

The Opening of the Black Box: Is Psychology Prepared?

Uriel G. Foa and David L. Margules

Temple University

Advances in methods for observing the neural and hormonal events that coordinate behavior pose a challenge for psychology. Such research suggests that these events are complex and highly organized developmentally. They are more likely to be understood when considered in their relationship to one another than when taken in isolation. Further, examples from a variety of areas appear to indicate that variables at different levels are rarely related one-by-one. Rather, the rule appears to be of pattern-to-pattern. On the psychological side a theory of patterns appears to be wanting. Some of the metatheoretical problems involved in developing such a theory are discussed. Methods of analysis for a large number of variables are available provided these variables are organized in patterns. A psychological theory meeting the new challenge requires autonomous developments within psychology, since it is unlikely to grow from advances in the neurological sciences.

This paper examines the relationship between behavior and its neural and hormonal substrata. It also attempts to clarify conditions that may facilitate a link up of these two areas of research. Recent evidence suggests that hormonal and neural events (both electrical and chemical) are better understood when considered in patterns of relationship than in isolation. In consequence it appears unlikely that neural, hormonal, and behavioral phenomena will be related one-to-one. A pattern-to-pattern relationship seems more probable. Present conceptualizations of behavior do not meet the requirements of linkage with neural or hormonal activity since they focus on isolated variables rather than on their pattern of interrelationships. In the last part of the paper we consider some metatheoretical and methodological notions that may foster the development of a more appropriate psychology theory.

We have long known that psychologically important events occur inside

The work reported in this paper was done in part while the senior author was in residence at the University of Cambridge, England. This work was supported by a grant-in-aid from Temple University. Robert A. Hinde is thanked for his invaluable comments and suggestions on an earlier version as well as for the opportunity to leisurely discuss with him the ideas presented in this paper. For an enlightening discussion we are also indebted to Susan D. Iversen. The insightful remarks of Richard Hallam are gratefully acknowledged. So are the suggestions of the Editor and of an anonymous reviewer of this Journal, as well as those of James Flynn. Request for reprints should be sent to Uriel G. Foa, 505 Weiss Hall, Temple University, Philadelphia, Pennsylvania 19122.

our bodies. Until recently they could not be observed. In spite of this limitation, some psychological theories offered conceptualization of such internal processes that could explain observable behavior. A typical example is provided by Freud's mechanisms of defense. These assumptions were not particularly useful in predicting behavior: indeed, the internal processes could only be inferred from behavior, after it had occurred.

In reaction to these shortcomings behaviorists suggested that we should ignore unobservable events. We should be able, they proposed, to predict the behavior of an organism by observing the stimuli that impinge upon it. Thus, for different reasons, adherents of either school did not need to worry about the internal-external relationship. However other investigators, often influenced by Lashley's thinking (e.g., Eccles, 1953; Hebb, 1965, 1980; Milner and Teuber, 1968; Weiskrantz, Mihailovic, and Gross, 1960), had the foresight to realize that the problems posed by the relations between brain and behavior could not forever be ignored.

Even for those who avoided facing the problem, this situation of blessed innocence is now coming to an end. A growing number of sophisticated techniques have begun to permit the observation of internal events. These techniques may be considered as still somewhat imprecise, but they are constantly improving. Not surprisingly, most advances have been made in animal studies, rather than in the investigation of humans. Indeed, some methods involve procedures too obtrusive to be applied to humans. Furthermore, the behavioral repertoire of animals is more limited and thus easier to be related to brain events. Yet progress in human research has also been made. Consider for example recording of electrical activity in muscles (e.g., Cacioppo and Petty, 1981), mapping brain pathways by monitoring of radio-labeled glucose (Kennedy, Des Rosiers, Jehle, Reivich, Sharpe, and Sokoloff, 1975), *in vivo* observation of cerebral blood flow by computed tomography enhanced by non-radioactive xenon gas (Gur, Good, Wolfson, Yonas, and Shabason, 1982), nuclear magnetic resonance, or the visualization by autoradiography of specific receptors for neurotransmitters in whole organs such as the brain (Pert, Kuhar, and Snyder, 1975).

These technical advances open exciting new vistas for the research psychologist. They also pose a challenge. Are we ready for it? And what could we do to improve our chances of meeting the challenge successfully? In examining these problems we shall maintain a dichotomy between externally observable variables, i.e., behavior, and internal variables, such as alpha rhythms, action potentials, enzyme concentrations and the like. Yet, dichotomy is an oversimplification. It seems likely that more than two sets of concepts will prove necessary to account for the relationship between brain and muscles. But the arguments that applied to the relationship between two sets, grossly labelled external and internal, will hold with more cogency for a larger number of them.

The research problem underlying internal and external studies can be roughly stated as follows: "What is the mutual influence (or relationship) between states of the organism and behaviors." More specifically: "Which changes in internal states are induced by behavior and, reciprocally, what changes in behavior are induced by internal events?" An attempt to answer these questions invites consideration of the nature of neurological and psychological data. Those provided by internal observation are likely to be organized in structural patterns, their functional significance coming from the pattern rather than from each separate component of it.

Ubiquity of Patterns

Evidence on the significance of patterns can be located in a variety of areas. Consider the coding of genetic information: each instruction is represented by a specific sequence of three bases, taken from the four found in the DNA structure. The information is provided by the sequence and not by each base considered in isolation, so that the mere frequency distribution of the four bases bears no relationship to the meaning of the instructions. When DNA had still to be identified as the genetic material, biologists assumed that the heritable differences between organisms must be determined by protein structures. Indeed proteins were the only molecules known to be capable both of sufficient variety of form and specificity of function, as exemplified by enzymes. The structure of DNA, containing as it does only four different kinds of bases, did not seem to offer sufficient potential for either structural variation or specificity. In fact, it was at one time believed that DNA consisted of a mixture of small molecules, containing one of each of the four bases in random sequence, the so-called "statistical tetranucleotide." The discovery in the 1940's that DNA molecules are very much longer than this and that the genetic material is indeed DNA, was followed by the finding that the frequency distribution of the four bases varies widely among the DNA of different organisms (Strickberger, 1968, pp. 48-59). The elucidation of the structure of DNA by Watson and Crick stimulated speculation in the 1950's on the nature of the genetic code, including the following proposal, which subsequently proved to be correct. By taking the four bases three at a time, 4^3 or 64 different kinds of instructions can be encoded into a linear DNA molecule, and this is more than sufficient to specify a linear sequence of the 20 different kinds of amino acids on which protein structure, and hence enzyme specificity, depend.¹ This example is particularly instructive because it shows how an unwarranted one-to-one assumption (one base for each instruction) can lead the investigator astray. It is not by chance that the breaking of the genetic code followed the discovery of the structure. It could not possibly have preceded it, since the information is carried by the structure.

¹John A. Grunau: Personal communication, 1971.

Patterns in Chemical Structure

Patterns are also important for decoding the information carried by the amino acid sequence of polypeptide chains. This sequence itself is not directly relevant to the biological function of the molecule because polypeptide chains spontaneously fold and assemble themselves rapidly into three dimensional globular forms. The three dimensional shape or conformation of protein molecules determines its specific biological function (Anfinsen, 1973). Moreover, many proteins have the capacity to change their conformation when they bind a ligand. For example, when the protein hemoglobin binds oxygen, its subunits interact cooperatively to accomplish this by shifts in molecular conformation. When hemoglobin releases its oxygen its conformation returns to the original state (Monod, Wyman, and Changeaux, 1965). The capacity to shift conformation reversibly also occurs in allosteric (other sites) enzymes that bind one ligand at a primary site and one or more modulator molecules at secondary sites. Each modulator acts to change the conformation of the enzyme in different ways making it either more or less likely to bind its primary ligand. Similarly, allosteric receptors have the capacity to change conformation after binding certain modulators (Monod, et al., 1965). Further, *in vitro* work indicates that opioid (μ) receptors are shifted into a conformation that binds opioid agonists when sodium modulator ions are in short supply (Pert and Snyder, 1974). The effect of such receptor occupation may encourage sodium retention in the body and stimulate appetite. This brings sodium concentrations up to physiological levels sufficient to shift the opioid (μ) receptors towards a conformation that binds opioid antagonists. Such agents may promote sodium excretion and tend to inhibit appetite (Margules, 1981). These patterns of modulation at sites on regulatory enzymes and receptors may be crucial for understanding molecular events underlying behavioral regulation.

Patterns in Neuronal Circuits

Self-assembly not only occurs at the molecular level but also in neuronal circuits during development. Here again, pattern in four dimensions may provide insight into psychological processes such as selective attention. Recently, opiate receptor gradients have been reported along hierarchically organized cortical systems of rhesus monkeys that sequentially process modality specific sensory information of a progressively more complex nature (Lewis, Mishkin, Bragin, Brown, Pert, and Pert, 1983). This suggests that the pattern of opiate receptors in cortex plays a role in the affective filtering of sensory stimuli and in emotion-induced selective attention. A similar distribution of gradients has been reported for dopamine in the cortex of rhesus monkeys and African green monkeys (Lewis, et al., 1983).

Patterns of neuronal connections are dependent on sensory input in post-natal development as demonstrated by the failure of certain cortical "barrels" to develop if certain sensory vibrissae are destroyed at birth (Van der Loos and Woolsey, 1973). Similarly the visual cortex develops an abnormal pattern upon reduction of visual input (Wiesel and Hubel, 1963). Apparently signals from the environment influence the genetically guided program of neuronal development to modify the pattern of neuronal circuitry.

Patterns in Neural Events

Evidence is accumulating that electrical neural phenomena also involve consideration of patterns. For example, Donchin (1979) reviewing work on event-related brain potential notes that the weakness of early studies can be attributed, in part, to a tendency to treat the event-related potential as if it is a global representation of the state of cortical tissues. ". . . It has proven, however, far more fruitful . . . to consider the event-related potential a sequence of overlapping components, each possibly representing activity of different populations of nerve cells and each standing in different, often orthogonal, relations to experimental variables (p. 24)." A similar conclusion was reached by Gevins (1981) and others who studied electrical potential in the human brain during a simple task of judging distances or the magnitude of a number. Their results suggest that "many areas in both hemispheres were involved in a complex manner even in single judgments" (p. 213). This line of thought is also reflected in the work of Iversen and Fray (1982) who cautioned that the change of behavior following interference with a pathway in the brain reflects not only loss of the contribution of the lesioned system, but also dysfunction within a wider network associated with the dopamine neurons. This brief review suggests that internal events, be they electrical or chemical, are better understood when considered in patterns rather than in isolation. How then do these patterns of events relate to a single specific behavior? Evidence bearing on this question is examined next.

Internal-External Relationship

The one-to-one assumption in the relationship between behavior and brain is denied by some findings of Luria (1966). His research on disturbances of higher mental functions in the presence of local brain lesions indicates that more than one brain activity is involved in any given behavior and conversely a given activity such as handwriting may be impaired in different ways varying with the location of the brain lesion. Moreover, when a handwriting component, such as directionality, is impaired, we may also expect to find this component impaired in other domains of behavior. Social direction (e.g., differentiation between what one does to self and what one does to other) is

one example of a behavior which may be defective due to disturbances in the directionality component. More recently Luria and his associates expanded this notion by suggesting, on the basis of clinical observations, that the same behavioral system may be related to different cortical structures at different stages of its ontogenetic development (Luria, Simernitskaya, and Tubylevich, 1970). Fentress (1976) went even further by proposing that cerebral organization may change in different states of activation. A complex brain-task relationship is also evident in sensory functions. Employing a visual discrimination task, Iversen (1973) found that monkeys with a posterior inferotemporal lesion show impairment of pattern discrimination but perform almost as well as normal monkeys in simple color discrimination. These results suggest that more than one brain function is involved in visual discrimination.

Recent Evidence

Further support is provided by more recent work dealing with the relationship between internal and external variables. Lynch (1980) after reviewing evidence on the relation between a region of the brain—the posterior parietal association cortex—and psychological functions, concluded as follows:

Evidence has been presented from the human clinical literature and from experimental lesion and behavioral-electrophysiological studies of monkeys which suggests that posterior parietal association cortex is intimately concerned with several different aspects of behavior and higher nervous function in both humans and monkeys. Clinical studies have shown that posterior parietal damage causes disruption of many behavioral and intellectual processes related to sensation, perception, attention, and motor control. The effects of damage to posterior parietal cortex in monkeys are similar to those that follow analogous damage in humans to the minor hemisphere, although there is evidence that the contralateral defect of attention that is so striking in humans is less severe in monkeys, and that disorders of motor control are more profound and longer-lasting in monkeys than in humans. . . . Available evidence suggests that there is no single heading under which all of the functional mechanisms of the parietal association cortex can be classified. The results discussed here confirm that parietal association cortex is critical for the performance of sensory and perceptual processing at a high level. . . . However, the results also support the proposal that posterior parietal cortex contains, in addition to its sensory association mechanisms, other functional units that are primarily devoted to the initiation and control of certain motor acts, and yet other units that are involved in the modulation of the sensory and motor processes by attentional, motivational, and emotional factors. (p. 497)

Likewise, Vanderwolf and Robinson (1981) noted that the activity of neocortical waves does not relate one-to-one with the state of arousal or consciousness.

Commenting on the Vanderwolf and Robinson (1981) paper, Krnjevic (1981) noted: "It is notoriously difficult to interpret 'brain waves' (EEG activity). When an attempt is made to correlate types of brain activity with specific aspects of behavior—another 'phenomenon' that does not readily lend itself to precise, objective analysis—the complications are further com-

pounded (p. 484)." In the same vein, Vinogradova (1981) tartly remarked: ". . . it is a sweet, but deceptive dream that any brain state, reflected in EEG changes, must be immediately translatable into easily interpretable overt movements for the benefit of the experimenter (p. 496)." With reference to sleep-waking states, Jones (1981) proposes that the relationship between brain activity and behavior "should be approached through a more holistic view, involving constellations of physiological and behavioral events (p. 483)." Support for the soundness of these views comes from the recent discovery of the mechanism linking an instinct to its genes.

Egg-Laying Behavior: Coordinating by Combinatorial Sets of Neuropeptides

Instincts are among the simplest of behaviors, but there is not a simple chemical basis for them. Take for example the egg-laying behavior of the marine snail, *Aplysia*. Previously this behavior was thought to be mediated by one neuropeptide known as egg-laying hormone (ELH). One peptide can be specified by one gene, making it theoretically possible for a single gene to be fully responsible for an instinct. We now know that this is not the case in *Aplysia* (Schiller, Jackson, McAllister, Schwartz, Kandel, and Axel, 1982). There is a family of nine or more genes that specify ELH-like peptides in *Aplysia*. Moreover, each gene in the family specifies a different long polypeptide chain that contains ELH along with three or four other biologically active peptides. The chain is set up with predetermined cleavage sites where enzymes can act to liberate these peptides so that they can be released together. The release provokes a coordinated series of actions that allows egg-laying to occur successfully. Why is more than one peptide specified by each gene in the family?

The answer appears to lie in a behavioral analysis of egg-laying behavior. In order for egg-laying to be successful it is necessary for *Aplysia* to inhibit locomotion so that the egg-laying string will not be scattered. One of the peptides could be targeted to act at motor neurons to inhibit locomotion. Next, head waving begins followed by egg-laying. The egg string is gathered together into a clump by mouth, making it essential that the *Aplysia* be totally anorexic, least it devour its own eggs. Anorexia is often associated with reproductive behavior in many species, including humans. This raised the possibility that another peptide is targeted to induce a powerful anorexia by an action on neurons concerned with ingestive behavior. Another peptide, perhaps ELH itself could be targeted to cause egg extrusions and so on. This analysis emphasizes the roles of different target tissues in the execution of instinctive behavior pattern. There is no reason why one gene could not produce all of the neuropeptides necessary to properly prepare all the targets. Why are there nine or more genes involved?

An analysis of the cell types that produce ELH-like peptides may suggest an answer. At least two very different cell types make these peptides: one is a neuron and the other is a hormone-producing cell. Each of these cells expresses a different ELH gene. This means that ELH-like peptides and related peptides will be produced at different sites in the body during egg-laying behavior. Apparently there is no primary site or center controlling this event. More than one production site may be needed and various ELH messages may be necessary in order to induce the behavior. Each site appears to release peptides that contain a fixed ELH sequence along with a variable sequence (Schiller, et al., 1982). Margules (1981) advanced the possibility that this variable sequence represents address information specific to the cell type that released it. The address information could be used as a means of communication between production sites. This hypotheses may account for some of the gene products but not all nine gene products. Other possibilities include the idea that some of the genes may be pseudogenes. Finally, some of these genes may be expressed at different times during development in some cell types and not others. Much of the complexity of the developmental chemistry remains to be worked out. It is clear, however, that even instincts, the simplest of the organized behavior patterns, are regulated by complex patterns of peptide production and processing. Indeed, similar sets of gene families and combinatorial peptides are responsible for the energy conserving behavioral reactions mediated by the pro-opiomelanocortin gene (Margules, 1981). The pro-opiomelanocortin gene, like the ELH gene, exerts this control through the production of several hormones including the MSH hormones, ACTH and beta-endorphin. Similarly, there are at least three families of genes that give rise to a number of opioid peptides. In each peptide the fixed enkephalin sequence at the N-terminal end of the molecule regulates energy conserving behavior. By contrast, the sequences at the carboxyl end of the molecule vary. Their functions have not been established, with a notable exception.

The sequence in beta-endorphin, has been shown to bind with high specificity to complement, a component of the immune system that acts to lyse bacteria (Schweigerer, Teschemacher, and Bhakdi, 1982). It is tempting to speculate that complement presents the enkephalin end of beta-endorphin to bacteria in order to sedate the bacteria in preparation for the lysing. Indeed, unicellular organisms such as amoeba and paramecium have opioid receptors on their surface. If so, beta-endorphin has influence on the immune system, on one hand, and on behavior on the other. Relating patterns of variables on both sides appears to be an important, perhaps crucial, requirement. It demands coordination of different disciplines such as immunology, endocrinology, and psychology. Ader and Good (1981) have suggested that these will be integrated into a new field to be known as psychoneuroimmunology. Progress which has been made toward other models also promoting integration will be reviewed next.

The Missing Model

Bindra (1976) proposed a general model of the relationships between brain events and behavioral events such as those we have described briefly. According to Bindra's model there is no one-to-one correspondence between brain and behavior. Rather, each brain activity is involved in different behaviors and each behavior is related to a number of brain activities. This model, Bindra (1976, p. 27) noted, makes untenable the concept of distinctive neural centers for particular types of behavioral categories. It follows that a psychological theory suitable to establish relations with brain activity should possess a holistic quality of its own.

When this characteristic is missing, there is a strong temptation to relate complex internal variables to ill-defined external events. Duncan-Johnson and Kopell (1981), for example, reported a study in which subjects were requested to name the color of the ink in which a word was written. When the word referred to a color different from the one of the ink the total duration of the reaction time lengthened, while one of its components (labelled P300) did not. In this study the relationship between two sets of brain data was found to be related to a pair of stimuli. Seeing the word "blue" printed in red ink is an experience which is neither common nor very significant. Presumably then, interest in the phenomenon of interference stems from the assumption that it occurs with many other couples of stimuli as well. Unfortunately, the decision as to whether certain stimuli do or do not interfere with one another is left to our intuition. Would a square the sides of which are made up of the word "circle" produce interference? Or receiving a pay raise just a little higher than what I was told to expect? A psychological theory providing guidance to answer these sort of questions appears to be needed.

Such a theory should make allowances for the possibility than an organism can achieve the same functional relationship with the environment by employing different behaviors. Likewise the same behavior can be mediated by several different brain processes at different times.² The theoretical development we advocate may be fostered by the solution of certain metatheoretical issues. It is to these issues we now turn.

Some Metatheoretical Problems

Staat (1981) after considering the current state of psychology concluded that it lacks a unitary framework. It consists, laments Staat, of fragmented, isolated "islands of knowledge" (p. 239). Substantive areas of psychological inquiry can be approached at different "levels," such as: learning, developmental, personality, abnormal, interactional, and applied. By keeping these levels separate present-day psychology has avoided the problem of dealing

²Richard Hallam: Personal communication, 1982.

with a large number of variables. But the difficulties toward an integrate view of psychology may start even earlier, in the way we think about and formulate variables.

Choosing Variables

Too often our theories tell us which variables to observe (and which to exclude from observation) rather than stating which relationship we should expect. If we want to change a behavior, exponents of a certain school, for example, will propose that we clarify its roots in early childhood episodes. Other theorists will suggest a change of contingencies, or spelling out the advantages of a different behavior. Yet, more than one of these groups of variables is likely to influence the change. We also tend to focus on problematic variables: anxiety, poverty, aggression. Yet it may be difficult to understand anxiety without paying attention to bliss, poverty without studying riches, aggression without investigating meekness. Furthermore, we expect our variables to be reliable and have ecological validity. They should exhibit a certain constancy in time and space. Therefore phenomena of short duration or occurring only under very special conditions are excluded from observation. Yet they may be of great theoretical importance, as it is the case with subatomic particles in physics.

Problems of Definition

When we define variables we tend to pay excessive attention to the common meaning of the terms we use. "Does this instrument 'really' measure intelligence?" "I doubt this behavior could be called aggressive." Questions such as these reflect the fact that variables, particularly in social psychology, are constrained by the meaning, in ordinary language, of the words we employ to indicate them. Instead, we should strive for definitions which are unencumbered by the current meaning while permitting an easy recognition of instances of the phenomenon. These definitions should also avoid including the effect of the variable. Once reinforcement is defined as anything which increases the frequency emission of response, we short-circuit the important problem of classifying stimuli which may prove rewarding to various degrees, depending on the response and the situation (Stevenson-Hinde, 1973).

Equally misleading is to introduce the notion of observability into the definition (e.g., motivation is said to refer to unobservable internal states). Whether or not a variable can be observed is an important empirical fact, not a consideration of theoretical relevance. Indeed, realizing that some theoretically important variable cannot be observed in the present state of the art may well spur the search for methods to observe it, rather than demand a modification of the theory.

Problems of Analysis

No less deep and far reaching is the problem of operationalizing the definition. Different modes of operationalization often led to different results. These differences generate controversy about the relative merits of different operationalizations. Yet contradictory results may be due to a contingent variable not explicitly included in the design of the study: When this variable assumes values, say, from a to m , the relation between two variables of the study is positive. It becomes negative when the contingent variable assumes values higher than m .

Years ago Cane (1961) tartly noted that contradictory results mean that the description of the experiment was inadequate. Her admonition has been often ignored. Indeed, many papers have been written to expound the relative validity of contradictory findings, but few have been written to present models including contingent variables. One of them is Fiedler's (1967) contingency model of leadership effectiveness. In it the relationship between leadership style and its effectiveness is contingent upon the difficulty of the situation. Another notable exception is Bindra's (1976, pp. 124-136) contingent model of neural activity, which covers excitatory and inhibitory processes.

Meeting the New Challenge

Correcting problems of conceptualization, such as those we have briefly examined, will increase the number of variables that need to be considered. This increase is also a likely result of the integration among different levels advocated by Staat (1981). A large number of variables may appear difficult to handle, leading to the temptation of compounding or averaging them. But the task of dealing with many variables becomes feasible when the pattern of their interrelationship is known. Notice, for example, how easily we handle numbers, which are infinitely many but are ordered. Modest but instructive examples of known structures can be seen in the area of social behavior (e.g., Conte and Plutchik, 1981) and of interpersonal resources (Foa, 1971; Foa and Foa, 1980).

Cognate structural notions are found in the work of ethologists. They have described many instances in which behaviors appear to be organized in closely interwoven systems (Baerends, 1976) which are hierarchically ordered at various levels of complexity: a system, in turn, controls subsystems (Dawkins, 1976). In this way, both plasticity and rigidity of behavior can be achieved. Plasticity may refer to goal-directed behavior, rigidity to the need that the behavior is supposed to satisfy. Little advance has occurred in identifying behavior systems, although a beginning can be recognized in the classification of system types (Gallistel, 1980). Specification of the variables

involved in these systems appears necessary in order to utilize available methods for testing structures of proximity or similarity (Shepard, 1974). So far their utilization remains limited in the absence of substantive theoretical work resulting in the formulation of structural hypotheses. If our input is a hodge-podge of variables the likely result of the analysis is a hodge-podge structure. Analytic tools are somewhat like a cooking range: the best range in the world will not help make a good soup if we put into the pot a random collection of ingredients.

Identification of a structure enables us to state complex relationships in a parsimonious manner. Bower (1981), for example, found that the strength of recalling an emotion-linked event is directly related to the degree of similarity between the original emotion and the mood at the time of recalling. Thus, an event which occurred when I was happy will be recalled best when I am happy, worst when I am sad, and somewhat in-between when the emotional state is between sadness and happiness. Similarly, Foa, Foa, and Schwartz (1982) reported that the level of anxiety generated by stimuli indicating loss of a resource was inversely related to the distance between this resource and the one which the subject feared losing.

An attempt to establish the pattern of relationships among variables must begin with a taxonomy of events. The need for describing and classifying events has been forcefully expounded by Hinde (1979). Concern with "the importance of a firm basis of description and classification" (p. 6) constitutes a central argument in his treatment of interpersonal relations. It seems indeed incredible that a "science of behavior" did not even attempt to provide description and classification of behaviors distinct from the effects of those behaviors.

Concluding Remarks

Advances in the observation of hormonal and neurological processes provide sets of data which are best understood in clusters rather than as isolated variables. By contrast the psychological counterpart of these structures is often fragmentary and atomistic. There is some evidence and a considerable consensus of opinion that an atomistic psychology is ill suited to provide notions to which neurological phenomena can be related. Development of a more integrated psychological theory may require changes in the metatheoretical notions that we apply to the formulation of psychological concepts.

The possible consequences of a failure to make these changes are hard to foresee. It is, however, unrealistic to expect that discoveries in the working of the neural systems will provide an appropriate classification of behavioral and cognitive events. On this point we could not do better than to quote Bindra:

To explain intelligent behavior, then, is to show in terms of a more or less plausible theoretical scheme that the fundamental concepts used in the description of behavior are translatable into (or reducible to) the principles of neural sciences. This does *not* mean that the objective of explaining behavior is to replace all descriptions of behavioral phenomena and laws by neural descriptions: explanation of chemical reactions in terms of the principles of physics (physical chemistry) has not led to the discarding of chemical descriptions, nor has the discovery of genetic code meant an end to the descriptive laws of inheritance. What translatability means is simply a statement of equivalence (hypothetical or demonstrable) of the main concepts of the higher-level science to certain functional principles of lower-level (more fundamental) science. The purpose of formulating such explanations is not to replace one science by another, but to close the gap between two sciences—to proclaim their unity, in principle.

Nor should the present view of explanation be taken to mean that the explanation of behavior should be left to the endocrine and neural sciences—that once neuroendocrine sciences have developed to a high level, no behavioral studies would be required, for the laws of behavior would follow from the neuroendocrine principles. It may be true in the eyes of an ultimate knower, or when the whole task of science is done, that all behavioral principles may be implicit in the neuroendocrine sciences, and that chemistry may be only unexplicated physics, but this has no relevance for those who are still trying to discover the various principles of nature. In practice, laws of higher-level sciences (say, chemistry or psychology) have not been deduced or extrapolated from the laws of lower-level sciences (say, physics or neurology). In fact, it is the empirically determined principles of higher-level sciences that often aid in the elucidation of lower-level mechanisms. (1976, p. 19)

Furthermore, noted Hinde (1976), successively higher levels of analysis bring forth novel properties. For instance, there are properties of interaction between two individuals that could not be predicted from the behavior of each one of them (e.g., being in strong agreement).

In the absence of autonomous developments in psychology, neuroendocrine scientists may become more concerned with physiological functions *per se*, rather than in their relation to psychological events. Historically, psychophysiology has become more and more divorced from the problem of relating external to internal events and has focused primarily on physiological events.³ Alternatively, brain investigators may develop a mini-psychology of a sort, ancillary to their main interests. It is therefore important to answer the challenge posed by the opening of the black box: bringing psychological thinking to a level of integration which will foster the discovery of the complex relations between brain and behavior.

³Richard Hallam: Personal communication, 1982.

References

- Ader, R., and Good, R.A. (Eds.). *Psychoneuroimmunology*. Academic Press, 1981.
- Afinsen, C.B. Principles that govern the folding of polypeptide chains. *Science*, 1973, 181, 223-230.
- Baerends, G.P. The functional organization of behavior. *Animal Behavior*, 1976, 24, 727-738.
- Bindra, D. *A theory of intelligent behavior*. New York: Wiley, 1976.
- Bower, G.H. Mood and memory. *American Psychologist*, 1981, 36, 129-148.
- Cacioppo, J.T., and Petty, R.E. Electromyograms as measure of extent and affectivity of information processing. *American Psychologist*, 1981, 36, 441-456.
- Cane, V. Some ways of describing behavior. In W.H. Thrope and O.L. Zangwill (Eds.), *Current problems in animal behavior*. Cambridge: Cambridge University Press, 1961.
- Conte, H.R., and Plutchik, R. A circumplex model for interpersonal personality traits. *Journal of Personality and Social Psychology*, 1981, 40, 701-711.
- Dawkins, R. Hierarchical organization: A candidate principle for ethology. In P.P.G. Bateson and R.A. Hinde (Eds.), *Growing points in ethology*. Cambridge: Cambridge University Press, 1976.
- Donchin, E. Event-related brain potential: A tool in the study of human information processing. In H. Begleiter (Ed.), *Evoked brain potential and behavior*. New York: Plenum, 1979.
- Duncan-Johnson, C.C., and Kopell, B.S. The "Stroop" effect: Brain potential localizes the source of interference. *Science*, 1981, 214, 938-940.
- Eccles, J.C. *The neurophysiological basis of mind*. Oxford, England: Clarendon Press, 1953.
- Fentress, J.C. Dynamic boundaries of patterned behavior: Interaction and self organization. In P.P.G. Bateson and R.A. Hinde (Eds.), *Growing points in ethology*. Cambridge: Cambridge University Press, 1976.
- Fiedler, F.E. *A theory of leadership effectiveness*. New York: McGraw-Hill, 1967.
- Foa, U.G. Interpersonal and economic resources. *Science*, 1971, 71, 345-351.
- Foa, E.B., and Foa, U.G. Resource theory: Interpersonal behavior as exchange. In K.J. Gergen, M.S. Greenberg, and R.H. Willis (Eds.), *Social exchange: Advances in theory and research*. New York: Plenum, 1980.
- Foa, U.G., Foa, E.B., and Schwarz, L.M. Generalization of anxiety along the structure of interpersonal resources. *Journal of Social and Biological Structures*, 1982, 5, 189-198.
- Gallistel, C.R. From muscles to motivation. *American Scientist*, 1980, 68, 398-409.
- Gevins, A.S., Doyle, L.C., Cuttillo, B.A., Schaffer, R.E., Tannehill, R.S., Ghannam, J.H., Gilcrease, A.V., and Yeager, C.L. Electrical potential in human brain during cognition: New method reveals dynamic patterns of correlation. *Science*, 1981, 213, 918-922.
- Gur, D., Good, W.F., Wolfson, S.K., Jr., Yonas, H., and Shabason, L. In vivo mapping of local cerebral blood flow by Xenon-enhanced computed tomography. *Science*, 1982, 215, 1267-1268.
- Hebb, D.O. The evolution of mind. *Proceedings of the Royal Society, B*, 1965, 161, 376-383.
- Hebb, D.O. *Essay on mind*. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1980.
- Hinde, R.A. Interaction, relationship, and social structure. *Man*, 1976, 11, 1-17.
- Hinde, R.A. *Toward understanding relationships*. London, England: Academic Press, 1979.
- Iversen, S.D. Brain lesions and memory in animals. In J.A. Deutch (Ed.), *Physiological bases of memory*. New York: Academic Press, 1973.
- Iversen, S.D., and Fray, P.J. Brain catecholamines in relation to affect. In A. Beckman (Ed.), *The neural basis of behavior*. New York: Spectrum, 1982.
- Jones, B.E. Understanding the physiological correlates of a behavioral state as a constellation of events. *The Behavioral and Brain Sciences*, 1981, 4, 482-483.
- Kennedy, C., Des Rosiers, M.H., Jehle, J., Reivich, W., Sharpe, F., and Sokoloff, L. Mapping of functional neural pathways by autoradiographic survey of local metabolic rate with [¹⁴C] deoxyglucose. *Science*, 1975, 187, 850-853.
- Krnjevic, K. Cellular mechanisms of cholinergic arousal. *The Behavioral and Brain Sciences*, 1981, 4, 484-485.
- Lewis, M.E., Mishkin, M., Bragin, E., Brown, R.M., Pert, C.B., and Pert, A. Opiate receptor gradients in monkey cerebral cortex: Correspondence with sensory processing hierarchies. *Science*, 1983, 211, 1166-1169.

- Luria, A.R. *Higher cortical functions in man*. New York: Basic Books, 1966.
- Luria, A.R., Simernitskaya, E.G., and Tubylevich, B. The structure of psychological processes in relation to cerebral organizations. *Neuropsychologia*, 1970, 8, 13-19.
- Lynch, J.C. The functional organization of posterior parietal association cortex. *The Behavioral and Brain Sciences*, 1980, 3, 485-534.
- Margules, D.L. Opioid and anti-opioid actions in the survival and reproduction of individuals. In S.D. Cooper (Ed.), *Theory in psychopharmacology* (Vol. 1). New York: Academic Press, 1981.
- Milner, B., and Teuber, H.L. Alterations of perception and memory in man: Reflections on methods. In L. Weiskrantz (Ed.), *Analysis of behavioral change*. New York: Harper, 1968.
- Monod, J., Wyman, J., and Changeux, J.P. On the nature of allosteric transitions: A plausible model. *Journal of Molecular Biology*, 1965, 12, 88-118.
- Pert, C.B., Kuhar, J., and Snyder, S. Autoradiographic localization of the opiate receptors in brains. In A. Goldstein (Ed.), *The opiate narcotics: Neurochemical mechanisms in analgesia and dependence*. New York: Pergamon Press, 1975.
- Pert, C.B., and Snyder, S.H. Opiate receptor binding of agonists and antagonists affected differentially by sodium. *Molecular Pharmacology*, 1974, 10, 868-879.
- Schiller, R.H., Jackson, J.F., McAllister, L.B., Schwartz, J.H., Kandel, E.R., and Axel, R. A family of genes that codes for ELH, a neuropeptide eliciting a stereotyped pattern of behavior in *Aplysia*. *Cell*, 1982, 28, 707-719.
- Schweigerer, L., Teschemacher, H., and Bhakdi, S. Specific non-opiate binding sites for human beta-endorphin on the terminal complex of human development. *Nature*, 1982, 296, 572-574.
- Shepard, R.N. Representation of structure in similarity data: Problems and prospects. *Psychometrika*, 1974, 39, 373-421.
- Staats, A.W. Paradigmatic behaviorism, unified theory, unified theory construction methods, and the zeitgeist of separatism. *American Psychologist*, 1981, 36, 239-256.
- Stevenson-Hinde, J. Constraints on reinforcement. In R.A. Hinde and J. Stevenson-Hinde (Eds.), *Constraints on learning: Limitations and predisposition*. New York: Academic Press, 1973.
- Strickberger, M.W. *Genetics*. New York: Macmillan, 1968.
- Tyrer, P.J., and Lader, M.H. Central and peripheral correlates of anxiety: A comparative study. *The Journal of Nervous and Mental Diseases*, 1976, 162, 99-104.
- Van der Loos, H., and Woolsey, T.A. Somatosensory cortex: Structural alterations following early injury to sense organs. *Science*, 1973, 179, 395-398.
- Vanderwolf, C.H., and Robinson, T.E. Reticulo-cortical activity and behavior: A critique of the arousal theory and a new synthesis. *The Behavioral and Brain Sciences*, 1981, 4, 459-476.
- Vinogradova, O.S. Behaviorism and voluntarism. *The Behavioral and Brain Sciences*, 1981, 4, 496-497.
- Weiskrantz, L., Mihailovic, C., and Gross, C.G. Effects of stimulation of frontal cortex and hippocampus on behavior in the monkey. *Science*, 1960, 131, 1443-1444.
- Wiesel, T.N., and Hubel, D.H. Single-cell responses in striate cortex of kittens deprived of vision in one eye. *Journal of Neurophysiology*, 1963, 26, 1003-1017.