. F. Studies of cerebral function on primates. *Comp. Psychol. Monogr.*, 1936, 13, 3–60.

James, W. *Principles of psychology.* Dover, 1950, Vol. 1, pp. 489–490, 177–179.

Kerr, D. I. B. & Hagbarth, K. E. An investigation of olfactory centrifugal fiber system. *J. Neurophysiol.*, 1955, 18, 362–374.

Klüver, H. Functional significance of the geniculo-striate system. *Biological symposia.* Lancaster: Jaques Cattell Press, 1942, pp. 253–300.

Kochen, M. & Galanter, E. H. The acquisition and utilization of information in problem solving and thinking. *Information and Control*, 1958, 1, 267–288.

Köhler, I. Uber aufbau und wandlagen der wahrnehmugswelt. *Oesterr. Akad. Wiss. Philos.-Histor. Kl.*, 1951, 227, 1–118.

Köhler, W. *The place of value in a world of fact.* New York: Liveright Publishing Co., 1938.

Köhler, W. & Held, R. The cortical correlate of pattern vision. *Science*, 1949, 110, 414–419.

Köhler, W., Neff, W. D., & Wegener, J. Currents of the auditory complex in the cat. *J. cell. comp. Physiol.*, 1955, 45, 1–24.

Köhler, W. & Wegener, J. Currents of the human auditory complex. *J. cell. comp. Physiol.*, 1955, 45, 25–54.

Kuffler, S. W. & Gerard, R. W. The small-nerve motor system to skeletal muscle. *J. Neurol. Physiol.*, 1947, 10, 383.

Kuffler, S. W. & Hunt, C. C. The mammalian small-nerve fibers: a system for efferent nervous regulation of muscle spindle discharge. *Patterns of Organization in the Central Nervous System* (Res. Publ. Ass. nerv. ment. Dis.), 1952, 30, pp. 24–47.

Lashley, K. S. The problem of cerebral organization in vision. *Biological Symposia.* Lancaster: Jaques Cattell Press, 1942, pp. 301–322.

Lashley, K. S. In search of the engram. *Physiological Mechanisms in Animal Behavior.* New York: Academic Press, 1950, pp. 454–482.

Lashley, K. S. Functional interpretation of anatomic patterns. *Patterns of Organization in the Central Nervous System* (Res. Publ. Ass. nerv. ment. Dis.), 1952, 30, pp. 537–539.

Lawrence, D. H. Acquired distinctiveness of cues: I. Transfer between discriminations on the basis of familiarity with the stimulus. *J. exp. Psychol.*, 1949, 39, 776–784.

Lawrence, D. H. Acquired distinctiveness of cues: II. Selective association in a constant stimulus situation. *J. exp. Psychol.*, 1950, 40, 175–188.

Lawrence, D. H. & Mason, W. A. Food intake in the rat as a function of deprivation intervals and feeding rhythms. *J. comp. physiol. Psychol.*, 1955, 48, 267–271.

Leary, R. W., Harlow, H. F., Settlage, P. H. & Greenwood, D. D. Performance on double alternation problems by normal and brain-injured monkeys. *J. comp. physiol. Psychol.*, 1952, 45, 576–584.

Lewin, K. *Principles of topological psychology.* New York: McGraw-Hill Book Co., 1936.

Mach, E. *Contributions to the analysis of sensations* (tr. C. M. Williams). Chicago: Open Court, 1897.

Maier, N. R. F. Reasoning in humans. I. On direction. *J. Comp. Psychol.*, 1930, 10, 115–143.

Malmo, R. B. Interference factors in delayed response in monkeys after removal of frontal lobes. *J. Neurophysiol.*, 1942, 5, 295–308.

Mann, H. B. & Whitney, D. R. On a test of whether one of two random variables is stochastically larger than the other. *Ann. Math. Statist.*, 1947, 18, 50–60.

McNemar, Q. *Psychological statistics.* New York: Wiley, 1955, p. 332.

Meyer, J. S. Studies of cerebral circulation in brain injury. IV. Ischemia and hypoxemia of the brain stem and respiratory center. *EEG clin. Neurophysiol.*, 1957, IX, 83–100.

Miller, G. A. *Language and communication.* New York: McGraw-Hill, 1951, pp. 223–248.

Miller, G. A., Heise, G. A., & Lichten, W. The intelligibility of speech as a function of the context of the test materials. *J. exp. Psychol.*, 1951, 41, 329–335.

Mishkin, M. Visual discrimination performance following ablations of the temporal lobe: II. Ventral surface vs. hippocampus. *J. comp. physiol. Psychol.*, 1954, 47, 187–193.

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

Mishkin, M. & Pribram, K. H. Visual discrimination performance following partial ablations of the temporal lobe: I. Ventral vs. lateral. *J. comp. physiol. Psychol.*, 1954, 47, 14–20.

Mishkin, M. & Pribram, K. H. Analysis of the effects of frontal lesions in monkeys: I. Variations of delayed alternation. *J. comp. physiol. Psychol.*, 1955, 48, 492–495.

Mishkin, M. & Pribram, K. H. Analysis of the effects of frontal lesions in monkeys: II. Variations of delayed response. *J. comp. physiol. Psychol.*, 1956, 49, 36–40.

Nissen, H. U., Riesen, A. H. & Nowles, V. Delayed response and discrimination learning by chimpanzees. *J. comp. Psychol.*, 1938, 26, 361–386.

Olds, J. A preliminary mapping of electrical reinforcing effects in the rat brain. *J. comp. physiol. Psychol.*, 1956, 49, 281–285.

Parsons, T. *The social system*. Glencoe, Ill.: The Free Press, 1951, 14–15.

Penfield, W. Bilateral frontal gyrectomy and postoperative intelligence. *Res. Publ. Ass. nerv. ment. Dis.*, 1948, 27, 519–564.

Petrie, Asenath. *Personality and the frontal lobes*. London: Routledge and Kegan Paul, 1952.

Piaget, J. *The language and thought of the child*. (tr. Marjorie Gabain) New York: Noonday Press, 1955, pp. 171 240.

Pribram, K. H. Toward a science of neuropsychology: (method and data). *Current Trends in Psychology and the Behavioral Sciences*. Pittsburgh: Univ. of Pittsburgh Press, 1954, 115–142.

Pribram, K. H. Comparative neurology and the evolution of behavior. *Behavior and Evolution*. New Haven: Yale Univ. Press, 1958, 140–164. (a)

Pribram, K. H. Neocortical function in behavior. *Symposium on Interdisciplinary Research in Behavioral, Biological, and Biochemical Sciences*. Madison: Univ. of Wisconsin Press, 1958, 151–172. (b)

Pribram, K. H. Concerning the neurophysiological correlates of limbic system stimulation. *Symposium on Brain Stimulation*. Houston: Univ. of Houston Press, in press.

Pribram, K. H. & Bagshaw, Muriel. Further analysis of the temporal lobe syndrome utilizing fronto-temporal ablations. *J. comp. Neurol.*, 1953, 99, 347 375.

Pribram, K. H. & Fulton, J. F. An experimental critique of the effects of anterior cingulate ablations in monkeys. *Brain*, 1954, 77, 34–44.

Pribram, K. H. & Kruger, L. Functions of the "olfactory brain." *Ann. N. Y. Acad. Sci.*, 1954, 58, 109–138.

Pribram, K. H. & Mishkin, M. Analysis of the effects of frontal lesions in monkey: III. Object alternation. *J. comp. physiol. Psychol.*, 1956, 49, 41–45.

Pribram, K. H. & Weiskrantz, L. A comparison of the effects of medial and lateral cerebral resection on conditioned avoidance behavior of monkeys. *J. comp. physiol. Psychol.*, 1957, 50, 74–80.

Richter, C. P. Experimental production of cycles in behavior and physiology in animals. *Acta med. Scand.*, 1955, 152, 36 37.

Riesman, D., Glazer, N. & Denny, R. *The lonely crowd: a study of the changing American character*. New Haven: Yale Univ. Press, 1950, 184–209.

Riopelle, A. J., Alper, R. G., Strong, P. N. & Ades, H. W. Multiple discrimination and patterned string performance of normal and temporal-lobectomized monkeys. *J. comp. physiol. Psychol.*, 1953, 46, 145–149.

Rylander, G. Personality analyses before and after frontal lobotomy. *Res. Pub. Ass. nerv. ment. Dis.*, 1948, 27, 691–705.

Scheibel, M., Scheibel, A., Amollica, A. & Moruzzi, G. Convergence and interaction of afferent impulses on single units of reticular formation. *J. Neurophysiol.*, 1955, 18, 309–331.

Segundo, J. P. Reticular formations—a survey. *Acta Neural. Latino Amer.*, 1956, 2, 245 281.

Shannon, C. E. & Weaver, W. *The mathematical theory of communication*. Urbana: Univ. of Illinois Press, 1949.

Sherrington, C. C. *The integrative action of the nervous system*. New Haven: Yale Univ. Press, 1947 (1906).

Skinner, B. F. *The behavior of organisms: an experimental analysis*. New York: D. Appleton-Century Co., Inc., 1938.

Stamm, J. S. Control of hoarding activity in rats by the median cerebral cortex. *J. comp. physiol. Psychol.*, 1954, 47, 21–27.

Stamm, J. S. The function of the median cerebral cortex in maternal behavior of rats. *J. comp. physiol. Psychol.*, 1955, 48, 347 356.

Stevens, S. S. Mathematics, measurement and psychophysics. *Handbook of Experimental Psychology*. New York: John Wiley and Sons, Inc., 1951, 31–32.

von Neumann, J. & Morgenstern, O. *Theory of games and economic behavior*. Princeton, N. J.: Princeton Univ. Press, 1953, 19, 20; 24–28; 39 41; 60–73.

Weiskrantz, L. Behavioral changes associated with ablation of the amygdaloid complex. Ph.D. Dissertation, Harvard University, 1953.

Werner, H. Musical "micro-scales" and "micro-melodies." *J. Psychol.*, 1940, 10, 149–156.

Werner, H. & Wapner, S. Toward a general theory of perception. *Psychol. Rev.*, 1952, 59, 324–338.

Werner, H. & Wapner, S. The Innsbruck studies on distorted visual fields in relation to an organismic theory of perception. *J. Psychol. Rev.*, 1955, 62, 130–138.

Wertheimer, M. *Productive thinking*. New York: Harper, 1945.

Wiener, N. *Cybernetics*. New York: John Wiley and Sons, Inc., 1949.