2 Self-Consciousness and Intentionality

A Model Based on an Experimental Analysis of the Brain Mechanisms Involved in the Jamesian Theory of Motivation and Emotion

KARL H. PRIBRAM

I. A NEUROBEHAVIORAL ANALYSIS OF BRAIN MECHANISMS IN MOTIVATION AND EMOTION

A. Introduction

The recent revolution in psychology has readmitted cognition and consciousness as legitimate areas of scientific investigation. The study of cognitive processes has made rapid strides by taking as its model brain mechanisms assumed to be similar to those of the digital computer (Miller, Galanter, and Pribram, 1960) and by utilizing reaction-time data investigations of memory for verbally coded materials. The currently projected volumes on consciousness and self-regulation presuppose that equally effective strides can be made in our research on, and understanding of, consciousness. The title of the series, in fact, suggests that data on self-regulation, utilizing biofeedback procedures, will provide the substance upon which such strides will be based.

But if understanding comparable to that attained for cognition is to be achieved, an experimentally based model of the brain processes operative in consciousness must also be made available. The purpose of this paper is to provide the outlines of such a model.

KARL H. PRIBRAM · Department of Psychology, Stanford University, Stanford, California.

There are many meanings attributed to the term *consciousness*. Webster's dictionary covers a dozen. There have been articles written on the consciousness of cells; Eastern mystics speak of the consciousness of stones; Jungians deal with universal human consciousness (see Ornstein, 1972, 1973 for review). I have, in another manuscript (Pribram, 1976b), taken a somewhat more direct and perhaps practical approach to definition. These largely definitional issues need not concern us here since self-consciousness can be clearly distinguished from other forms of consciousness.

Self-consciousness is said to occur when an observer is able to describe both the observed and the observing. Philosophers (Husserl, 1928) have called this ability *intentionality*—thus the subtitle of the present manuscript. The term is derived from *intention*, an aim of an action which may or may not be realized. The separateness of intent and outcome of an action was generalized by Brentano (1925, 1960) to the objects of perceptual "acts." This generalization has proved to be prescient. Recent evidence from brain research (see Pribram, 1971, 1974, 1976a) has shown that the same parts of the brain (the basal ganglia) that control motor function also control sensory input. These controls operate by changing the set point of receptors (see below) in muscles or sense organs and are therefore ideally suited to function as intentionality mechanisms.

Thus the outcomes of actions and the objects of perception come to form one universe—the realized universe of existence—while the intentional universe is dispositional and may even be unrealizable (the awkward term *intentional inexistence* was meant to convey this nonreality). The difficulty with such terminolgy is, of course, that other philosophers can counter with the proposition that the phenomenal experience of dispositions exists just as much as the outcomes of actions and the objects of experience and that, to some, these dispositions are *the* existential reality. For us here, the distinction, not the argument, is the important concern: In studies of self-regulation both disposition and outcome are realized. After all, the instrumentation that allows the externalization (objectively demonstrating the separate existence) of dispositions is the innovation that makes the scientific study of self-consciousness now possible.

Behavioral psychologists have ordinarily designated dispositions by the terms *emotion* and *motivation*. The intentionality of motivation is relatively obvious, although Miller, Galanter, and Pribram (1960) dis-

tinguish between motive and intent as follows:

> Jones hires Smith to kill someone. Smith commits the murder, but he is caught and confesses that he was hired to do it. Question: Is Smith Guilty? If we consider only the motives involved, the employer is guilty because he was motivated to kill, but the gunman is not guilty because his motive was merely to earn money (which is certainly a commendable motive in a capitalistic society). But if we consider their intentions, then both parties are equally guilty, for both of them knowingly undertook to execute a Plan culminating in murder. (p. 61)

Motive in ordinary and legal language apparently refers more to the feelings involved, while *intent* refers to the aims of actions. A similar distinction can be made in the case of emotions: The feelings of emotional elation or upset can be separated from their "aim" or target— e.g., accomplishing rapport with someone whom one is in love with. The fact that motivational and emotional feelings (dispositions) can be distinguished from their referents makes intentionality possible. The purpose of studies of self-consciousness is to enhance intentionality by providing independent controls (self-regulation) on motivational and emotional dispositions. Stated in this fashion, it becomes clear that the terms *intentionality* and *volition* have a good deal in common. In popular parlance, of course, to "intend" something is to "will" it. The issue of self-consciousness is therefore also the issue of voluntary control, and any proposed brain model must take this into account.

Interestingly, William James (1950) dealt with these related issues in a most sophisticated manner. I want here, therefore, to develop and evaluate by both positive and negative comment the Jamesian model, critically but not polemically. Rather the presentation will review a series of clinical observations and laboratory experiments specifically designed to test aspects of the model with the aim of providing a modification based on currently available data.

B. Case History

The observations and experiments were begun within the framework of a James–Lange view of the problem, a view that William James (1950) proposed as follows: "Bodily changes follow directly the perception of the exciting fact and—our feeling of the same changes as they occur *is* the emotion" (Vol. II, p. 449). As did most investigators at the time, and perhaps even now, I took this to mean that emotional feelings

result when visceroautonomic mechanisms become activated. This aspect of the theory is attributed by William James to Carl Lange, who had suggested that emotional feelings were due to changes in vascularity and other visceral processes. True, the work of Walter Cannon (1927) had made it mandatory to replace peripheral with central mechanisms, but these were still thought of in terms of visceroautonomic processes. It was, after all, the "head ganglion" of the autonomic nervous system that concerned Cannon.

My entry into the problem was due to a patient, a Greek woman in her early fifties, who suffered from Jacksonian epileptic seizures always initiated and almost always limited to the left part of her face. Characteristically, even before any muscular twitching, there would be a profuse outpouring of perspiration sharply restricted to the left side of the face and neck as if by a line drawn to separate the two sides. To make a long story short, Paul Bucy and I (Bucy and Pribram, 1943) diagnosed a brain tumor and found and removed a circumscribed oliogodendroglioma located in the right precentral motor cortex. The patient recovered completely with no residual paralysis and with elimination of the seizures.

The localized sweating shown by this woman was caused by irritation of the precentral motor cortex and thus called into question the idea then held that it was the hypothalamus which was the "head ganglion" of the autonomic nervous system. Obviously, cortical mechanisms played some role in the regulation of visceroautonomic activity.

C. A Mediobasal Motor System

After publication of this patient's story, it became clear to me that visceroautonomic auras were not altogether rare in epileptic patients. However, the great majority of such auras could be referred to pathology in and around the Island of Reil and the pole of the temporal lobe. I therefore began a program of research to map the cortical sites in nonhuman primates from which visceroautonomic responses could be obtained by electrical stimulations. The initial experiments were performed at the Yerkes laboratory with a Harvard inductorium and produced equivocal and unreliable results. I heard, however, that at Yale a new method of cortical stimulation had been developed—a thyrotron stimulator which put out square waves instead of sine waves—and that

pulse duration as well as voltage and frequency could be controlled. With this stimulator, Arthur Ward had been able to produce visceroautonomic effects from excitation of the anterior part of the cingulate gyrus (Ward, 1948), and Robert Livingston had succeeded in showing similar effects from the posterior orbital surface of the frontal lobe (Livingston, Fulton, Delgado, Sachs, Brendler, and Davis, 1948). Because of the connections of these portions of the frontal cortex via the uncinate fasciculus, which had been demonstrated not only anatomically but with strychnine neuronography by McCulloch, Bailey, and von Bonin (Bailey, von Bonin, and McCulloch, 1950)—experiments I had had an opportunity to observe—I decided to go to Yale to extend the stimulation experiments to the temporal pole. There I found Birger Kaada, who had just begun his thesis with the aim of analyzing not only the visceroautonomic but also the "suppressor" effects of cingulate gyrus stimulation. Working in adjacent laboratories, obtaining identical effects from stimulation of the temporal pole and the cingulate cortex, late one night we joined forces and mapped the entire area from above the corpus callosum to below it, and by turning the monkey on his back and letting the frontal lobe hang away from the base of the skull, we traced the entire region effective in producing visceroautonomic responses: cingulate, subcallosal, medial and posterior orbital, anterior insular, periamygdaloid, and temporal polar cortex. This was made especially easy once the Sylvian fissure was opened by gentle retraction and temporarily packed with cotonoid patties. In short, we mapped (Kaada, Pribram, and Epstein, 1949; Kaada, 1951) a continuous region of cortex lying on the edge, the limbus of the anterior portion of the cerebral hemisphere, which, when stimulated, produced respiratory arrest, a drop in blood pressure, changes in heart rate, eye movements, turning of the head, and under proper circumstances, suppression (or occasionally enhancement) of spinal reflexes. We had mapped a mediobasal motor cortex.

What then of the visceroautonomic seizures in the patient with the precentral oliogodendroglioma? In another series of experiments Patrick Wall and I (Wall and Pribram, 1950) mapped the lateral surface of the cortex and, again to make a long story short, found that such responses could be obtained from the classical precentral motor cortex. Despite a whole series of attempts, we were unable to specify the difference between these responses and those obtained from the mediobasal cortex.
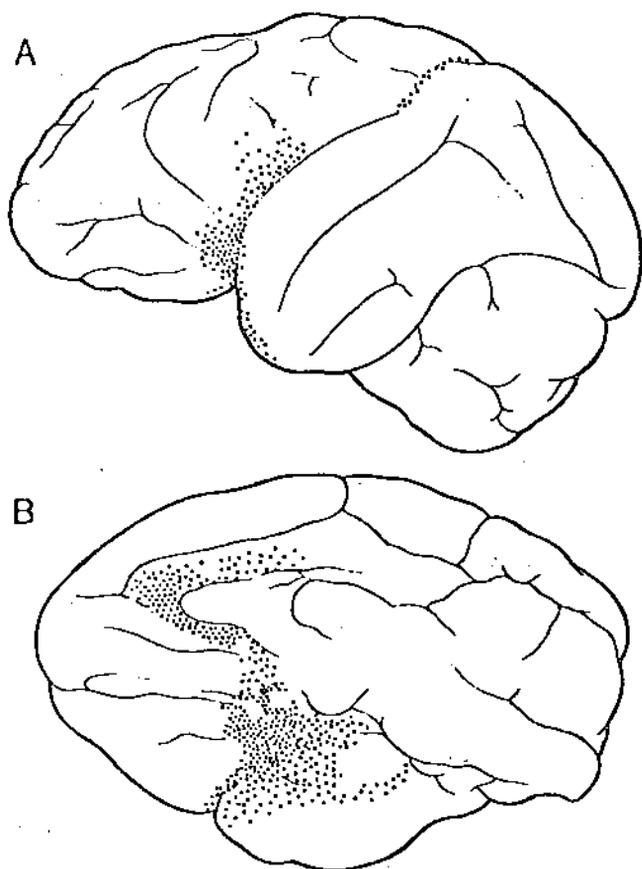
FIGURE 1.   The medial-basal motor cortex. Black dots indicate areas for which electrical stimulation produces changes in blood pressure, heart rate, respiratory rate, eye movements, and gross bodily movements. (A) Lateral surface: (B) Medial-basal surface. One accomplishes this view by making a slit in the lateral part of the hemisphere and bringing the basal surface in line with the medial surface.

It should not have been altogether surprising that visceroautonomic responses are obtained from stimulations that also produce somatomotor responses. Even stimulation of the hypothalamus, the head ganglion of the autonomic nervous system, produces somatomotor as
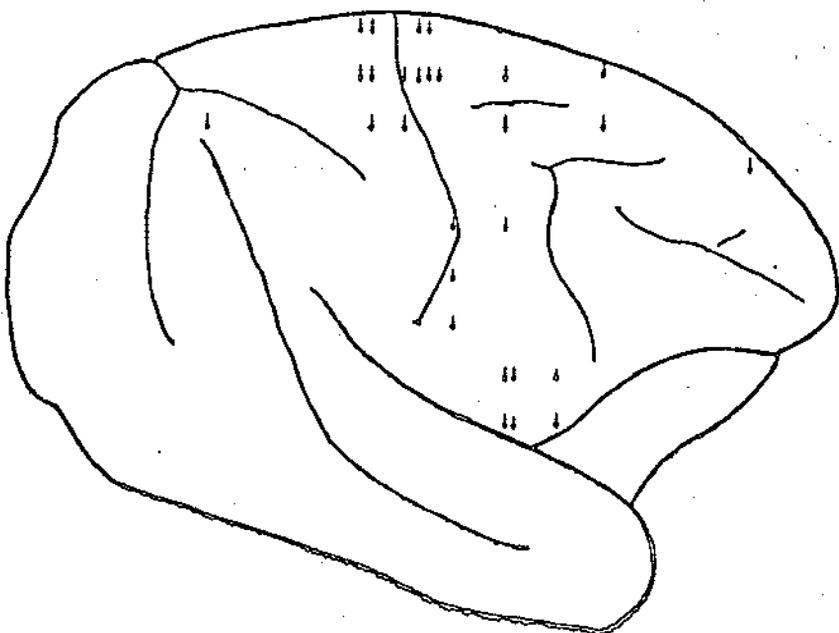
FIGURE 2. Points of stimulation in the somatosensory motor cortex of the lateral extent of the hemisphere giving rise to changes in blood pressure, heart rate, respiratory rate, and discrete movement.

well as visceral responses. In fact, William James (1950) had stated the issue clearly:

> If the neural process underlying emotional consciousness be what I have now sought to prove it, the physiology of the brain becomes a simpler matter than has been hitherto supposed. Sensational, associational, and motor elements are all that the organ need contain. The physiologists who, during the past few years, have been so industriously exploring the brain's functions, have limited their explanations to its cognitive and volitional performances. Dividing the brain into sensory and motor centres, they have found their division to be exactly paralleled by the analysis made by empirical psychology of the perceptive and volitional parts of the mind into their simplest elements. But the emotions have been so ignored in all these researches that one is tempted to suppose that if these investigators were asked for a theory of them in brain-terms, they would have to reply, either that they had as yet bestowed no thought upon the subject, or that they had found it so difficult to make distinct hypotheses that the matter lay among the problems of the future, only to be taken up after the simpler ones of the present should have been definitely solved.

And yet it is even now certain that of two things concerning the
emotions, one must be true. Either separate and special centres, affected to
them alone, are their brainseat, or else they correspond to processes occur-
ring in the motor and sensory centres already assigned, or in others like
them, not yet known. If the former be the case, we must deny the view that
is current, and hold the cortex to be something more than the surface of
"projection" for every sensitive spot and every muscle in the body. If the
latter be the case, we must ask whether the emotional *process* in the sensory
or motor centre be an altogether peculiar one, or whether it resembles the
ordinary perceptive processes of which those centres are already recognized
to be the seat. Now if the theory I have defended be true, the latter
alternative is all that it demands. Supposing the cortex to contain parts,
liable to be excited by changes in each special sense-organ, in each portion
of the skin, in each muscle, each joint, and each viscus, and to contain
absolutely nothing else, we still have a scheme capable of representing the
process of the emotions. An object falls on a sense-organ, affects a cortical
part, and is perceived; or else the latter, excited inwardly, gives rise to an
idea of the same object. Quick as a flash, the reflex currents pass down
through their preordained channels, alter the condition of muscle, skin, and
viscus; and these alterations, perceived, like the original object, in as many
portions of the cortex, combine with it in consciousness and transform it
from an object-simply-apprehended into an object-emotionally-felt. No new
principles have to be invoked, nothing postulated beyond the ordinary
reflex circuits, and the local centres admitted in one shape or another by all
to exist. (Vol. II, pp. 472-474)

Note that James emphasizes the sensory aspects of these "reflex
currents." We shall return to this point presently. But at the time of the
discovery of the mediobasal motor mechanism I *was* surprised and, in a
way, a little disappointed—we had not been able to confirm our hy-
pothesis that some part of the cerebral mantle dealt exclusively with
visceral mechanisms and could thus be thought of as a "visceral
brain"—a substrate for a Langian conception of "emotion." I might add
that everyone did not share this disappointment—Paul MacLean, my
office mate and collaborator in experiments mapping by electrical stim-
ulation and strychnine neuronography the organization of mediobasal
cortex (Pribram, Lennox, and Dunsmore, 1950; Pribram and MacLean,
1953; MacLean and Pribram, 1953), was more convinced by our reports
of visceroautonomic regulations by mediobasal cortex than by their
invariable concomitance with somatomotor effects (MacLean, 1949).
But for me the disappointment was real and led to puzzlement as to just
what could be the meaning of this juxtaposition of visceroautonomic
and somatomotor mechanisms to the brain's role in emotion and moti-
vation. I therefore turned to other techniques to help resolve these
issues.

D. The Limbic Systems and Behavior

First, it was necessary to obtain evidence that the limbic medio-basal motor mechanisms are in fact critically involved in motivational and emotional processes. To rephrase the question in experimentally testable terms, evidence had to be obtained to show that behavior ordinarily considered to be representative of motivational and emotional processes is disrupted by resections or excitations of the limbic mediobasal mechanism. As it turned out, the results of the experiments undertaken took us a long way into reformulating the problem of what constitutes such behavior.

A series of studies designed to analyze the syndrome described by Heinrich Klüver and Paul Bucy (Klüver and Bucy, 1937) to follow total temporal lobectomy provided the evidence. Klüver and Bucy had included taming, increased oral and sexual behavior, and visual agnosia
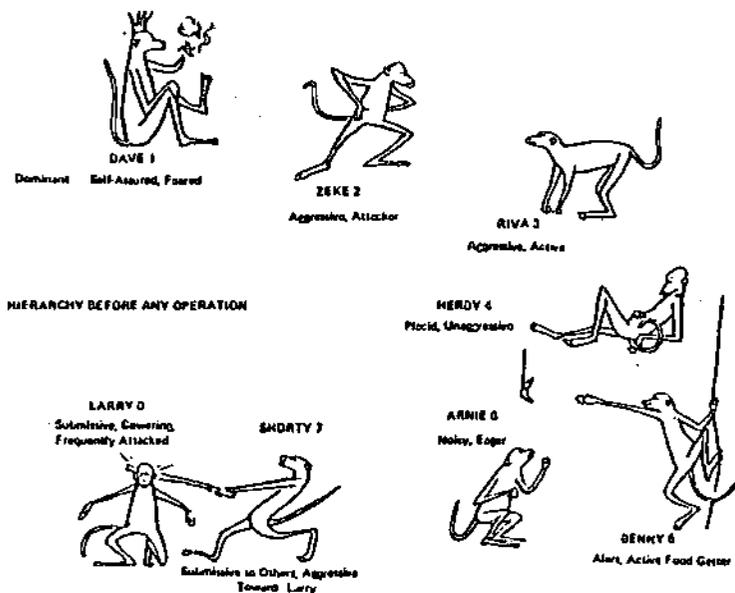

FIGURE 3(A)   Dominance hierarchy of a colony of eight preadolescent male rhesus monkeys before any surgical intervention.
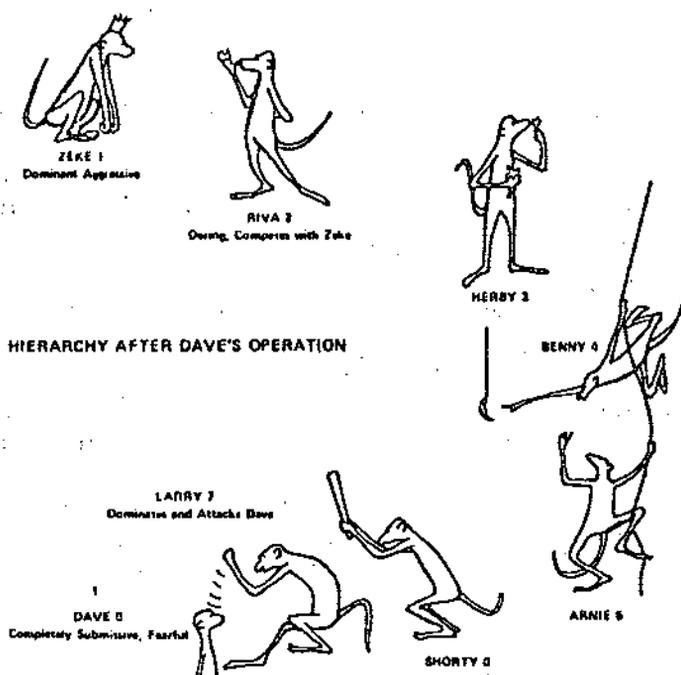
ZEKE I
Dominant Aggressive

RIVA 2
Daring, Competes with Zeke

HERBY 3

HIERARCHY AFTER DAVE'S OPERATION

BENNY 4

LARRY 7
Dominates and Attacks Dave

DAVE 8
Completely Submissive, Fearful

ARNIE 5

SHORTY 6

FIGURE 3(B)   Same as (A) after bilateral amygdalectomy had been performed on Dave. Note his drop to the bottom of the hierarchy.

in their syndrome. Our studies (Blum, Chow, and Pribram, 1950; Chow, 1951; Mishkin and Pribram, 1954; and Pribram, 1954) showed the agnosia to be due to resection of the lateral portions of the temporal lobe; however, these results make up a body of evidence which, though related to the issues being examined here, constitute a sufficiently separate domain to warrant presentation on another occasion (see, for example, Pribram, 1969, 1975). The remaining part of the syndrome was obtained full-blown when lesions were restricted to the anterior limbic portions of the lobe—those comprising the temporal lobe portions of the mediobasal motor mechanism (Pribram and Bagshaw, 1953). Subsequent studies showed the entire mediobasal motor system to be involved (Pribram and Weiskrantz, 1957).

Specifically, tests were performed to measure feeding, fleeing (avoidance), fighting (dominance), mating, and maternal (nesting) behavior (see reviews by Pribram, 1958, 1960). The fairly gross changes in

RIVA 1
Dominant, Not Threatened
by Others

HERBY 2

BENNY 3

ARNIE 4

HIERARCHY AFTER ZEKE'S OPERATION

ZEKE 7
Submissive to Others,
Intermittently Aggressive
Toward Dave
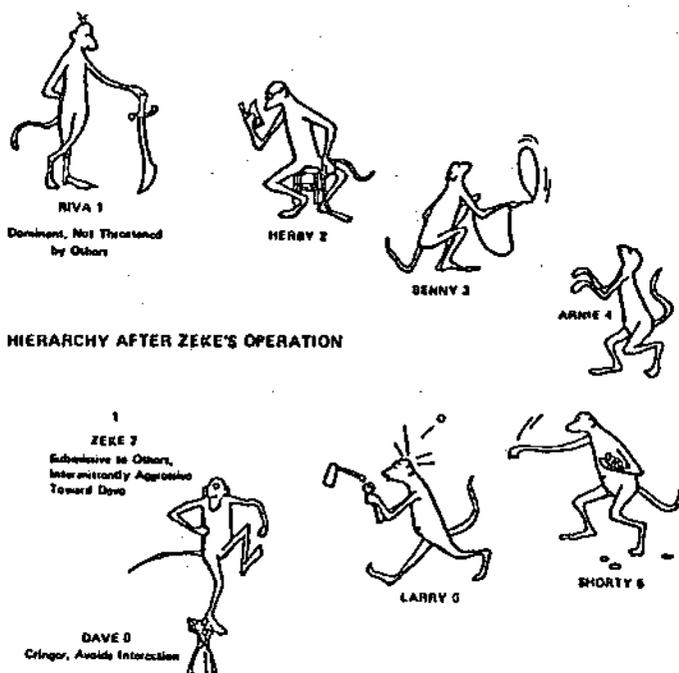
LARRY 5

SHORTY 6

DAVE 0
Cringer, Avoids Interaction

FIGURE 3(C) Same as (A) and (B) except that both Dave and Zeke have received bilateral amygdalectomies.

these behaviors following lesions of the limbic motor systems are so well known by now that I want here to present more quantitative data.

The effects of these lesions on *fighting* were observed in social situations (Rosvold, Mirsky, and Pribram, 1954). A group of eight preadolescent male monkeys were housed together until a more or less straight-line dominance hierarchy became stably established. Dominance was initially rated on the basis of order of obtaining food pellets inserted into the colony space, one by one through a metal tube. The dominance rating obtained in this way was then checked against quantitative observations of threatening gestures, actual fighting contacts, grooming contacts, and position displacements. Such observations were made not only in the colony when the group was together as a whole but also for all possible dyads. Then the clearly dominant monkey was submitted to psychosurgery. As expected, he fell to the bottom of the hierarchy. Interestingly, however, this drop was effected over a
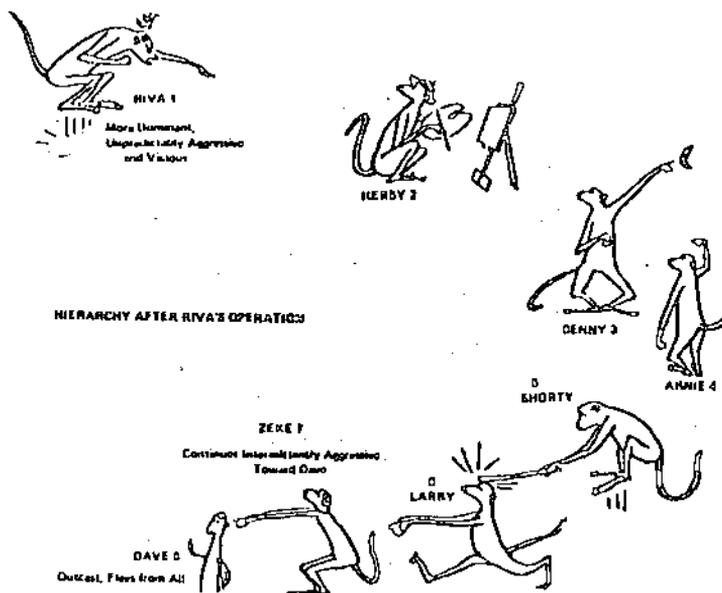
FIGURE 3(D) Final social hierarchy after Dave, Zeke and Riva have all had bilateral amygdalectomies. Note that Riva fails to fall in the hierarchy. Minimal differences in extent of locus of the resections do not correlate with differences in the behavioral results. The disparity has been shown in subsequent experiments to be due to Herby's nonaggressive "personality" in the second position of the hierarchy.

48-hour period during which interactions with the other monkeys gradually lowered the "status" of the previously dominant monkey.

This experience was essentially replicated when we performed surgery on the formerly Number 2 and now dominant animal. When, however, we attempted to repeat the procedure for a third time, the expected effects did not occur. In fact, the original Number 3 animal became, if anything, *more* aggressive and dominant. My colleagues in the study, Hal Rosvold and Alan Mirsky, of course, blamed inadequate surgery for this development, but histological verification failed to confirm their suspicions. In fact, the lesion of this last monkey extended further than that of one of the others, and all lesions encompassed the same anatomical structures.

What, then, could account for our results? Briefly, examination of our data, especially of the 48 initial postoperative hours in the colony,

and observations of other colonies of monkeys made us believe that lack of interaction between the operated subject and the original Number 4 monkey was responsible for the original Number 3 monkey's failure to fall in dominance. Many subsequent observations in dyadic situations confirmed this belief: Postoperative monkeys were especially sensitive to the way they were treated by their cage mates and handled by their caretakers. The immediate postoperative taming could be prolonged for years by gentling procedures, whereas ordinary neglect and occasional rougher treatment would produce either an excessively fearful or an unpredictably aggressive monkey. These results make it unlikely that some fundamental mechanism responsible for aggression had been excised; rather some brain process sensitive to the social environment seems to have been tapped.
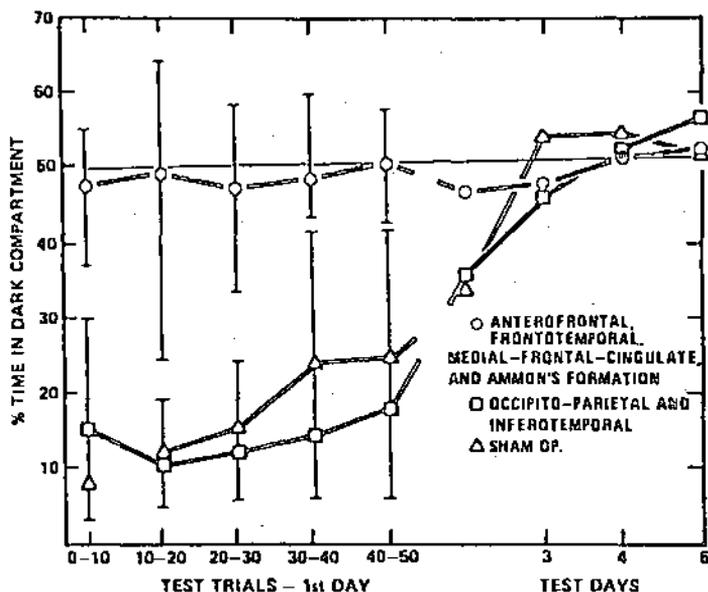

FIGURE 4(A)   Graph of the percentage of time spent by various groups of animals in the dark (previously shocked) compartment of a shuttle box during postoperative extinction of a preoperatively acquired conditioned avoidance. The scores for the first extinction day are recorded in 10-trial blocks; subsequent extinction trials are plotted in 50-trial blocks (one test day). Vertical bars indicate range of performance.
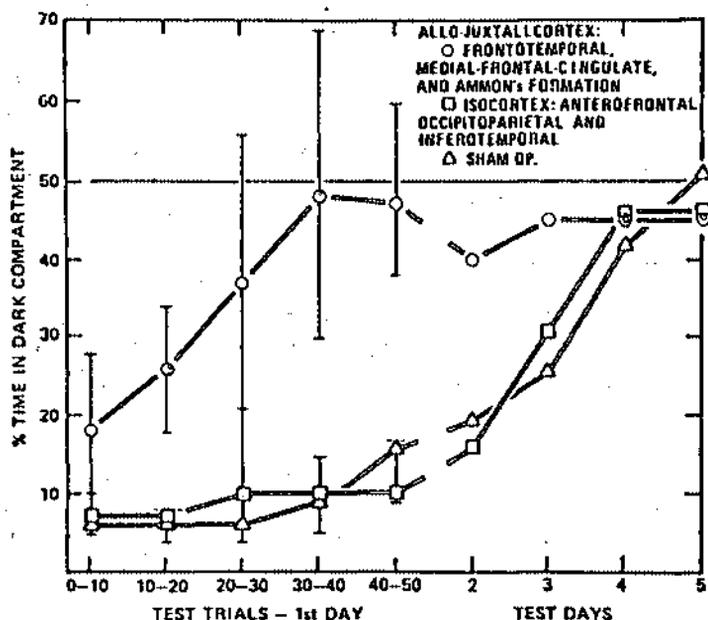
FIGURE 4(B) Graph of the percentage of time spent by the various groups of animals in the dark (previously shocked) compartment of a shuttle box during postoperative reextinction of postoperatively reacquired conditioned avoidance. Trial blocks divided as in 4(A). Bars indicate range of performance.

Similar results were obtained when *fleeing,* (avoidance) was tested by Weiskrantz and myself (Pribram and Weiskrantz, 1957) in a classical shuttle box. Escape proved unaffected by limbic lesions, but learning, extinction, and relearning of conditional avoidance behavior were affected. It should be noted in passing that limbic and not lateral forebrain lesions (except for frontal in the case of extinction) produced such results; however, neither classical sensory and motor resections nor basal ganglion removals were included in these studies.

Perhaps the clearest indication of what type of regulation is accomplished by the mediobasal motor mechanism came from our studies of *feeding.* Postoperatively, monkeys with lesions in these limbic areas often failed to eat for a time (usually not more than a week). Once they recovered, however, they might eat twice as much per day as preopera-

tively, and this increased food intake usually lasted for months (Pribram and Bagshaw, 1953).

Further analysis almost immediately uncovered a paradox. Despite this marked increase in feeding in an *ad libitum* situation, Schwartzbaum and I (Schwartzbaum, 1961) found that the monkeys with lesions were less sensitive to food deprivation or satiation when made to work for their food. They appeared "hungrier" when food was available but less "hungry" when they were deprived and food could be obtained only by the pressing of a lever to obtain pellets (on a variable interval schedule). But this was not all; the loss of sensitivity was not limited to variations in the internal state produced by the deprivation but extended as well to variations in the external characteristics of the food,
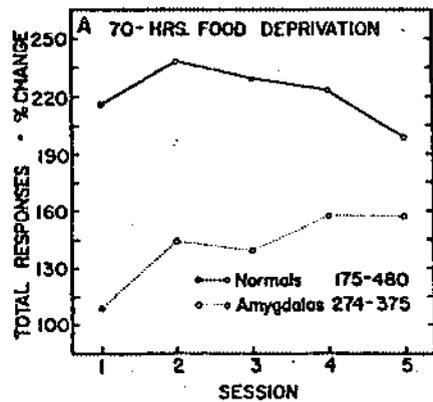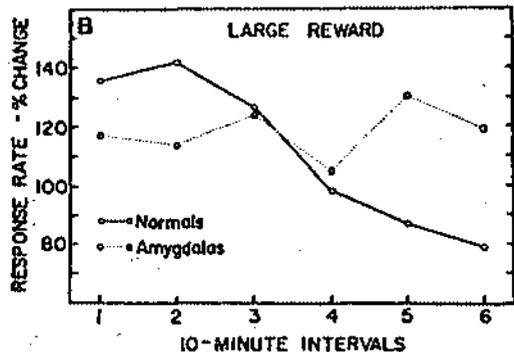

FIGURE 5(A) Effect of food deprivation on number of responses emitted by normal and bilaterally amygdalectomized monkeys in a fixed-interval operant-conditioning situation. Note that the percentage change in total number of responses is plotted on the graph. Absolute values are indicated in the right lower corner. 5(B) The effects of the changing of reward size on bilaterally amygdalectomized and normal monkeys on response rate in a fixed-interval situation. Note that normal animals satiate rapidly in a session when the pellet size is increased.

such as the size of the pellets received as a consequence of lever pressing (Schwartzbaum, 1960a, 1960b).

These results paralleled those that were being reported from analyses of feeding disturbances produced by ventromedial and far-lateral hypothalamic lesions. Miller, Bailey, and Stevenson (1950) found that rats who became obese in *ad libitum* feeding situations might starve if required to make the effort to cross a barrier to obtain their food. And Teitelbaum (1955) showed that rats who would starve in *ad libitum* situations could be induced to attend and eat if the sensory attractiveness of the food was sufficiently enhanced.

Two major hypotheses derive from these observations, one with respect to the sensory, the other with respect to the motor processes regulated by the limbic (and hypothalamic) mechanisms:

1. Attention (i.e., reaction) to external as well as to internal stimulation is involved in motivational and emotional *feeling*.
2. Effort, not drive (e.g., as defined by *ad libitum* feeding and lever pressing), is the critical variable determining motivational and emotional *expression* in behavioral responses.

Let us examine the evidence related to each of these hypotheses in turn.

II. THE ROLE OF ATTENTION IN MOTIVATIONAL AND EMOTIONAL REACTIONS

A. *Transfer of Training*

In order to bring the altered reactions to external stimulation of the lesioned monkeys into sharp focus, I decided to test them in a series of tasks which were as minimally related to motivation and emotion as I could find and yet might provide some indication of function. The point of departure for selecting these tasks was the dramatic change in dominance displayed in the social colony experiment. The lesioned monkeys behaved postoperatively as if they had never experienced the colony structure—they seemed to have to learn anew the repertoire of aggressive interactions that established their place in the hierarchy. They appeared not to transfer their prior experience to the postoperative situation.

Thus a series of *transfer-of-training* tasks was devised. The first, undertaken with Schwartzbaum (Schwartzbaum and Pribram, 1960), used a transposition paradigm in which the monkeys were initially trained to choose the lighter of two gray panels and were then tested on a pair of panels of which the formerly lighter one was now the darker of the test pair. All control subjects continued to choose the lighter panel, but the lesioned animals behaved oddly. They hesitated and then chose randomly between the two panels. It appeared as if they perceived the test situation to be novel and proceeded accordingly.

The results of a second experiment performed with Muriel Bagshaw (Bagshaw and Pribram, 1965) supported the findings of the first. In this experiment Heinrich Klüver's equivalence test (Klüver, 1933) was used. The monkeys were trained to choose the larger of two moderately sized squares and tested on a pair of smaller ones. Again the control subjects chose the larger panel throughout while the lesioned monkeys behaved as if the test panels presented them with an entirely novel situation.

Both the transposition and the equivalence results could be attributed to an altered gradient of generalization of input following the lesion. Eliot Hearst and I (Hearst and Pribram, 1964a, 1964b) put this possibility to test and found generalization unimpaired. In neither positive nor negative reinforcing situations were the monkeys' generalization gradients changed by the lesion. Thus transfer of training appears to be dissociable from sensory generalization—and perhaps might be more appropriately thought of in terms of "motor generalization"—a view consonant with the fact that lesions of the mediobasal motor cortex were the responsible agent in producing the changes.

TABLE 1
Number of Transposed Responses Made on Transposition Tests

Day	Normals					Amygdalectomized				
	439	441	443	447	Mdn.	397	405	438	442	Mdn.
1	6	5	6	6		2	5	2	4	
2	5	5	5	6		3	6	2	2	
Total	11	10	11	12	11.0	5	11	4	6	5.5

The effects of amygdalectomy on transfer of training to a new but related task. Note that the amygdalectomized monkeys treat the task as completely novel, whereas their normal controls transpose their responses on the basis of their earlier experience.

B. Psychophysiological Experiments

The observations on response to novelty made in these neurobe-
havioral experiments were considerably enhanced by some obtained in
psychophysiological studies. One possibility, consonant with the Jame-
sian hypothesis, would be that motivation involved the somatomotor
system while emotion invoked visceroautonomic processes. Thus, de-
spite the juxtaposition of their central mechanism, peripheral differ-
ences could account for the behavioral distinction. This possibility was
put to direct test in a series of experiments which assayed the effects on
visceroautonomic indicators of resections rather than stimulations of
portions of the mediobasal, limbic motor mechanism. Such experi-
ments allowed observations to be made under physiologically normal
conditions for many months and even years in a variety of environmen-
tal circumstances that ordinarily produce visceroautonomic reactions.
The question was asked as to which of these circumstances produced
altered reactions or absence of reaction in the lesioned monkeys.

To summarize a decade of experiments, Muriel Bagshaw, Daniel
Kimble, and I (Bagshaw, Kimble, and Pribram, 1965; Kimble, Bagshaw,
and Pribram, 1965) found that the forebrain lesions had, as might be
expected, no effect on peripheral, reflexly produced visceroautonomic
reactions. Galvanic skin responses (GSR), heart, and respiratory
changes occurred in normal amount and frequency when the monkeys
moved or when gentle electric shock was applied to the soles of their
feet. We found (Bagshaw and J. Pribram, 1968), if anything, that the
threshold for obtaining such reactions was lower than in normal sub-
jects. By contrast, however, when response to novel stimulation or to
conditioning was tested, visceroautonomic reactivity was grossly defi-
cient. The visceroautonomic components of orienting and conditioning
were markedly attenuated or completely eliminated by the lesions
(Bagshaw and Benzies, 1968).

Analysis showed that the deficit in conditioning was to some
considerable extent due to a restriction in anticipatory reactions to the
unconditional stimulus which occurred in control subjects (Bagshaw
and Coppock, 1968). Thus the situations in which the deficit was
manifest were those that demanded reactions to recurring events, not
reactions to the events themselves. The fact that limbic forebrain struc-
tures, the mediobasal motor mechanisms, are critically involved in the
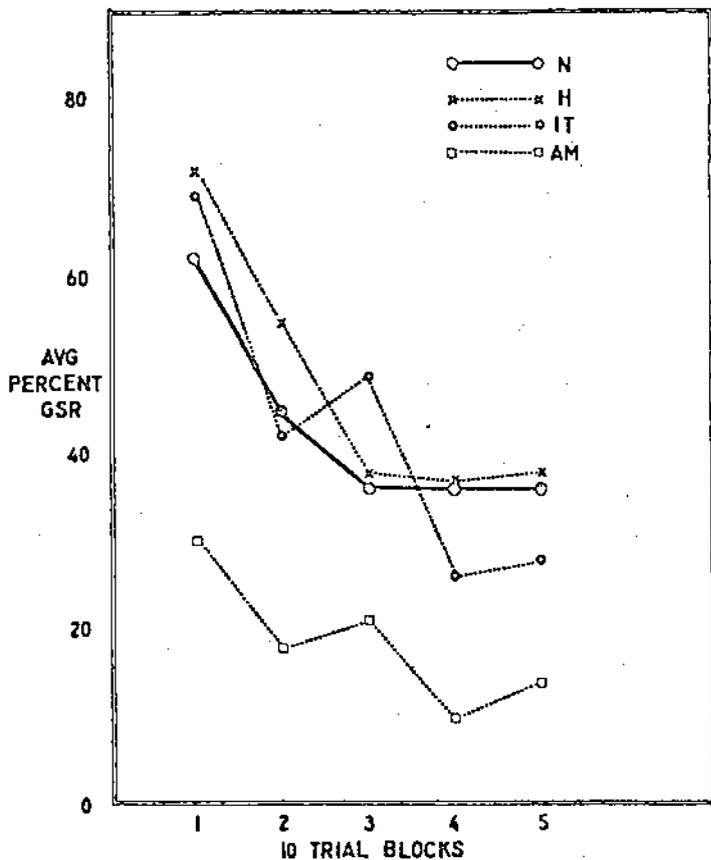reaction to novelty as well as in motivational and emotional reactions

FIGURE 6.   Curves for overall percentage of GSR responses to the first 50 presentations of an irregularly presented 2-sec tone. Amygdalectomized (AM), hippocampectomized (H), control (IT), and unoperated (N) groups.

suggests a major modification of Jamesian theory: *Emotional and motivational feeling comes about not by any direct bodily reaction to perceived events, but by a change in the sets, expectations, and anticipations produced by such events.*

C. Habituation

The simplest expression of such sets or expectations is *habituation*. And, in fact, habituation of a locomotor response in a repetitive situa-
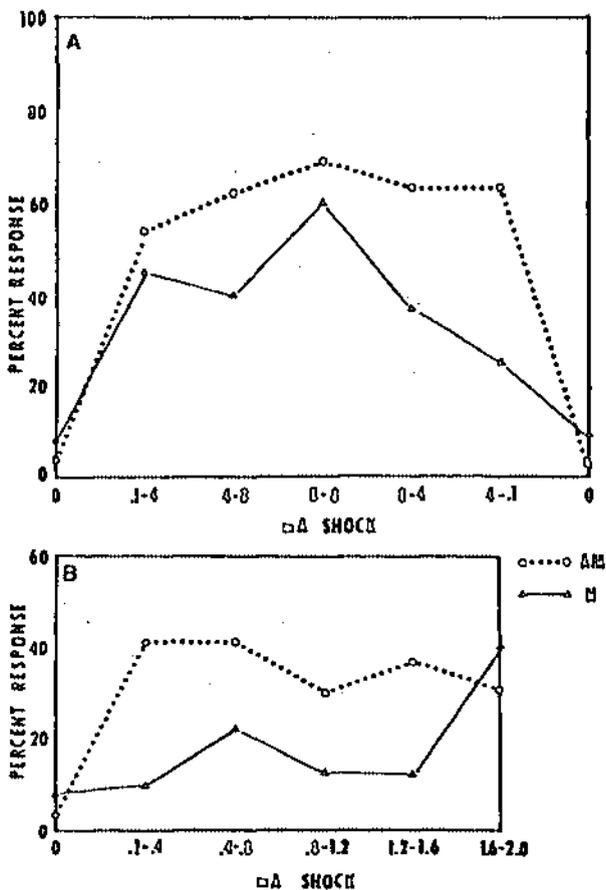
FIGURE 7(A)   Curves of percentage GSR generated by three runs of stimuli of ascending and descending intensity (in map) by the amygdalectomized (AM) and control (N) groups. 7(B)   A finer breakdown of stimulus values from .1 to 1.0 mamp, pooled ascending and descending values.

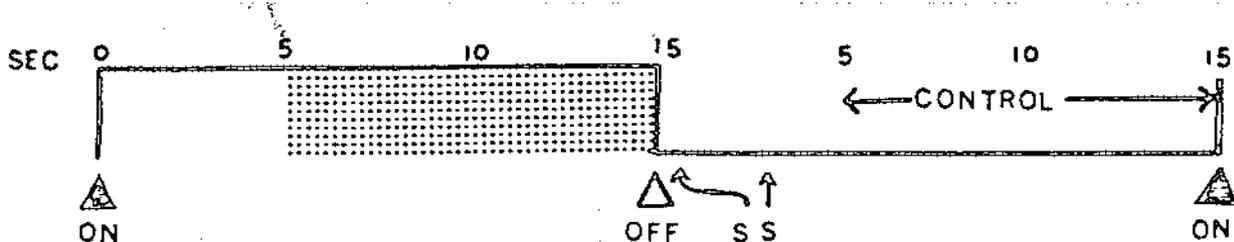tion has been repeatedly shown to be impaired by lesions of the mediobasal motor mechanism (Ruch and Shenkin, 1943). This failure to habituate has often been termed *hyperactivity*, though it was soon established that it was more truly a hyperreactivity (Mettler and Mc-Lardy, 1948). The hyperreactivity is, however, not so much an increased initial reaction (though there is some of this as seen in the GSR

threshold to shock experiment) as it is a persistence of reactivity long after controls have become habituated.

But here we meet a paradox. Behaviorally, the monkeys with lesions of the mediobasal motor system fail to habituate, i.e., they continue to orient long after control subjects react to a recurring situation as familiar (Schwartzbaum, Wilson, and Morrissette, 1961). As already described, however, when we looked to visceral-autonomic responses to indicate orienting, such responses could hardly be found (Bagshaw, Kimble, and Pribram, 1965). The evidence thus suggests that visceroautonomic responses are integral to habituation.

Can visceroautonomic responses be integral to habituation and also be the determinants of emotional feeling? In man habituation precludes awareness. We are not ordinarily aware of wearing clothes that have become familiar, of movements that have become habitual, of digestive functions or heart beats that recur more or less regularly. Only when dishabituation takes place do we notice such objects and events. The feeling is therefore attendant on dishabituation—disruption of the current set or state. Bodily changes may accompany the disruption, and the ensuing visceral and somatosensory input may in fact contribute to the general emotional or motivational feeling. But, as I have reviewed elsewhere (Pribram, 1967a, 1967b, 1971, Chapter 11), the attribution of specific feelings to the change in state is as much a function of the situation in which the change occurs as it is of the visceral and somatic changes per se. As pointed out in the introduction, the feeling of upset can readily be distinguished from the disposition (e.g., being in love) from which the upset takes its origin.

Habituation poses another problem. If we habituated in every recurring situation we would never be able to deal with such situations; we would never learn, would never be able to attend to now this, now that aspect of a situation. The organism must possess a mechanism which overrides habituation. In a recent review, Diane McGuinness and I (Pribram and McGuinness, 1975) spelled out the details of this system, which appears to depend on greater involvement of the soma-tomotor rather than of the visceroautonomic system. The data suggest that three separate but interacting neural systems govern the reaction to novelty and its habituation. One system controls arousal, which is defined in terms of phasic physiological responses to input. The arousal control circuits center on the amygdala, a core structure in the mediobasal motor system. A second system controls activation, which is de-

TRIALS	GRP	5-10 SEC ON	10-15 SEC ON	5-10 SEC OFF	10-15 SEC OFF
FIRST 40	NORM	3.7	7.0**	3.9	7.0
	AMX	3.2	3.3	3.9	6.3
SECOND 40	NORM	5.7**	8.8*	6.2	4.5
	AMX	2.7	4.8	3.5	4.3
All 80	NORM	9.3	14.5*	10.3	7.0
	AMX	5.8	8.2	7.3	6.3

FIGURE 8. ·Mean number of GSR occurring in 10-sec period of light on just preceding light offset (CS) in the first 40 and in the second 40 trials for each group. Conditioning paradigm presented above table.

fined in terms of tonic physiological readiness to respond. The readiness circuits center on the basal ganglia of the forebrain. A third system was discerned which coordinates arousal and activation. This coordinating activity apparently demands effort. Its circuitry centers on the hippocampus.

Even at the hypothalamic level the distinction between an arousal and a readiness mechanism exists. In the feeding mechanism, for instance, the ventromedial region (the one involved in making obese rats in the *ad libitum* situation) has been shown to monitor the utilization of blood sugar during satiety, while the far lateral hypothalamic region functions reciprocally to intiate feeding when utilization has come to a halt. The satiety mechanism stops behavior; the feeding mechanism makes behavior go. And recent evidence (Ungerstedt, 1974; Fibiger, Phillips, and Clouston, 1973) has shown these far lateral hypothalamic effects to be due to disruption of basal ganglia circuits. Elsewhere (Pribram, 1971, Chapter 10) I have suggested that emotional arousal becomes organized around "stop" mechanisms and that motivational readiness is an elaboration of "go" mechanisms. As detailed in the review, there is ample evidence that the limbic forebrain (e.g., the amygdala and the hippocampus) participates in such processes. Here it is important to recall that the evidence also shows that this participation takes place by way of the organism's reactivity to novelty and familiarity. The evidence is thus consonant with that from the clinic where epileptic auras of *déjà* and *jamais vu* preceding psychomotor seizures are considered pathognomonic of disturbances of the limbic mediobasal motor formations.

D. James Reconsidered

In his opening paragraph on emotions, William James suggested that "emotional reaction usually terminates in the subject's own body whilst the instinctive (motivational) reaction is apt to go farther and enter into practical relations with the exciting object" (1950 Vol. II, p. 442). This distinction rather than the one more commonly attributed to James—that emotion is essentially viscerally determined—is borne out by our review of current data. James was overly impressed with Lange's argument because "reactions that terminate in one's own body" (i.e., self-regulatory reactions) tend to display a larger visceral component

than do "reactions" which "enter into practical relations with the
exciting object." Entering into practical relations demands somatomo-
tor activity. Yet emotional arousal also involves the somatomotor sys-
tem, and somatomotor activity is accompanied by visceroautonomic
changes. In short, we have a considerable amount of evidence which
demands a modification of the James–Lange position that "bodily
changes follow directly the perception of the exciting fact and our
feeling of these same changes is the emotion." *Feelings* of familiarity, of
elation and depression, of assertion and aggression, and of sleepiness
and alertness have been shown to depend on *brain* processes (see
Pribram, 1971, Chapters 10 and 15; Pribram and McGuinness, 1975; or
Marshall and Teitelbaum, 1974, for a review of the evidence that relates
neurochemical brain systems to these dispositional states). Bodily
changes are *initiated* by these brain processes, but not, as James
thought, by the processes that directly perceive. Rather, the bodily
changes are induced by mechanisms which monitor the familiarity and
novelty of situations. Bodily changes, both visceroautonomic and so-
matomotor, do appear to be integral to emotional and motivational
expression, however, in that they do in fact help to distinguish their
mechanisms of operation. But even here the distinction does not rest on
which peripheral mechanism becomes activated, but rather on how
they both are used. If the brain processes regulating bodily changes
lead the organism into doing something about a situation, i.e., "enter-
ing into practical relations" with it, motivational mechanisms become
active; when these brain processes result in reactions "terminating
within the subject's own body," emotional mechanisms are set into
operation. This, then, is the essential distinction between motivational
and emotional expression: What mechanism sets one rather than the
other process in motion?

III. EFFORT AND THE EXPRESSION OF MOTIVATION AND
EMOTION

A. *Part Behaviors and Their Integration*

In attempting to answer this question, we need to examine the
impact of the finding that effort, rather than drive, is the critical
variable determining the behavioral response. Presumably, therefore, it

is effort that resolves whether the organism will react emotionally (i.e., by attempted self-regulation) or motivationally (i.e., by entering into practical action). Effort is a measure of the resistance which must be overcome in order to do a certain amount of work in a specified time. It is analogous to force in physical systems and an expression of the capacity for exerting power, the rate of doing work. And work is a measure of the energy required to change the state of a system (see McFarland, 1971, p. 4, for the derivation of these definitions).

The critical question is, therefore, What are the variables which constrain a system to resist a change in state? A homeostatic system, by definition, is one that resists change by virtue of its negative feedback. But additional constraints develop (hyperstability) when several such systems interact (Ashby, 1960). Thus a drop in basal temperature may result in shivering, in motor activity, in sleeping, or in eating. Motor activity and eating have been shown to be reciprocally related over short time periods—they appear constrained by the basal temperature variable. It therefore takes effort to attempt to eat during or immediately after exercising and vice versa (see Brobeck, 1963, for a thought-provoking and thorough review of these data).

There is considerable evidence as to the neural organization that invokes such constraints. Electrical stimulations in the hypothalamic region, when carried out with small electrodes, give rise to only parts of behavioral acts, such as jaw or tongue movements, swallowing, pilo- or genital erection, head thrusts, etc. Further, these part behaviors appear to be more or less randomly interspersed with one another. Adjacent stimulations do not produce a completed behavior pattern (Roberts, 1969).

When larger electrodes are used, a different pattern emerges. Now chewing, drinking, sexual, or aggressive behaviors are elicited full-blown. But interestingly, which behavior is elicited depends to some considerable extent on the environmental situation in which the stimulation occurs. Thus a rat, when initially stimulated, may drink every time the electrical current is applied to his brain. He is now left overnight in a cage with no opportunity to drink but with several pieces of wood to chew on. The brain stimulation is kept up intermittently all night. The next morning the rat is provided with the opportunity either to drink or to chew. Now, brain stimulation from the identical site will as often elicit chewing as drinking (Valenstein, Cox, and Kakolewski, 1969; Valenstein, 1970).

B. The Precentral Motor Cortex and Action

These results have led to a controversy similar to that which for many years centered on the functions of the classical precentral motor cortex. The issue concerned the nature of the motor representation: Is it punctate, representing discrete muscles or even parts of muscles, or are movements, sets of muscle contractions, flexibly represented? I have elsewhere (Pribram, 1971, Chapters 12 and 13) pointed out that neuroanatomically the representation is indeed punctate, that neurophys-

iologically, i.e., with fairly gross electrical stimulations of awake animals and humans, movements rather than discrete muscle contractions are obtained, and that which movement is elicited depends on body and limb position, prior stimulation, etc. But I also have shown (Pribram, Kruger, Robinson, and Berman, 1955–56) that neither of these views is sufficient to explain the results of neurobehavioral experiments. These show that resection of the classical motor cortex fails to interfere with any muscular contraction, or even with any set of muscular contractions. All movements can be shown to remain intact when
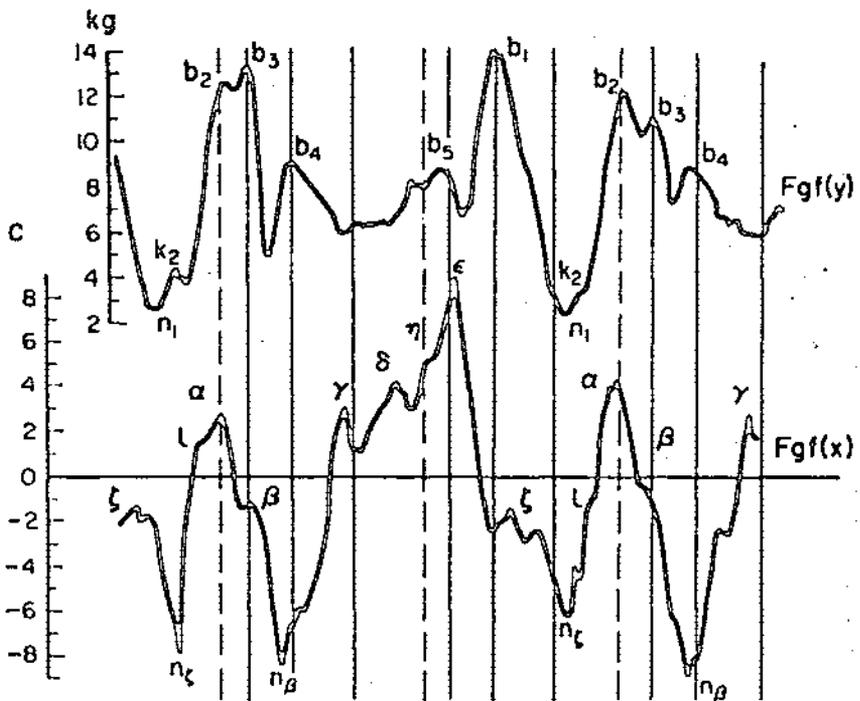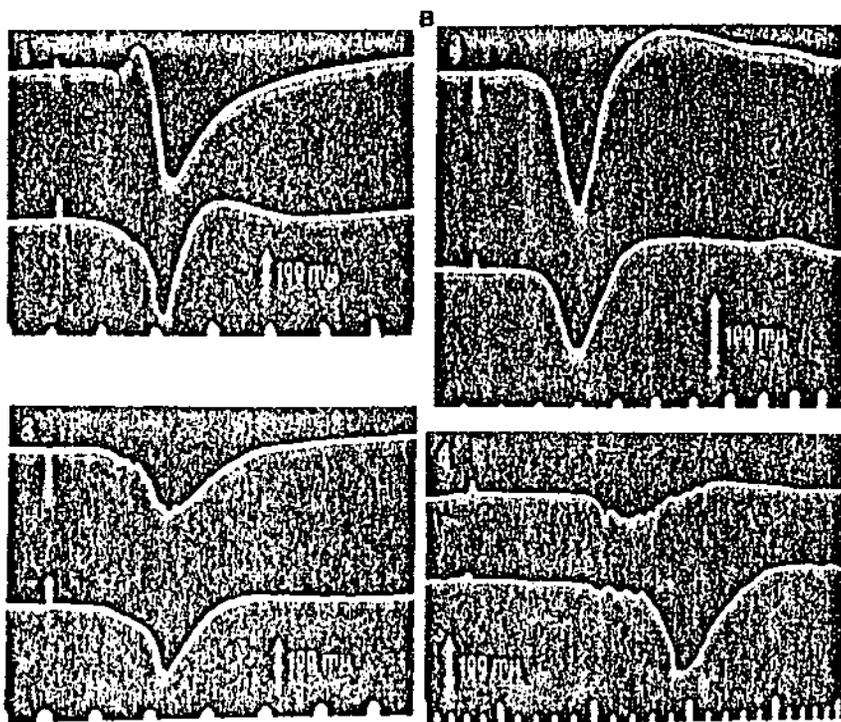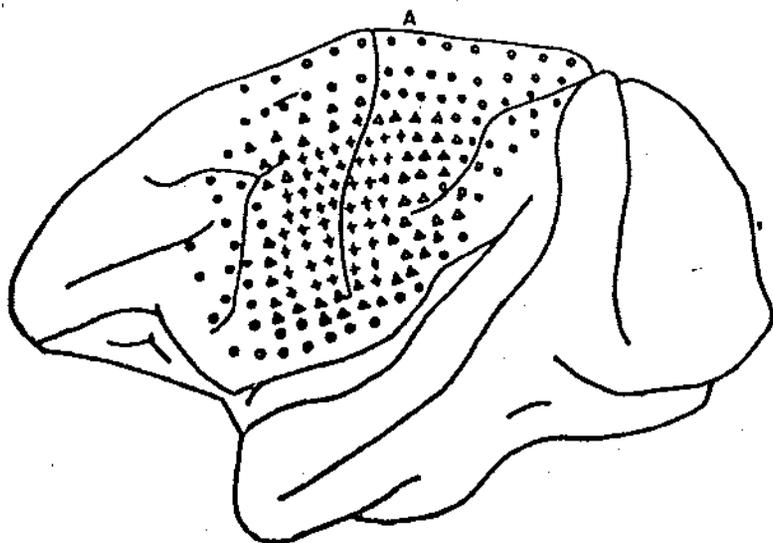

FIGURE 9(A) Subject in black costume with white tape. (Reprinted with permission from N. Bernstein, 1967.) 9(B) Cinematograph of walking. Movement is from left to right. The frequency is about 20 exposures per second. (Reprinted with permission from N. Bernstein, *The Co-ordination and Regulation of Movements.* © Pergamon Press Ltd., 1967.) 9(C) Force curves at the center of gravity of the thigh in normal walking. (Above) vertical components. (Below) Horizontal components. (Reprinted with permission from N. Bernstein, *The Co-ordination and Regulation of Movements.* © Pergamon Press, Ltd., 1967.)

they are examined in a sufficient range of situations. Yet the monkeys were defective in solving latch-box problems, and the deficiency was not due to any overt difficulty in sequencing the movements. I therefore came to the conclusion that the essential representation in motor cortex was neither of individual muscles nor of movements, but of actions, defined as environmental consequences of movements.

Subsequent reports (Bernstein, 1967) have clarified the possible mechanisms by which a representation of environmental consequences could come about. For instance, cinematographic records are made of people performing relatively repetitious tasks, such as hammering a nail or running over rough terrain when dressed in black with white markings on their limbs. Such records display continuous wave forms which can be analyzed as if they were modulated sine waves. The use of such a Fourier analysis allows accurate prediction to be made of the extent of the next movement in the series, the next hammer blow or step. If this can be done by an investigator in this fashion, it is not far-fetched to believe that it can be done in a similar way by the subject's motor system. The essential representation would therefore be the equivalent of the mathematical operation of Fourier analysis, a considerable saving in storage over representing each movement and sequence of movements that might ever be utilized. This program, or a similar stored set of mathematical rules, could readily assemble the more or less randomly dispersed part-functions which have been demonstrated with discrete stimulations, much as these rules have been used to make a computer-driven dot display that is interpreted by the observer as a running or dancing figure (Johansson, 1973).

Other experiments (Evarts, 1967) have shown with microelectrodes that muscle length is not the relevant variable to which motor cortex neurons respond. These experiments were performed on fully awake

monkeys taught to pull an adjustable counterweighted lever. The response of motor cortex units did not vary with the length of the excursion of the lever but with the *effort* necessary to move it—the force that had to be applied to overcome the resistance to movement due to the weight.

C. Effort and Volition

Thus both in the hypothalamic experiments and in the experiments on classical motor cortex, situational stimulus variables are seen to be critically involved (this accounts for the findings of Teitelbaum, 1955, that enhanced attractiveness of food helps overcome the resistance to eating shown by the animals with lesions in the lateral hypothalamus). Both of these parts of the brain do, of course, receive rather direct inputs from exteroceptors. In the case of the classical motor cortex, our discovery (Malis, Pribram, and Kruger, 1953) of these paradoxical inputs to a "motor" region provided the original impetus for this line of investigation. In the case of the hypothalamus and mediobasal motor cortex, the existence of these direct inputs from exteroceptive receptors is just now beginning to be established with microelectrode and new neuroanatomical autoradiographic techniques (see, e.g., Cowan, Adamson and Powell, 1961; Cowan, Gottlieb, Hendrickson, Price, and Woolsey, 1972). However, some early neurophysiological results exist showing changes in electrical activity evoked by peripheral stimulation (Bailey and Sweet, 1940; Dell, 1952; Pribram and MacLean in Fulton, 1951, p. 57).

The distributed representation of part behaviors is the neural substrate upon which effort variables (as induced by deprivation, for instance) critically operate to determine whether the expressed behavior is to be emotional or motivated. We have seen that even at the neural unit level, neurons in motor systems are directly sensitive to effort variables—i.e., they respond according to the constraints of the moment. The constraints that need to be overcome by effort have thus been shown to be externally as well as internally determined. This was especially clear in experiments on the classical motor cortex: Effort is what correlated with neural unit activity, not changes in muscle length. Similar correlations need to be established at the unit level in the mediobasal motor systems, but, as noted above, the indications from

neurobehavioral data are that some sort of anticipatory mechanism based on the constraints developed by repetition (familiarity, habituation) rather than "bodily change" per se is involved.

The upshot of these results is that motivation and emotion reflect the effort involved in changing bodily systems, not the changes themselves. Effort is a brain process (involving the hippocampal circuit—see Pribram and McGuinness, 1975, for a review of the evidence) that apppears to be critical in determining whether a reaction is to be motivated or emotional.

D. The Jamesian Theory of Will

We need, therefore, to take a look at another domain of Jamesian theory. We have already noted the fact that some sort of appraisal of familiarity rather than a direct perception of a situation initiates the motivational–emotional process. We also reviewed the evidence that the distinction between emotional and motivational behavior was best stated by the Jamesian view that emotional reactions "terminate within the body" (i.e., are self-regulatory), while motivational reactions "enter into practical relations with the exciting object." The Langian portion of the James–Lange theory—that emotions are the feelings generated by visceral reactions—we found untenable. And finally we found that we must invoke "effort" as the critical variable which determines whether a reaction is to be emotional or motivated. Effort is discussed by James under the rubric of *will*. His definition of what leads to voluntary actions reads much as we have stated it here, if we interpret the words *anticipatory image* to mean the resultant of the mathematical operation from which the next movement in a series can be predicted:

> An anticipatory image, then, of the sensorial consequences of a movement, plus (on certain occasions) the fiat that these consequences shall become actual, is the only psychic state which introspection lets us discern as the forerunner of our voluntary acts. (1950, Vol. II, p. 501)

But again, James can be interpreted as taking a dual stance. He quoted at length from Ferrier, who attempted to show that input from muscular contraction (usually the holding of one's breath when other evidences of muscular contraction are missing) is *necessary* for the experience of effort. (Ferrier was making the argument against Wundt, whose views were that efferent rather than the afferent neural activity

was perceived as effortful). James heartily endorsed Ferrier's views:

> [the experiments reviewed] prove conclusively that the consciousness of
> muscular exertion, being impossible without movement *effected somewhere*,
> must be an afferent and not an efferent sensation; a consequence, and not an
> antecedent, of the movement itself. An idea of the amount of muscular
> exertion requisite to perform a certain movement can consequently be
> nothing other than an anticipatory image of the movement's sensible effects.
> (Vol. II, p. 505)

Note carefully here what James was saying. Superficial reading
makes the statement sound like another version of the James–Lange
theory: James–Lange for emotion; James–Ferrier for motivation and
will. But here James clearly stated that "an anticipatory image of the
movement's sensible effects" is involved. Such an "image" must be a
brain, not a peripheral, process. A careful reading of this passage makes
one wonder whether the Jamesian theory of emotions, interpreted as
peripheralist, has not been grossly misinterpreted as well. James im-
plicitly and explicitly always had a brain process in mind whenever
discussing mind (thoughts, feelings, consciousness, attention, etc.). In
summarizing his chapter on emotions, James was discussing brain
processes, not peripheral ones:

> To sum up, we see the reason for a few emotional reactions; for others a
> possible species of reason may be guessed; but others remain for which no
> plausible reason can even be conceived. These may be reactions which are
> purely mechanical results of the way in which our nervous centres are
> framed, reactions which, although permanent in us now, may be called
> accidental as far as their origin goes. In fact, in an organism as complex as
> the nervous system there must be many such reactions, incidental to others
> evolved for utility's sake, but which would never themselves have been
> evolved independently, for any utility they might possess. Sea-sickness, the
> love of music, of the various intoxicants, nay, the entire aesthetic life of
> man, we have already traced to this accidental origin. It would be foolish to
> suppose that none of the reactions called emotional could have arisen in this
> quasi-accidental way. (Vol. II, p. 484)

We note, therefore, that the contemporary view of the theory of
motivation and emotion proposed by William James is in one respect
grossly misleading. While James wrote that emotional feeling was
based on visceral sensations, he also wrote that such feeling was
coordinate with a brain process resulting from the visceral sensation.
This central aspect of Jamesian theory becomes even more clearly stated
with respect to motivation and has been little appreciated by James's
critics.

On the other hand, James was in error in suggesting that emotion depended on immediate visceral sensation (or that motivation depended on immediate sensations derived from the somatic musculature). Cannon's classic experimental demonstrations that an organism is capable of emotional responses despite visceral deafferation have been the source of the major rebuttal to James's position, although exceptions to the validity of Cannon's claims have also been voiced (e.g., Beebe-Center, 1971; Schachter, 1967; Mandler, 1967).

Reviewed here have been additional experiments that make it necessary to modify Jamesian theory of emotion. James clearly wrote of "an anticipatory image" when dealing with motivation. On the basis of the experimental results on limbic system function—which have shown that visceral responsiveness follows the appreciation of novelty and the appraisal of changes in sets, expectations, and anticipations, not directly on perceived events per se—it is now mandatory to think in like fashion about emotion.

However, we also reviewed an aspect of Jamesian theory which is acceptable today and accounts for James's overemphasis on immediate bodily sensations while at the same time providing a useful distinction between emotion and motivation: Emotional expression tends to terminate within the organism while motivations enter into practical relations with the exciting event. Entering into practical relations often involves effort or will—thus the distinction still used in the neurological clinic of the apposition of emotional to voluntary behavior.

IV. A CONTROL-THEORY MODEL OF SELF-REGULATION AND SELF-CONSCIOUSNESS

A. The Model

In the introduction I suggested that the scientific study of self-consciousness would show rapid progress provided a technique and a brain model were made available. The technique of biofeedback leading to the self-regulation of dispositional states appears to fill part of this need. The present manuscript has attempted to show that Jamesian theory might be useful in launching the necessary brain model.

What sort of model, then, can be constructed from these elementary observations? What form of discourse is available to describe the model? What type of "*in vitro*" simulations can aid our understanding of the processes and mechanisms involved?'

I want to propose that contemporary control theory can and does provide the model, the language, and initial understanding of the brain processess and mechanisms involved in the interrelated domains of motivation and emotion, of effort and will, and of self-regulation and self-consciousness. Specifically, the concepts of feedback and feedforward as they describe closed and open (helical) loop systems are useful in the formulation of a testable model of this domain of inquiry in precise, scientifically useful terms.

Control theory is no foreigner to biological and neurological explanation. The term *regulation* is as often used as the term *control*, but biological principles are almost universally regulatory principles—i.e., principles invoking mechanisms of control. With regard to the issues under consideration, homeostasis and homeorhesis are thoroughly tested conceptions and *biofeedback* has become a household word. And to view the nervous system as an information-processing mechanism is now standard practice among neurophysiologists.

The proposal derived directly from Jamesian theory states simply that emotion is essentially based on closed-loop feedbacks, while motivations go beyond these and "enter into practical relations" by way of information-processing, open-loop, feedforward mechanisms. The maintenance of "practical relations" demands repeated changes (bias-ing) in the constraints (the feedbacks) operating on the system; thus voluntary effort is a necessary concomitant of open-loop processes.

The most generally known innovation in control theory has been the formal description of the concept of feedback (e.g., Miller, Galanter, and Pribram, 1960), a circular process initiated by a test, a matching of two settings. When there is mismatch, one of the settings becomes fixed, while the other triggers an operation which continues until a match is produced. Thus a test-operate-test-exit sequence, a TOTE, characterizes the feedback: For example, if the setting of a thermostat and that of room temperature are incongruent (mismatch) a furnace is turned either on or off until congruence is established.

More recently another, equally useful conception—feedforward (e.g., see MacKay, 1969; Mittelstaedt, 1968; Pribram, 1971)—has been found important. In feedforward control, an operation procedes to a
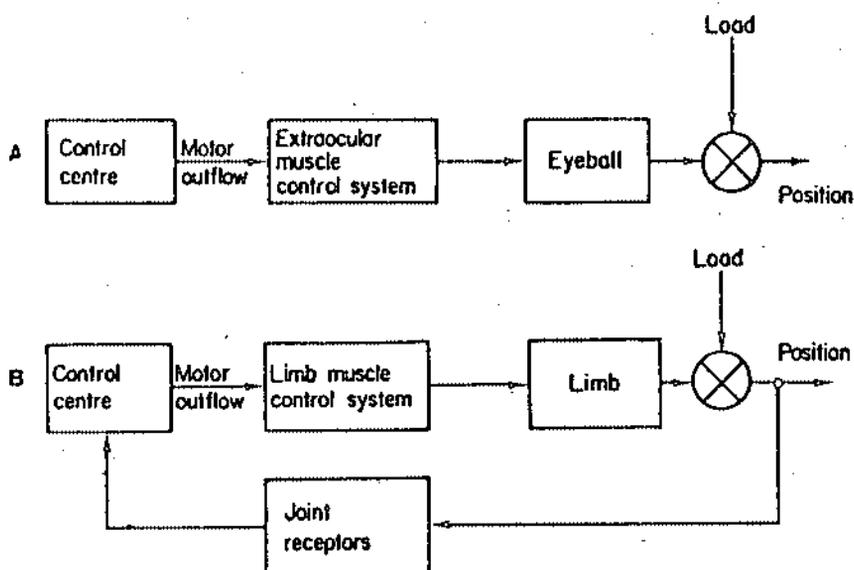
FIGURE 11(A) Eyeball position control system: (open-loop, feedforward) and (B) limb position control system: (closed-loop, feedback). (Reprinted with permission from D. J. McFarland, *Feedback Mechanisms in Animal Behavior.* ° Academic Press, 1971.)

predetermined end point. For example, in most apartments, the furnace continues to operate for fixed periods, irrespective of local temperature conditions.

The distinction between feedback and feedforward has been extremely useful in the analysis of engineering and biological systems, which ordinarily are composed of complex combinations of feedback and feedforward processes. Two types of combinations have been extensively studied. In one, feedback processes become associated or multiply linked with each other, producing an extremely stable system resistant to change (i.e., they exhibit equilibrium and inertia). An engineering example of such a system is the multilinking of power plants in the northeastern United States, which guards against frequent local disruptions, though it is vulnerable to occasional massive failure. Biologically, physiological drive systems have been found to display this type of organization. Thus food intake, muscular activity, temperature regulation, and water metabolism are interdependent regulatory mechanisms which, as a rule, operate to maintain basal temperature

constant. The associative links which make up this and similar systems have been studied extensively (e.g., see review by Brobeck, 1963) and their operating characteristics thoroughly analyzed (Ashby, 1960).

Combinations based primarily on feedforward processes are ubiquitous; they constitute our computer technology. For the most part, such combinations contain feedbacks as well. Biologically, combinations of feedforwards occur in parallel, processing signals simultaneously by virtue of overlapping neighborhood interactions, and constitute one class of cognitive processes (see Neisser, 1967; Eccles, 1967; Pribram, 1971). When feedback loops are included, hierarchical sequential arrangements called *plans* or *programs* are constituted (Miller, Galanter, and Pribram, 1960). Parallel and hierarchical processing mechanisms provide the foundations of contemporary cognitive theory.

In biology, homeostatic processes, oscillating phenomena such as biological rhythms and clocks, and load-adjusting mechanisms such as those regulating muscular contraction have all been shown dependent upon feedback organization (Pribram, 1971). The essential characteristic of such systems is that they depend upon a match between two settings. A mismatch produces an error signal which controls the operation of the system until equilibrium—match—is reestablished. This homeostatic conservation of equilibrium is akin to that described by the first law of thermodynamics, which states that the conservation of *energy* is maintained because change elicits an "equal and opposite reaction." Energy concepts are therefore appropriate to a description and an understanding of feedback organizations and, in fact, are regularly used, as for example in the description of the "effort" or "work" involved in load-adjusting mechanisms.

Information concepts, by contrast, have often been linked to the second law, and in fact, information has often been termed (e.g., by Brillouin, 1962) *neg-entropy* (see also von Foerster, 1965). Confusion has arisen because there has been a tendency to label "error" (the mismatch signal) *information*. But "error" has nothing in common with this type of "information": The amount of information contained in a message does not depend on the processing of its errors. Ashby (1963) details the distinction in terms of the constraints (limits on the independence of the functioning parts) operating on the processing system, the constraints on variety. Information is a measure of variety; redundancy (repetition), a measure of constraints. (For a comprehen-
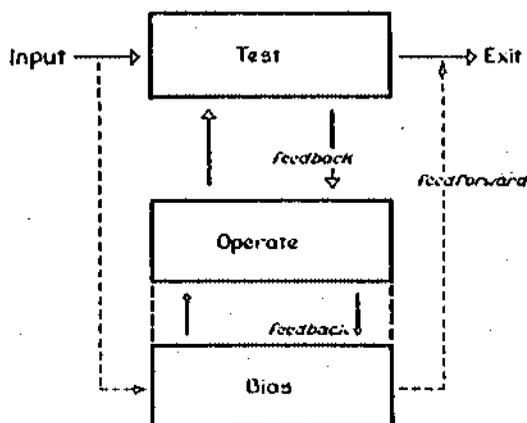
FIGURE 12. The TOTE servomechanism modified to include feedforward. Note the parallel processing feature of the TOTE.

sive discussion of the nature of constraint in physics and biology, see Pattee, 1971). *Information* thus refers to the content of a communication, while *redundancy* reflects the context or code in which information is communicated. Feedback organizations constrain systems to equilibrium. Thus *error* becomes a term denoting redundancy or lack thereof, not information. When a long-distance conversation is interrupted by a periodic whoosh, the constraint (the context in which the information is relayed) becomes disturbed—the conversation becomes unintelligible and a mismatch is conveyed to the sender, who then repeats the same information more slowly with greater emphasis and perhaps several times, changing the structure of the constraints operating during the conversation without altering its content (the amount of information).

From this it follows that the invoking of biofeedback procedures accomplishes its purpose by providing an external bias on the internal feedbacks that maintain the ordinary homeostases operating in the system. The bias, maintained with effort, produces conscious voluntary control on the system, which now is an information-processing, feedforward, open-loop, helical mechanism rather than just an unconscious error-processing, feedback, closed-loop system.

The outline of a model for self-regulation and self-consciousness

thus appears to be relatively easy to discern. Even the neural mechanisms involved are to some extent becoming known. With regard to the effort involved in the coordination of internal control with external demand, the evidence of the critical role of hippocampal circuit has been reviewed elsewhere (see Pribram, 1971, Chapter 15; Pribram and McGuinness, 1975). With respect to the coordinations involved in the maintenance of "practical relations" with the exciting event, the cerebellar circuit appears critical (Pribram, 1971, Chapter 13). Both hippocampal and cerebellar mechanisms, based on somewhat comparable anatomical structure, can be thought to perform rapid calculations of probable future states from extrapolations of present and immediately past circumstances. The remainder of the system can thus change its operations to achieve or preclude that particular estimated future state's occurring. New calculations then take place and the process is repeated, monitoring and extrapolating continuously the changes, or lack thereof, which result.

B. Attention Span and Self-Consciousness

While the proposal of a plausible model of self-regulation and self-consciousness is thus feasible, understanding the genesis of self-consciousness poses greater difficulties. Two points are clear: A change from feedback to feedforward organization effected through biofeedback procedures leads to conscious, voluntary control; we exercise this control by "paying" attention. Thus the key to understanding the genesis of self-consciousness is attention, and specifically the set of problems psychologists deal with under the rubrics of *attention span* and *central capacity*.

James, in discussing the span of attention, reviewed (1950, Vol. I, pp. 427–435) the reaction-time experiments of Wundt, Exner, and Munsterberg. He concluded that the results indicate that shorter times are elicited by the following mechanisms:

> (1) The accommodation or adjustment of the sensory organs; and (2) The anticipatory preparation from within of the ideational centres concerned with the object to which the attention is paid . . . The two processes of sensorial adjustment and ideational preparation probably coexist in all our concrete attentive acts. (Vol. I, p. 434).

Again, attention consists of:

> a collection of activities physiologically in no essential way different from

the overt acts themselves. If we divide all possible physiological acts into
adjustments and executions, the nuclear self would be the adjustments
collectively considered. (Vol. 1, p. 302)

We note here the recurring theme which differentiates "adjustments"
that end within the organism's body and "executions," which go
beyond into practical actions. Further, a "nuclear self" can be ascer-
tained by consideration of the collection of *adjustments* which shorten
reaction time.

Today, reaction-time experiments have once more raised the issue
of attention span and its dependence on some sort of nuclear self or
competency to adjust central capacity. The issue is handled in the
Pribram–McGuinness review (1975) in terms of control theoretic con-
cepts and is worth repeating here because of its relevance to the
problem of the mechanism which brings about self-consciousness.

C. Central Competency

In living systems, an arousing stimulus often *increases* the uncer-
tainty of the organism by its novelty. This effect of input information is
contrary to that obtained in nonliving communication systems, where
information conveyed always *reduces* uncertainty. The difference be-
tween living and nonliving systems can be conceptualized in terms of
the channel over which the communication takes place. In nonliving
communication systems the channel is akin to a sensorimotor channel
which is fixed in capacity and does not alter with the communication.
Living systems (and also computers) have the capability of memory,
which alters the *competence* with which they process information (Pri-
bram, 1971, Chapters 14 and 16). This is produced by the alteration of
channel redundancy and superficially resembles a change in the num-
ber of channels with fixed capacity. The increase in competence is the
result of an increase in the complexity of the neuronal model, an
encoding process described as "chunking" the information (Miller,
1956; Simon, 1974). This and similar mechanisms in human informa-
tion-processing effect a change in central processing very different from
that produced by a simple increase in the number of fixed-capacity
channels available.

The evidence that information-processing competency can be
changed in living organisms comes from a variety of problem-solving
situations. Kahneman (1973), in reviewing several such studies from

the psychophysiological literature, suggested that "arousal" is in fact an indicator of a change in capacity—"the allocation of spare capacity"— much as this is changed in nonliving systems by an increase in the number of channels available. He also goes on to equate *"arousal"* and *"capacity"* with *"effort"* and *"attention"* in a global fashion. As noted, however, emotional arousal is indicative of but one sort of attention, and effort is involved only when the situation demands the regulation of arousal and motivational readiness to produce a change in information-processing competency.

The way in which competency is controlled by brain systems in the living primate is demonstrated by the finding that removal of the area of the brain usually called *sensory* or *posterior intrinsic* or *"association"* *cortex* reduces the sampling of novel alternatives. The opposite effect is obtained when the lateral frontal cortex is resected. Removal of this same frontal cortex leads to an increase in behavioral orienting and an abolition of the viscerautonomic components of orienting. There thus appear to be opposite effects (posterior and frontal) on the number of alternatives sampled in a situation. This was interpreted to indicate a dual control mechanism determining the ability to sample (Pribram, 1960).

Supportive behavioral evidence came from an experiment by Butter (1968, 1969), in which he investigated the number of features usually attended by monkeys while discriminating between two cues. He did this by eliminating each feature in turn in various combinations. He found that resection of the same brain region (the posterior cortex) that produced a restriction in the number of alternatives sampled also produced a restriction in the number of features used to make the discrimination.

Electrophysiological evidence has been obtained that the posterior and frontal cortex contribute opposing controls on sensory channels. This evidence is based on changes produced in the recovery cycles of the system (the speed with which the system recovers to its full capacity after a sudden, intense stimulus) and the alterations produced in the shape of visual receptive fields (Spinelli and Pribram, 1966, 1967).

These changes in sensory channels were, however, *not* attributed to a simple change in the *number* of channels of fixed capacity, as the effects of surgical resection have shown that as little as a few percent of an anatomically defined sensory channel is sufficient for ordinary discrimination learning, performance, and transfer (Lashley, 1929; Galam-

bos, Norton, and Frommer, 1967; Chow, 1970). The remainder of any input channel appears to be redundant, spare channel capacity, under most circumstances. The results on the control of input channels by posterior and frontal cortex were therefore interpreted (Pribram, 1967c) as influencing *redundancy, not sensory capacity* in the usual information theoretic sense. Specifically, it was suggested that the input systems acted as channels in which spatial and temporal multiplexing could occur, a suggestion similar to that put forward by Lindsay (1970).

On the basis of the data reviewed above, Kahneman's (1973) concept that arousal involves an increase in the number of sensory channels available can be generalized to include constraints involving the redundancy characteristics (the competency) of that capacity. Kahneman's discussion approached such a generalization when he spoke of changes in "structural connections between components." In technical language, such changes in competency would be reflected in changes in the equivocation of the channel (defined as the sum of noise and redundancy). Competency is the reciprocal of equivocation. Effort can then be defined as the measure of the attention "paid" to increase or maintain efficiency by reducing equivocation, i.e., enhancing competency.

D. External Versus Internal Constraint

Garner (1962) in his analysis of the structure of redundancy has shown that the total amount of constraint operating in any system of variables can be divided into internal and external components. *Internal constraints* refer to the relationships among the system of variables under consideration, while *external constraints* refer to the relationship between these variables and some external referent system of variables. In our neurophysiological experiments we considered the constraints that describe the central operation of the channel as internal and the constraints that refer to operations on the environmental situation which control its sensory input as external. In addition, it was found important to distinguish between temporal (repetition of the use of the channel or variable over time) and spatial (replication of the variable over space) redundancy for each of Garner's categories.

Specifically, it was suggested (Pribram, 1967c) that when the frontal system becomes involved in the orienting reaction, the internal

redundancy in the input channel is increased so that all of the information being simultaneously processed becomes "chunked" into one unit. By contrast, when the posterior cortex becomes involved in the attentional process, internal redundancy in the input channels is decreased, separating the bits of information in each channel from each other. This is concomitant with enhancement of external redundancy, which according to Garner's findings enhances the ability to make discriminations, i.e., to categorize input.

In short, the controls on emotion and motivation operate on the mechanisms of redundancy, on the constraints operating within and between channels, rather than on the "information" being processed. These constraints involve a neuronal model and may be conceived of as operating on *memory* rather than on input information. Another way of stating this is to say that the controls operate on the representational context in which the informational content is processed.

A good deal of additional evidence can be cited to show that competency rather than sensory channel capacity per se is controlled by the attentional systems discussed here. For instance, the studies of Anderson and Fitts (1958) cited by Garner (1962) show that as much as 17 bits of sensory information can be simultaneously processed. The work of Lindsay (1970), which demonstrated the relationship between sensory discriminability (difficulty in distinguishing between inputs) and central processing competency, has already been mentioned. Pribram, Lim, Poppen, and Bagshaw (1966) and Mishkin and Pribram (1955), using various forms of the delayed alternation tasks, attributed the differential-effects obtained after resections of two reciprocal frontoamygdala systems as due to selective alterations in the structure of internal redundancy (spatial and temporal, respectively) of the remaining processing competency. Further, Pribram and Tubbs (1967) have shown that when the delayed alternation task, the nemesis of monkeys with frontal-lobe resections, is externally parsed or chunked as a result of making the intertrial intervals asymmetric, the deficit is completely overcome. Similarly Wilson (1968) analyzed the trade-off between tasks involving external temporal and spatial redundancy in reciprocal mechanisms (anterior and posterior inferotemporal cortex) which have been delineated within the posterior system.

Thus, both Kahneman's (1973, pp. 8, 9, 15) and this analysis attribute the control of attention to alternations in information-processing channels, not the direct control on information and uncertainty

per se. We differ in that Kahneman focused on the problem of increasing the number of channels of fixed capacity—the "allocation of spare capacity"—while this analysis emphasizes the broader issue of competency, defined by any constraints operating on the structure of channel redundancy. We also differ in separating readiness from arousal and in that we do not identify attention, arousal, readiness, and effort as different names for the same process. Finally, the model put forward here specifies that effort accompanies only those attentional processes which result in a change in the representational organization of the information-processing mechanism. Part of the mechanism detailing how and when effort is expended during attention has been revealed by studies measuring peripheral autonomic and somatic changes.

A way to picture this somewhat technical account of the model is as follows. Most psychologists today view the limitation on central processing to be due to a fixed frame (i.e., "frames of consciousness"), which limits the momentary capacity of a channel, much as does the exoskeleton of a crustacean. The model proposed here is that the limits, (the constraints) are not exoskeletal but endoskeletal—they operate by virtue of the internal structure of the channel, not by some outer shell, or "frame," that encases it. Further, the evidence from brain research as well as from behavioral research indicates that the internal skeleton is flexible: It can be reorganized into a variety of configurations. Organization involves "paying" attention and comes about in two ways: through purely mnemonic internal emotional "adjustments" (control of internal redundancy) or through the motivational "execution of practical relations" with external events (control of external redundancy).

A good deal remains to be explained. Do these observations dealing with overall central capacity and competency also apply to how the attentional mechanism becomes intentional? That is, what brain processes allow the act and actor, percept and perceiver, to be simultaneously attended? Does self-consciousness accrue simply as a dividend from the fact that central competence as a whole fluctuates around the "magical number 7" (Miller, 1956), or is a higher-order constraint necessary to its genesis? Is, as suggested here, the change from a homeostatic, error-processing feedback mechanism to the parallel processing of information in an open-loop mechanism sufficient explanation, or is the change from a holonomically constrained system (described by integrable differential equations) to a nonholonomic

system the essential development? What role do the limbic forebrain
structures (involved in psychomotor seizures) have in making parallel
or nonholonomic processes possible? And are either parallel or nonho-
lonomic attentional mechanisms the essence of such typically human
information-processing abilities as practical skills and linguistic com-
munication and the memory mechanisms associated with such abili-
ties?

This is as far as the outlines of the model can take us today. Further
neuropsychological and neurophysiological research and even more
precise formulation of the brain mechanisms of intentionality, atten-
tion, emotion, and motivation in terms of control theory are needed.
But such formulations need not begin *de novo*. A beginning *was* made
by William James, as we have seen. In discussing certain clinical
observations, he clearly foreshadowed the endoskeletal model of com-
petency developed here and its relationship to self-consciousness:

> If we speculate on the brain-condition during all these different perversions
> of personality, we see that it must be supposed capable of successively
> changing all modes of action, and abandoning the use for the time being of
> whole sets of well organized association-paths. In no other way can we
> explain the loss of memory in passing from one alternating condition to
> another. And not only this, but we must admit that organized systems of
> paths can be thrown out of gear with others, so that the processes in one
> system give rise to one consciousness, and those of another system to
> another *simultaneously* existing consciousness. Thus only can we understand
> the facts of automatic writing, etc., whilst the patient is out of trance, and
> the false anaesthesias and amnesias of the hysteric type . . . Each of the
> selves is due to a system of cerebral paths acting by itself. If the brain acted
> normally, and the dissociated systems came together again, we should get a
> new affection of consciousness in the form of a third "Self" different from
> the other two, but knowing their objects together, as the result . . .
>
> Some peculiarities in the lower automatic performances suggest that
> the systems thrown out of gear with each other are contained one in the
> right and the other in the left hemisphere. The subjects, e.g., often write
> backwards, or they transpose letters, or they write mirror-script. All these
> are symptoms of agraphic disease. The left hand, if left to its natural
> impulse, will in most people write mirror-script more easily than natural
> script . . . On Hughlings Jackson's principles, the left hemisphere, being
> the more evolved organ, at ordinary times inhibits the activity of the right
> one; but Mr. Myers suggests that during the automatic performances the
> usual inhibition may be removed and the right hemisphere set free to act by
> itself. This is very likely to some extent to be the case. But the crude
> explanation of "two" selves by "two" hemispheres is of course far from Mr.
> Myer's thought. The selves may be more than two, and *the brain systems
> severally used for each must be conceived as interpenetrating each other in very
> minute ways.* [Italics mine] (1950, Vol. I, pp. 399-400)

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REFERENCES

ANDERSON, N. S., AND FITTS, P. M. Amount of information gained during brief exposures of numerals and colors. *Journal of Experimental Psychology*, 1958, 56, 362–369.

ASHBY, W. R. *Design for a brain: The origin of adaptive behavior* (2nd ed.). New York: Wiley, 1960.

ASHBY, W. R. *An introduction to cybernetics*. New York: Wiley, 1963.

BAGSHAW, M. H., AND BENZIES, S. Multiple measures of the orienting reaction and their dissociation after amygalectomy in monkeys. *Experimental Neurology*, 1968, 20, 175–187.

BAGSHAW, M. H., AND COPPOCK, H. W. Galvanic skin response conditioning deficit in amygdalectomized monkeys. *Experimental Neurology*, 1968, 20, 188–196.

BAGSHAW, M. H., KIMBLE, D. P., AND PRIBRAM, K. H The GSR on monkeys during orienting and habituation and after ablation of the amygdala, hippocampus and inferotemporal cortex. *Neuropsychologia*, 1965, 3, 111–119.

BAGSHAW, M. H., AND PRIBRAM, J. D. Effect of amygdalectomy on stimulus threshold of the monkey. *Experimental Neurology*, 1968, 20, 197–202.

BAGSHAW, M. H., AND PRIBRAM, K. H. Effect of amygdalectomy on transfer of training in monkeys. *Journal of Comparative and Physiological Psychology*, 1965, 59, 118–121.

BAILEY, P., AND SWEET, W. H. Effects on respiration, blood pressure and gastric motility of stimulation of orbital surface of frontal lobe. *Journal of Neurophysiology*, 1940, 3, 276–281.

BAILEY, P., VON BONIN, G., AND McCULLOCH, W. S. *The isocortex of the chimpanzee*. Urbana: The University of Illinois Press, 1950.

BEEBE-CENTER, J. G. The psychology of feeling. In *Encyclopedia Brittanica*, (Volume 9). Chicago: Benton, 1971 edition.

BERNSTEIN, N. *The co-ordination and regulation of movements*. New York: Pergamon, 1967.

BLUM, J. S., CHOW, K. L., AND PRIBRAM, K. H. A behavioral analysis of the organization of the parieto-temporo-preoccipital cortex. *Journal of Comparative Neurology*, 1950, 93, 53–100.

BRENTANO, F. *Psychologie vom empirischen Stanpunkt* (3rd ed.). Leipzig: 1925.

BRETANO, F. The distinction between mental and physical phenomena. In R. M. CHISHOLM (Ed.), *Realism and the background of phenomenology*. New York: Free Press, 1960, pp. 39–61.

BRILLOUIN, L. *Science and information theory* (2nd ed.). New York: Academic Press, 1962.

BROBECK, J. R. Review and synthesis. In M. A. B. BRAZIER (Ed.), *Brain and behavior* (Vol. 2). Washington: American Institute of Biological Sciences, 1963, pp. 389–409.

BUCY, P. C., AND PRIBRAM, K. H. Localized sweating as part of a localized convulsive seizure. *Archives of Neurology and Psychiatry*, 1943, 50, 456–461.

DUTTER, C. M. The effect of discrimination training on pattern equivalence in monkeys with inferotemporal and lateral striate lesions. *Neuropsychologia*, 1968, 6, 27–40.

BUTTER, C. M. Impairments in selective attention to visual stimuli in monkeys with infero-temporal and lateral striate lesions. *Brain Research,* 1969, 12, 374–383.

CANNON, W. B. The James–Lange theory of emotions: A critical examination and an alternative theory. *American Journal of Psychology,* 1927, 34, 106–124.

CHOW, K. L. Effects of partial extirpations of the posterior association cortex on visually mediated behavior. *Comparative Psychology Monographs,* 1951, 20, 187–217.

CHOW, K. L. Integrative functions of the thalamocortical visual system of cat. In K. H. PRIBRAM AND D. BROADBENT (Eds.), *Biology of memory.* New York: Academic Press, 1970, pp. 273–292.

COWAN, W. M., ADAMSON, L., AND POWELL, T. P. S. An experimental study of the avian visual system. *Journal of Anatomy (London),* 1961, 95, 545–563.

COWAN, W. M., GOTTLIEB, A. E., HENDRICKSON, J. L., PRICE, J. L., AND WOOLSEY, T. A. The autoradiographic deminstration of axonal connection in the central nervous system. *Brain Research,* 1972, 37, 21–51.

DELL, P. J. Correlations entre le système végétatif et le système de la vie de relation; mésencéphale, diencéphale et cortex cérébral. *Journal de Physiologie* (Paris), 1952, 44, 471–557.

ECCLES, J. C. Postsynaptic inhibition in the central nervous system. In G. C. QUARTON, T. MELNECHUK, AND F. O. SCHMITT (Eds.), *The neurosciences.* New York: Rockefeller University Press, 1967, pp. 408–427.

EVARTS, E. V. Representation of movements and muscles by pyramidal tract neurons of the precentral motor cortex. In M. D. YAHR AND D. P. PURPURA (Eds.), *Neurophysiological basis of normal and abnormal motor activities.* Hewlett, N.Y.: Raven Press, 1967, pp. 215–254.

FIBIGER, H. C., PHILLIPS, A. G., AND CLOUSTON, R. A. Regulatory deficits after unilateral electrolytic or 6-OHDA lesions of the substantia nigra. *American Journal of Physiology,* 1973, 225(6), 1282–1287.

FULTON, J. F. *Frontal labotomy and affective behavior: A neurophysiological analysis.* New York: Norton, 1951.

GALAMBOS, R., NORTON, T. T., AND FROMMER, C. P. Optic tract lesions sparing pattern vision in cats. *Experimental Neurology,* 1967, 18, 8–25.

GARNER, W. R. *Uncertainty and structure as psychological concepts.* New York: Wiley, 1962.

HEARST, E., AND PRIBRAM, K. H. Appetitive and aversive generalization gradients in amygdalectomized monkeys. *Journal of Comparative Physiological Psychology,* 1964a, 58, 296–298.

HEARST, E., AND PRIBRAM, K. H. Facilitation of avoidance behavior by unavoidable shocks in normal and amygdalectomized monkeys. *Psychological Reports,* 1964b, 14, 39–42.

HUSSERL, E. *Logische Untersuchungen* (4th ed.). Halle, 1928.

JAMES, W. *Principles of psychology* (Vols. 1 and 2 complete). New York: Dover, 1950.

JOHANSSON, G. Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics,* 1973, 14(2), 201–211.

KAADA, B. R. Somato-motor, autonomic and electro-corticographic responses to electrical stimulation of "rhinencephalic" and other structures in primates, cat and dog. *Acta Physiologica Scandinavica,* 1951, 23(Suppl. 83), 285.

KAADA, B. R., PRIBRAM, K. H., AND EPSTEIN, J. A. Respiratory and vascular responses in monkeys from temporal pole, insula, orbital surface and singulate gyrus: A preliminary report. *Journal of Neurophysiology,* 1949, 12, 347–356.

KAHNEMAN, D. *Attention and effort.* Englewood Cliffs, N.J: Prentice-Hall, 1973,

KIMBLE, D. P., BAGSHAW, M. H., AND PRIBRAM, K. H. The GSR of monkeys during

orienting and habituation after selective partial ablations of the cingulate and frontal cortex. *Neuropsychologia*, 1965, *3*, 121–128.

KLUVER, H. *Behavior mechanisms in monkeys.* Chicago: University of Chicago Press, 1933.

KLUVER, H., AND BUCY, P. C. "Psychic blindness" and other symptoms following bilateral temporal lobectomy in rhesus monkeys. *American Journal of Physiology*, 1937, *119*, 352–353.

LASHLEY, K. S. *Brain mechanisms and intelligence.* Chicago: University of Chicago Press, 1929.

LINDSAY, P. H. Multichannel processing in perception. In D. I. MOSTOFSKY (Ed.), *Attention: Contemporary theory and analysis.* New York: Appleton-Century-Crofts, 1970, pp. 149–171.

LIVINGSTON, R. B., FULTON, J. F., DELGADO, J. M., SACHS, E., JR., BRENDLER, S. J., AND DAVIS, G. Stimulation and regional ablation of orbital surface of frontal lobe. *Research Publications Association for Research in Nervous and Mental Disease*, 1948, *27*, 405–420.

MACKAY, D. M. *Information, mechanism and meaning.* Cambridge, Mass.. MIT Press, 1969.

MACLEAN, P. D. Psychosomatic disease and the "visceral brain": Recent developments bearing on the Papez theory of emotion. *Psychosomatic Medicine*, 1949, *11*, 338–353.

MACLEAN, P. D., AND PRIBRAM, K. H. A neuronographic analysis of the medial and basal cerebral cortex: I. Cat. *Journal of Neurophysiology*, 1953, *16*, 312–323.

MALIS, L. I., PRIBRAM, K. H., AND KRUGER, L. Action potentials in "motor" cortex evoked by peripheral nerve stimulation. *Journal of Neurophysiology*, 1953, *16*, 161–167.

MANDLER, G. The conditions for emotional behavior. In D. C. GLASS (Ed.), *Neurophysiology and emotion.* New York: Rockefeller University Press and Russell Sage Foundation, 1967, pp. 96–102.

MARSHALL, J. F., AND TEITELBAUM, P. Further analysis of sensory inattention following lateral hypothalamic damage in rats. *Journal of Comparative and Physiological Psychology*, 1974, *86(3)*, 375–395.

MCFARLAND, D. J. *Feedback mechanisms in animal behavior.* New York: Academic Press, 1971.

METTLER, A., AND MCLARDY, T. Posterior cuts in prefrontal leucotomy: A clinical-pathological study. *Journal Mental Science*, 1948, *94*, 555–564.

MILLER, G. A. The magical number seven, plus or minus two, or, some limits on our capacity for processing information. *Psychological Review*, 1956, *63(2)*, 81–97.

MILLER, G. A., GALANTER, E. H., AND PRIBRAM, K. H. *Plans and the structure of behavior.* New York: Holt, 1960.

MILLER, N. E., BAILEY, C. J., AND STEVENSON, J. A. Decreased "hunger" but increased food intake resulting from hypothalamic lesions. *Science*, 1950, *112*, 256–259.

MISHKIN, M., AND PRIBRAM, K. H. Visual discrimination performance following partial ablations of the temporal lobe: I. Ventral vs. lateral. *Journal of Comparative Physiological Psychology*, 1954, *47*, 14–20.

MISHKIN, M., AND PRIBRAM, K. H. Analysis of the effects of frontal lesions in monkey: I. Variations of delayed alternation. *Journal of Comparative and Physiological Psychology*, 1955, *48*, 492–495.

MITTELSTAEDT, H. Discussion. In D. P. KIMBLE (Ed.), *Experience and capacity.* New York: The New York Academy of Sciences, Interdisciplinary Communications Program, 1968, pp. 46–49.

NEISSER, U. *Cognitive psychology.* New York: Appleton-Century-Crofts, 1967.

ORNSTEIN, R. E. *The psychology of consciousness.* San Francisco: Freeman, 1972.

ORNSTEIN, R. E. *The nature of human consciousness: A book of readings.* San Francisco: Freeman, 1973.

PATTEE, H. H. Physical theories of biological coordination. *Quarterly Review of Biophysics*, 1971, *4, 2, & 3*, 255–276.

PRIBRAM, K. H. Toward a science of neurophysiology: (Method and data). In R. A. PATTON (Ed.), *Current trends in psychology and the behavioral sciences*. Pittsburgh: The University of Pittsburgh Press, 1954, pp. 115–142.

PRIBRAM, K. H. Comparative neurology and the evolution of behavior. In A. ROE AND G. G. SIMPSON (Eds.), *Behavior and evolution*. New Haven, Conn: Yale University Press, 1958, pp. 140–164.

PRIBRAM, K. H. A review of theory in physiological psychology. In *Annual Review of Psychology* (Vol. 11). Palo Alto, Calif.: Annual Reviews, Inc., 1960, pp. 1–40.

PRIBRAM, K. H. Emotion: Steps toward a neuropsychological theory. In D. C. GLASS Ed.), *Neurophysiology and emotion*. New York: Rockefeller University Press and the Russell Sage Foundation, 1967a, pp. 3–39.

PRIBRAM, K. H. Memory and the organization of attention. In D. B. LINDSLEY AND A. A. LUMSDAINE (Eds.), *Brain Function* (Vol. 4). Berkeley: University of California Press, 1967b, pp. 79–122.

PRIBRAM, K. H. The new neurology and the biology of emotion. *American Psychologist*, 1967c, *10*, 830–838.

PRIBRAM, K. H. The amnestic syndromes: Disturbances in coding? In G. A. TALLAND AND N. C. WAUGH (Eds.), *Pathology of memory*. New York: Academic Press, 1969, pp. 127–157.

PRIBRAM, K. H. *Languages of the brain: Experimental paradoxes and principles in neuropsychology*. Englewood Cliffs, N.J.: Prentice-Hall, 1971.

PRIBRAM, K. H. How is it that sensing so much we can do so little? In F. O. SCHMITT AND F. G. WORDEN (Eds.), *The Neurosciences Study Program, III*. Cambridge, Mass.: MIT Press, 1974, pp. 249–261.

PRIBRAM, K. H. The isocortex. In D. A. HAMBURG AND H. K. H. BRODIE (Eds.), *American handbook of psychiatry* (Vol. 6). New York: Basic Books, 1975, pp. 107–129.

PRIBRAM, K. H. Holonomy and structure in the organization of perception. In *Proceedings of the Conference on Images, Perception and Knowledge, University of Western Ontario*, 1976a.

PRIBRAM, K. H. Problems concerning the structure of consciousness. In G. GLOBUS, G. MAXWELL AND I. SAVODNIK (Eds.), *Consciousness and the Brain*. New York: Plenum Press, 1976b.

PRIBRAM, K. H., AND BAGSHAW, M. H. Further analysis of the temporal lobe syndrome utilizing frontotemporal ablations in monkeys. *Journal of Comparative Neurology*, 1953, *99*, 347–375.

PRIBRAM, K. H., KRUGER, L., ROBINSON, R., AND BERMAN, A. J. The effects of precentral lesions on the behavior of monkeys. *Yale Journal of Biology and Medicine*, 1955–56, *28*, 428–443.

PRIBRAM, K. H., LENNOX, M. A., AND DUNSMORE, R. H. Some connections of the orbito-fronto-temporal, limbic and hippocampal areas of *Macaca mulatta. Journal of Neurophysiology*, 1950, *13*, 127–135.

PRIBRAM, K. H., LIM, H., PUPPEN, R., AND BAGSHAW, M. H. Limbic lesions and the temporal structure of redundancy. *Journal of Comparative and Physiological Psychology*, 1966, *61*, 365–373.

PRIBRAM, K. H., AND MACLEAN, P. D. A neuronographic analysis of the medial and basal cerebral cortex: II. Monkey. *Journal of Neurophysiology*, 1953, *16*, 324–340.

PRIBRAM, K. H., AND MCGUINNESS, D. Arousal, activation and effort in the control of attention. *Psychological Review*, 1975, *82*, 116–149.

PRIBRAM, K. H., AND TUBBS, W. E. Short-term memory, parsing, and the primate frontal cortex. *Science*, 1967, *156*, 1765–1767.

PRIBRAM, K. H., AND WEISKRANTZ, L. A comparison of the effects of medial and lateral cerebral resections an conditioned avoidance behavior of monkeys. *Journal of Comparative and Physiological Psychology*, 1957, *50*, 74–80.

ROBERTS, W. W. Are hypothalamic motivational mechanisms functionally and anatomically specific? *Brain, Behavior and Evolution*, 1969, *2*, 317–342.

ROSVOLD, H. E., MIRSKY, A. F., AND PRIBRAM, K. H. Influence of amygdalectomy on social interaction in a monkey group. *Journal of Comparative and Physiological Psychology*, 1954, *47*, 173–178.

RUCH, T. C., AND SHENKIN, H. A. The relation of area 13 on orbital surface of frontal lobes to hyperactivity and hyperphagia in monkeys. *Journal of Neurophysiology*, 1943, *6*, 349–360.

SCHACHTER, S. Cognitive effects on bodily functioning: Studies of obesity and eating. In D. GLASS (Ed.), *Neurophysiology and emotion*. New York: Rockefeller University Press and Russell Sage Foundation, 1967, pp. 117–144.

SCHWARTZBAUM, J. S. Changes in reinforcing properties of stimuli following ablation of the amygdaloid complex in monkeys. *Journal of Comparative Physiological Psychology*, 1960a, *53*, 388–395.

SCHWARTZBAUM, J. S. Response to changes in reinforcing conditions of bar-pressing after ablation of the amygdaloid complex in monkeys. *Psychological Reports*, 1960b, *6*, 215–221.

SCHWARTZBAUM, J. S. Some characteristics of amygdaloid hyperphagia in monkeys. *American Journal of Psychology*, 1961, *74*, 252–259.

SCHWARTZBAUM, J. S., AND PRIBRAM, K. H. The effects of amygdalectomy in monkeys on transposition along a brightness continuum. *Journal of Comparative and Physiological Psychology*, 1960, *53*, 396–399.

SCHWARTZBAUM, J. S., WILSON, W. A., JR., AND MORRISSETTE, J. R. The effects of amygdalectomy on locomotor activity in monkeys. *Journal of Comparative and Physiological Psychology*, 1961, *54(3)*, 334–336.

SIMON, H. A. How big is a chunk? *Science*, 1974, *183*, 482–488.

SPINELLI, D. N., AND PRIBRAM, K. H. Changes in visual recovery functions produced by temporal lobe stimulation in monkeys. *Electroencephalography and Clinical Neurophysiology*, 1966, *20*, 44–49.

SPINELLI, D. N., AND PRIBRAM, K. H. Changes in visual recovery functions and unit activity produced by frontal and temporal cortex stimulation. *Electroencephalography and Clinical Neurophysiology*, 1967, *22*, 143–149.

TEITELBAUM, P. Sensory control of hypothalamic hyperphagia. *Journal of Comparative and Physiological Psychology*, 1955, *48*, 156–163.

UNGERSTEDT, U. Brain dopamine neurons and behavior. In F. G. SCHMITT AND F. O. WORDEN (Eds.), *The Neurosciences Study Program, III*. Cambridge, Mass.: MIT Press, 1974, pp. 695–704.

VALENSTEIN, E. S. Stability and plasticity of motivation systems. In G. C. QUARTON, T. MELNECHUK, AND G. ADELMAN (Eds.), *The neurosciences*. New York: Rockefeller University Press, 1970, pp. 207–217.

VALENSTEIN, E. S., COX, V. C., AND KAKOLEWSKI, J. W. The hypothalamus and motivated behavior: In. J. T. TAPP (Ed.), *Reinforcement and behavior*. New York: Academic Press, 1969, pp. 242–285.

VON FORESTER, H. Memory without record. In D. P. KIMBLE (Ed.), *The anatomy of memory*. Palo Alto, Calif.: Science and Behavior Books, 1965, pp. 388–433.

WALL, P. D., AND PRIBRAM, K. H., Trigeminal neurotomy and blood pressure responses
    from stimulation of lateral cerebral cortex of *Macaca mulatta*. *Journal of Neurophysiol-
    ogy*, 1950, *13*, 409–412.
WARD, A. A., JR. The cingular gyrus: Area 24. *Journal of Neurophysiology*, 1948, *11*, 13–23.
WILSON, M. Inferotemporal cortex and the processing of visual information in monkeys.
    Neuropsychologia, 1968, *6*, 135–140.