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Mind and Brain, Psychology and Neuroscience, the Eternal Verities

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We commonly attribute our awareness of the mind-brain issue to Descartes who pointed out that "brain" might well be understood in machinelike terms but that our views on "mind" depend on introspection. "Cogito ergo sum," I think, thus I am. Mind, self, self-consciousness are "subjective," private, and therefore inaccessible to what later came to be called "objective" study.

The advent of behaviorism should have immediately altered our views on the privacy of self-experience, the privacy of perception, thought, and feeling. Though not directly accessible to others, self-experiences can be verbally reported, consensually validated and in this fashion made "objective." Much of science is based on such indirection—we study the light emitted from stars, we do not palpate the stars themselves; we study the tracks made on an oscilloscope by subatomic particles, we do not come into direct contact with those "particles" themselves.

But radical behaviorists eschewed this readily available solution and instead chose to become materialist, physicalist, and "thoroughly scientific." Skinner (1971), for example, has repeatedly warned against the use of subjective terminology because its connotative meanings may corrupt stricter operational definitions based on verbal and instrumental behaviors. As I have indicated elsewhere (Pribram, 1979a), this amounts to throwing out the baby with the bath water, leaving one with a clean behavioral science which overlaps with but does not cover the range of a psychological science. Specifically, what is left out is subjective experience, that fascinating topic which brings most students into this field of inquiry.

The question arises as to why the radical behaviorists took the course they did. Here I want to explore the suggestion that mistaken though that course might be from the standpoint of psychological science, the mistake reflects the physicalistic and mechanistic views developed during the nineteenth century, views which the new science had to live through—to experience, if you will—before it could cope wholly with its own subject matter.

This exploration takes the form of this essay's title. First, the mind-brain issue is shown to have much deeper roots than those expressed by Descartes. Second, the impact of a scientific approach to the issue is illustrated by work on the specific problem of neural-perceptual isomorphism. Finally, the impact of this scientific work is reflected back onto the roots of the mind-brain issue, bringing the very latest understanding to bear on the earliest recorded expressions of men's and women's minds and thus their brains.

Verbalization, Nominalization, and Proposition

"In the beginning was the Verb," i.e., words originally referred to a flow of experience; early communication was "verbal"! The word *word* appears closely related to the word *verb*. At a recent conference on philosophy, during a presentation of the work of Spinoza we were apprised of the fact that initially Hebrew words were verbs denoting being, action, and process. Similar forms are said to exist in preclassical Sanskrit. Be that as it may, there is every evidence that human thought, including scientific thought, begins by nominalizing, reifying what at first are sensed as processes. Piaget has documented this development in children; biochemists routinely operate in this fashion when they isolate first a function of, for example, the pituitary gland, reify that function by giving it a name, for example, ACTH, and then search for "it" until the name is substantiated, that is, found to be a chemical substance.

The power of nominalization can be gleaned not only from its use in science but from such observations as those of Helen Keller whose world came to life once she could name, objectify, items previously experienced only as processes:

> I knew then that w-a-t-e-r meant that wonderful cool something that was flowing over my hand. That living word awakened my soul, gave it light, hope, joy, set it free! There were barriers still it is true, but barriers that could in time, be swept away. I left the well-house eager to learn. Everything had a name, and each name gave birth to a new thought. As we returned to the house, every object which I touched seemed to quiver with life. That was because I saw everything with a

> strange new sight that had come to me. On entering the door, I remembered the doll I had broken. I felt my way to the hearth and picked up the pieces. I tried vainly to put them together. Then my eyes filled with tears for I realized what I had done [she had earlier destroyed the doll in a fit of temper], and for the first time I felt repentance and sorrow (Helen Keller, 1903/1954).

As Walker Percy so clearly perceives (Coles, 1978), "Here . . . in a small space and a short time something extremely important and mysterious had happened. Seven year old Helen made her breakthrough from the good responding animal which behaviorists study so successfully to the strange name giving and sentence uttering creature which is Homo Sapiens."

Note that Helen Keller became aware of her thoughts at the same moment that she was able to name objects. She did not make the mistake of the radical behaviorists—subject as well as object were attended. Note also that in doing so, propositions were formed, remembrances, repentances, and sorrows could be entertained. Subject could be responsible for object, cause could lead to effect.

Irrespective of whether process descriptions in terms of verbs preceded or arose coterminally with nominalization and whether nominalization preceded or arose coterminally with propositional utterances, the entire set of linguistic operations described above did occur in human prehistory and do occur in the development of every human being. Thus the mind-brain issue is joined at the very inception of what makes us human—our ability to make propositions, i.e., to conceptualize processes as subjects acting on objects. In order to nominalize a process into a proposition made up of a subject, verb, and object, we must first categorize and then hierarchically arrange categories into logical relationships. We thus become *logical* animals—the word *logical* being derived from the word *logos*, Greek for "word."

Invariance, Rationality, and Harmony

But human beings are not just logical. They are also rational. *Rational* derives from *ratio*, a different sort of relationship than the logical. Ratios are expressed as invariances arranged harmoniously rather than as labels arranged hierarchically. The realm of the rational is music and musical mathematics, not the natural languages and logic.

Greek philosophers and their precursors clearly distinguished between logic and rationality. Pythagoras and Plato recognized music, not logic, as the model of rationality. An excellent account of this early emphasis on rationality can be found in Ernest McClain's *The Myth of Invariance* (1976). In this volume, McClain presents the counterpoint to "In the beginning was the Word (Verb)." He traces the history of rationality from the *Rg Veda*, the Egyptian Book of the Dead, the Bible, to Pythagoras and Plato. And this view of the rational equates it with the spiritual tradition in both Eastern and Western thought.

If the suggestion that indeed words were initially verbs designating process were validated, one might fruitfully inquire whether that process was the establishing of invariances through rationalizing (deriving ratios). In this sense, verbs were expressions of invariances and thus "In the beginning was the verb and the verb was with God." But God also must be understood as a verb, making the phrase read "and the verb was spiritual," i.e., rational. Only when nominalized do hierarchy and logical causality emerge: "And the Word was made flesh, and dwelt among us, and we beheld Her glory, the glory of the only begotten of the Father, was full of grace and truth." Note that the instantiation of the Word was female (notably better at natural languages than males—see, for example, the review by Pribram and McGuinness, 1979) and that "She" is hierarchically and causally related to God the Father, now completely nominalized as subject whose actions give rise to object. Note also that this proposition maintained its rationality, i.e., "was full of grace" but added logic ("and truth").

The point of reviewing this ancient prehistory and early history of thought is to note that the germ of the mind-brain issue is contained in any logical system, i.e., any system that derives from the use of *logos*, words in propositions in which subject(ive) and object(ive) are separated and causally related to one another. In addition, however, the point is also to emphasize that in another system, the rational, which is based on ratios, as in music, the Cartesian dilemma does not exist. In such a system the methods by which invariances are constructed are more patently clear as when a tempered scale is developed (Bernstein, 1976, speaks of tempered as "tampered"). The obvious and inexorable intertwining of the functions of biological brain with physical energies to constitute the psychological process is the hallmark of a rationality which was lost sight of in the Cartesian logic. Let us therefore now turn to current neuroscience and psychology to see where the results of experimental research have led with regard to the mind-brain issue.

The conception that the brain serves as a set of organs of mind inaugurates nineteenth-century psychology. The success of this conception is due largely to the work of anatomist Franz Joseph Gall, who proposed that:

> If . . . man has faculties which essentially distinguish him from the animal, and which give to him the peculiar character of humanity, he also offers in his brain . . . parts which animals have not; and the difference of effects is thus found to be explained by the difference of causes (1835, Vol. 1, p. 1003).

Gall's conceptions were supported by a large volume of clinical pathological observations. Some of these have been summarized in readily accessible form in the first Penguin volume on *Brain and Behavior* (Pribram, 1969a). Of course, Gall's thesis did not go unchallenged, especially when in the hands of a popular following:

it became degraded into the doctrine of phrenology. Nonetheless, these early observations did set the stage for a nineteenth-century physiologically based psychology, a psychology rooted in observation and experiment. By the end of the century the relation between brain and experience and brain and behavior was couched in terms not much different from those currently in use. The psychophysics of Fechner, Weber, Helmholtz, and Mach remains unmatched in wealth of experimental detail and conceptual sophistication. The role of brain function in psychology was modeled in clearly recognizable form by William James (1890) and Sigmund Freud (1895/1950). The work of Francois Magendie and Claude Bernard laid the foundations for the laboratories of physiological psychology of Wilhelm Wundt, Ivan P. Pavlov, and Walter B. Cannon. In this field of inquiry, the leap from the philosophically tortuous pronouncements of the eighteenth century to the scientific, data-based arguments of the twentieth century is indeed great.

However, this forward leap was brought to a sudden halt with World War I. The psychology of the first half of the twentieth century (to about 1960) marched to a different drummer, was infused with a different spirit. That spirit was behaviorism, and, strange as it may seem, the tune and rhythm of behaviorism hark back to another biological nineteenth-century tradition, that of Darwinian evolution. In a most interesting fashion, the conception of brain as man's crowning glory which is responsible for his unique psychology came into unconscious competition with the conception of the descent of man from his animal forebears.

Some of the reasons for this conflict have been reviewed extensively in another manuscript (which also reviews the nineteenth-century contributions alluded to above—Pribram & Robinson, in press). It is worthwhile, nonetheless, to abstract here some of the highlights of this issue and to note where things stand in this year of the centenary celebration of psychology as an experimental discipline.

Evolutionary Psychology

Behaviorism

Psychology, seen solely as "the science of behavior," became a broadly regnant dictum roughly from the mid-1920s to the mid-1950s of this century. The various forms of behaviorism heralded the triumphs of a (roguish) adolescent independence from mother philosophy, aunt education, and whatever other family ties might still bind. The stated aim was to mathematize, to develop laws in the image of the mechanistic physics of Newton. In the words of the founder:

> The behaviorist asks: Why don't we make what we can observe the real field of psychology? Let us limit ourselves to things that can be observed, and formulate laws concerning only those things. Now what can we observe? We can observe

behavior—*what the organism does or says*. And let us point out at once: that *saying* is doing—that is, *behaving*. Speaking overtly or to ourselves (thinking) is just as objective a type of behavior as baseball.

The rule, or measuring rod, which the behaviorist puts in front of him always is: Can I describe this bit of behavior I see in terms of "stimulus and response"? By stimulus we mean any object in the general environment or any change in the tissues themselves due to the physiological condition of the animal, such as the change we get when we keep an animal from sex activity, when we keep it from feeding, when we keep it from building a nest. By response we mean anything the animal does—such as turning toward or away from a light, jumping at a sound, and more highly organized activities such as building a skyscraper, drawing plans, having babies, writing books, and the like.

You will find, then, the behaviorist working like any other scientist. His sole object is to gather facts about behavior—verify his data—subject them both to logic and to mathematics (the tools of every scientist). He brings the new-born individual *into his experimental nursery* and begins to set problems: What is the baby doing now? What is the stimulus that makes him behave this way? He finds that the stimulus of tickling the cheek brings the response of turning the mouth to the side stimulated. The stimulus of the nipple brings out the sucking response. The stimulus of a rod placed on the palm of the hand brings closure of the hand and the suspension of the whole body by that hand and arm if the rod is raised. Stimulating the infant with a rapidly moving shadow across the eye will not produce blinking until the individual is sixty-five days of age. Stimulating the infant with an apple or stick of candy or any other object will not call out attempts at reaching until the baby is around 120 days of age (J. B. Watson, 1924/1959, pp. 6–7).

The behaviorist approach initiated by Watson was elaborated and modified by many successors, among whom the only figure of appreciable current influence is Burrhus Frederic Skinner. Watson was still interested in physiological measurement—behavior for Watson meant movement. For Skinner, behavior became the environmental consequence of the movement, the act of producing a paper record which "could be taken home at night and studied." Environmental consequences, not the physiology of human beings, became the substance and the tool of the behaviorist.

The important advance from this level of explanation [mental] that is made by turning to the nervous system as a controlling entity has unfortunately had a similar effect in discouraging a direct descriptive attack upon behavior. The change is an advance because the new entity beyond behavior to which appeal is made has a definite physical status of its own and is susceptible to scientific investigation. Its chief function with regard to a science of behavior, however, is again to divert attention away from behavior as a subject matter. The use of the nervous system as a fictional explanation of behavior was a common practice even before Descartes, and it is now much more widely current than is generally realized. At a popular level a man is said to be capable (a fact about his behavior) because he has brains (a

> fact about his nervous system). Whether or not such a statement has any meaning for the person who makes it is scarcely important; in either case it exemplifies the practice of explaining an obvious (if unorganized) fact by appeal to something about which little is known. . . . (I am not attempting to discount the importance of a science of neurology but am referring simply to the primitive use of the nervous system as an explanatory principle in avoiding a direct description of behavior) (B. F. Skinner, 1938, p. 4).

What led to this turn? Why, in this centenary year of Wundt's achievement of a well-rounded, experimentally based biological and social psychology has our inquiry so systematically espoused only the environmental and the social branches and denied its neurobiological roots?

There are, of course, many reasons. Perhaps the major of these was the discovery of methodological behaviorism, i.e., that behavior is indeed a potent measure of mental phenomena. In testing this potency, it is not altogether surprising that the measure became, for a while, its own end. While Watson's psychology (1924/1959) was still physiologically rooted, his message was that behavior should take its own measure, fly free, and leave mind behind in the bosom of philosophy. And in the hands of Tolman (1932), Hull (1943, 1951), and Skinner (1938) behavioral science did just that—successfully. So successfully in fact that the question now can be raised as to just what might be the relationship of a science of behavior to psychology, conceived as the study of the "psyche," i.e., mental processes (see, for example, Pribram, 1979a).

This success of behaviorism was in part due to the technical developments that characterize so much of twentieth-century science. Soon it was recognized that more than the behavior of muscle groups could be measured, the occupation of Sechenov (1863/1965), Pavlov (1927), Bechterev (1911), and Watson (1924/1959). In addition, the behavior of the entire organism could be controlled by mazes (the data base for Tolman, 1932, for instance); by problem and choice boxes (upon which Thorndike, 1898, 1913–1914, and Yerkes, 1904, depended); by check lists (as in "intelligence" tests and "opinion" polls); and by panels and levers (as developed by Skinner, 1938). A wealth of data accumulated, and with the advent of computerized testing mechanisms (e.g., Pribram, 1969b) continued to increase.

Toward the latter part of the twentieth century, a reasonable question was what this wealth had gained for psychology. One certain gain is the wealth itself. There was no question but that reliable data were obtained in controlled situations where before there were only records of subjective experience. Methodological behaviorism, in its accumulation, had constructed a science of behavior in which the variables that control behavior in limited situations had been adumbrated. Tools had been developed to simplify and abstract the problems of psychology much as the inclined plane had been developed to simplify and abstract the problems of mechanics in physics. The behaviorists' tools were applied to pharmacology, neurophysiology, education, and therapeutics, with varying success.

But what relevance did these data have to the persistent problems of psychology, problems such as the acquisition and storage of memory; its organization into representations of experience; the access to such representations via thought and attention; the use of these same representations in behaving skillfully and/or intentionally, to name but a few? It remained for the latter part of the century to address the problems of *psychology* with these tools.

Meantime, while a functionalist behaviorism came to hold sway in the second quarter of this century, a new structuralism developed in anthropology and linguistics. This structuralism searched not so much for the anatomical organs of mental faculties as for the structures of process. "Structure" in this new sense meant stable organizations, identifiable orders in ongoing functional relationship—a turning away from an unreconstructed functional behaviorism. In 1942 Merleau-Ponty framed an essentially functional existentialism (being-in-the-world) into *The Structure of Behavior*. Later, George Miller, Eugene Galanter, and Karl Pribram produced *Plans and the Structure of Behavior* (1960).

> As our debate progressed and our conceptions of Plans became clearer, a conviction grew on us that we were developing a point of view toward large parts of psychology. We then began to wonder how we might best characterize our position so as to contrast it with others more traditional and more familiar. The question puzzled us. We did not feel that we were behaviorists, at least not in the sense J. B. Watson defined the term, yet we were much more concerned—in that debate and in these pages, at least—with what people did than with what they knew. Our emphasis was upon processes lying immediately behind action, but not with action itself. On the other hand, we did not consider ourselves introspective psychologists, at least not in the sense Wilhelm Wundt defined the term, yet we were willing to pay attention to what people told us about their ideas and their Plans. How does one characterize a position that seems to be such a mixture of elements usually considered incompatible? Deep in the middle of this dilemma it suddenly occurred to us that we were subjective behaviorists. When we stopped laughing we began to wonder seriously if that was not exactly the position we had argued ourselves into. At least the name suggested the shocking inconsistency of our position (Miller, Galanter, & Pribram, 1960, p. 211).

Skinner, the arch enemy of subjectivism, was ultimately moved to modify his stance, perhaps in part by such developments as have just been noted. He suggested that a distinction could be drawn between behaviorism as method and behaviorism as theory. The result was expressed in terms of a new "radical behaviorism" (patterned perhaps after William James's radical empiricism).

> The statement that behaviorists deny the existence of feelings, sensations, ideas, and other features of mental life needs a good deal of clarification. Methodological behaviorism and some versions of logical positivism ruled private events out of

> bounds because there could be no public agreement about their validity. Introspection could not be accepted as a scientific practice, and the psychology of people like Wilhelm Wundt and Edward B. Titchener was attacked accordingly. Radical behaviorism, however, takes a different line. It does not deny the possibility of self-observation or self-knowledge or its possible usefulness, but it questions the nature of what is felt or observed and hence known. It restores introspection but not what philosophers and introspective psychologists had believed they were "specting," and it raises the question of how much of one's body one can actually observe.
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> The position can be stated as follows: what is felt or introspectively observed is not some nonphysical world of consciousness, mind, or mental life but the observer's own body. This does not mean, as I shall show later, that introspection is a kind of physiological research, nor does it mean (and this is the heart of the argument) that what are felt or introspectively observed are the causes of behavior. An organism behaves as it does because of its current structure, but most of this is out of reach of introspection. At the moment we must content ourselves, as the methodological behaviorist insists, with a person's genetic and environmental histories. What are introspectively observed are certain collateral products of those histories.
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> The environment made its first great contribution during the evolution of the species, but it exerts a different kind of effect during the lifetime of the individual, and the combination of the two effects is the behavior we observe at any given time. Any available information about either contribution helps in the prediction and control of human behavior and in its interpretation in daily life. To the extent that either can be changed, behavior can be changed (Skinner, 1976, pp. 18–20).

Plans and the Structure of Behavior led a sizable portion of the community of experimental psychologists away from a radical behaviorism that eschewed cognitions, thought, ideas, consciousness, and will, into a subjective behaviorism in which these concepts were conceived as based on orderly (structured) interactions between environmental and brain processes and thus amenable to scientific inquiry. Merleau-Ponty had argued for a similar change from the opposite direction. Subjectivity as an existential, unsharable experience was held to be sharable (i.e., observable) as behavior and thus more amenable to inquiry than had been suspected.

At the same time that these developments were taking place in the body of experimental and philosophical psychology, something of a growing conservatism characterized physiological psychology. The trend in this subdiscipline was toward a reductionism which, if continued, would have had physiological psychology absorbed by neurophysiology, an absorption at the expense of physiological psychology as a psychological discipline. (An example may be found in the author's presidential address to the Division of Physiological Psychology of the APA, 1970.) Simultaneously, however, there transpired a courtship of a branch of physiological psychology—neuropsychology—by cognitively oriented psychologists, and this courtship produced a number of results that led in the opposite direction. Not the least of these results was the re-animation of neuropsychology by such issues and phenomena as attention, problem-solving, complex perceptions, contextual determinants of information processing, artificial intelligence, and the like.

Neuropsychology

On a certain construction, Lashley, Hebb, Sperry, and Pribram are all "behavioral scientists," and on an even looser construction they might even be called "technical behaviorists" in their choices of dependent variables. But the classical behaviorism of Watson, the neobehaviorism of Hull, and the radical behaviorism of Skinner involved more than a choice of dependent variables. As an *ism* such positions presupposed something of a philosophy of science, something of an ontology, even something of a system of social ethics. Understood in these terms, the formal tradition of behaviorism is an *ism* that found much to reprove in both the distant and the recent history of neurophysiological psychology, for in the latter discipline there has been a willingness, even a necessity, to accept the verbal reports of subjectively experienced cognitive, ideational, conscious, affective, volitional, and motivational aspects of human psychology (see Pribram, 1962, 1971b). Radical behaviorism took an ontological stand against a causal role for any subjectively labeled central states and representations in the organization of behavior. It insisted that they exist, if at all, only as physically specifiable neural or endocrine states or as epiphenomena of observable behavior.

The issue is important and can perhaps be brought into focus by the following analogy. Physicists studying atoms observe the properties of hydrogen and oxygen. They find lawful relations among their interactions as when two hydrogen atoms combine with one oxygen atom in a certain way to make up a molecule of H_2O. Now, however, the scientists find that H_2O has peculiar properties not shared by H and O while separate. Thus, H_2O liquefies at ordinary earth temperatures and solidifies when the temperature drops just a bit. And when it solidifies it floats on its liquid base, something most other things do not do. The following issues are now raised by the scientists who made these observations. Some want to label the H_2O combination "water" because common language calls it that. Others state that such labeling is unscientific. Next the question is raised whether water as such is in any way causally related to hydrogen and oxygen. Certainly the combination H_2O places constraints on the distribution of H and O, and the uses to which H and O can be put. But also water makes life as we know it possible. These chemical and biological consequences of combining H and O are far-reaching. Are they therefore any less scientific? Is the downward "causation" of the effects of combining H and O on their distribution to be ignored? Are chemists and biologists "soft" in their approach to science when they discuss the properties of water?

Take these statements and substitute *brain*, or more accurately, *body—organ-*

ism—for hydrogen and *environment* for oxygen. Behaviorally effective interactions, i.e., combinations, produce a new level of organization. Is it all right to label some of the combinations *vision*, others *attention*, others *love*, and *dignity*, and *freedom*, just as we labeled H_2O *water?* And are there "causal" relationships between freedom and the distributions of brains and organisms in the world? What is wrong with a psychology that holds that, for example, freedom makes spiritual life possible just as the wetness of water makes biological life possible? These were questions addressed by brain scientists such as Sherrington (1955), Sperry (1976), Penfield (1975), Eccles (1976) and Pribram (1979b), and philosophers such as Popper (1977), in response to earlier behavioristic stances such as Gilbert Ryle's logicolinguistic critique of the "ghost in the machine" (1949).

Isomorphism: The Percept, the Cortex, and the World

There are many experimental findings that relate brain, behavior, and experience. Psychophysics, psychophysiology, and neuropsychology abound with illustrations of the relationship between brain and mind, provided one is willing to infer mental constructs from instrumental behavior and the verbal reports of experience. Several of these examples have been detailed elsewhere (see Pribram, 1970, 1971a). For this essay, however, it seems more effective to pursue one line of research and to show how it bears on the mind-brain issue.

The example deals with the problem of isomorphism. Mary Henle (1977) has called attention to the fact that the problem has not been dealt with adequately either at the conceptual or the experimental level. What then is the problem, and how does it relate to the mind-brain issue? Simply stated, the theory of isomorphism suggests that some recognizable correspondence exists between the organization of our perceptions and the organization of our brain states. With regard to the mind-body problems, therefore, isomorphism is of central concern. No form of identity between mind and brain can be entertained if isomorphism does not hold—if it does, identity is still not mandatory, of course. To the extent that isomorphy exists, our existential understanding of the intimate relationship between mind and brain is correspondingly enhanced.

Isomorphism literally means "of the same form." What needs to be shown is that a brain state measured electrically or chemically has the same form, the same configuration as the mental percept. Recently, Roger Shepard (1979) has extended the concept to include what he calls a close functional relationship between brain representation and percept. Henle rightly criticizes this extension by pointing out that a naming response could be interpreted as "functionally related" yet be far from exhibiting the property of sharing the same form.

What are the facts? First, Wolfgang Köhler demonstrated that steady-state current shifts occur in the appropriate receiving areas of the brain cortex when a visual or auditory stimulus is presented. This shift coterminates with the presentation, and in the same and subsequent experiments it was shown that the shift accompanies the desynchronization of the electroencephalogram (see Pribram, 1971b, for review). At the same time a series of experiments undertaken by Lashley (1951) and his students placed gold foil over the cortex in order to short out direct currents, and another series performed by Sperry (1955) placed insulated mica strips into grooves cross-hatched into the cortical surface. Neither of these experimental procedures nor another in which electrical epilepsy was produced (Pribram, 1971b) resulted in *any* deficiency in discrimination performance of cats and monkeys. This led Köhler to remark that not only his theory but every other brain theory of perception had been jeopardized. In personal discussions and letters it was suggested that perhaps microfields centering on synaptic events might substitute for or underlie the macrofields (see, for example, Beurle, 1956; Pribram, 1960). Köhler died before any precise conceptual or experimental implementation of these ideas could be accomplished.

Meanwhile, unit recordings of the responses of single cells in the brain cortex had shown that in the visual cortex the response was especially brisk to lines presented in a specific orientation (Hubel & Wiesel, 1959). In view of the finding that below cortex the responsive field of neurons was circular, a Euclidean interpretation of the neural mechanism of perception became popular: below cortex spots, align the spots (by convergence) to make up lines, and from lines any other figure can be constructed by simply extrapolating the process hierarchically. The appeal of the formulation was the appeal of isomorphism—at last the evidence seemed to indicate that brain geometry and mind geometry were the same.

The basis of this cellular isomorphism is, of course, superficially different from that proposed by Köhler. He had suggested that steady-state currents were the measure of isomorphism while the unit recordings relied on nerve impulse responses. But closer inspection shows that this difference is not critical: the responsive fields of neurons are made up of their dendrites and are therefore ordinarily referred to as receptive *fields*. Receptive fields receive inputs via synapses. Thus the geometry of the receptive field in fact is the geometry of the steady-state microfields (hyper- and depolarizations) engendered in the synapto-dendritic network of the neuron from which the unit recording is obtained. And, as noted, toward the end of his life Köhler had come to entertain the possibility that it was in fact these synapto-dendritic locations which determined his cortical "fields."

Although the relationship between the data obtained with unit recordings and the proposal of brain-percept isomorphism has not been enunciated heretofore, the overwhelming intuitive appeal of this Euclidean solution to the problem, even for Gestalt oriented perception psychologists such as Teuber, has almost certainly stemmed from a tacit acknowledgment of the relationship.

It would be nice if this were where the discussion of isomorphism could end. But nature and especially biological nature is wayward in dealing with those who wish to broach her secrets. In the late 1960s and 1970s it became apparent in several laboratories around the world, e.g., Stanford (Spinelli & Barrett, 1969; Spinelli, Pribram, & Bridgeman, 1970), Harvard (Pollen, Lee, & Taylor, 1971; Pollen & Ronner, 1975), Cambridge (Campbell & Robson, 1968; Movshon, Thompson, & Tolhurst, 1978), Leningrad (Glezer, Ivanoff, & Tscherbach, 1973), and Massachusetts Institute of Technology (Schiller, Finlay, & Volman, 1976), that the line-selective neurons in the visual cortex displayed inhibitory and excitatory sidebands in their receptive fields. Their responsivity varied more as a function of the width and spacings of several parallel lines (gratings) presented in a preferred orientation than as a function of any single line. This was conceptualized by the Cambridge group as indicating that the cells were responding to what Fergus Campbell called the spatial frequency of repetition of such parallel lines in a grating rather than to any single line. This view was based on the fact that repeated presentations of a grating of a particular spatial frequency would influence not only the subsequent response to that grating but to gratings with "harmonic" relationships to the initial grating. Campbell therefore proposed that the visual system operates on spatial patterns of light much as the auditory system operates on temporal patterns of sound. Recently the geometric versus spatial frequency hypotheses have been put to critical test by Russell DeValois at the University of California at Berkeley with a clear quantitative result against the geometric and in favor of the frequency mode of operation (DeValois, Albrecht, & Thorell, 1978a,b).

Evidence has been accumulating for almost a century that such wave form descriptions of sensory processing are valid. Georg Simon Ohm (of Ohm's Law of the relationship between electrical current, voltage, and resistance) suggested in 1843 that the auditory system operates as a frequency analyzer, perhaps according to Fourier principles. The Fourier theorem states that *any* pattern, no matter how complex, can be analyzed into a set of component sine waves, i.e., a set of completely regular wave forms each at a different frequency. Hermann von Helmholtz developed Ohm's suggestion by a series of experiments which provided evidence that such decomposition takes place in the cochlea. Helmholtz proposed that the cochlea operates much like a piano keyboard, a proposal which was subsequently modified by Georg von Bekesy (1960) on the basis of further experimentation which showed the cochlea to resemble more a stringed instrument brought to vibrate at specific frequencies. Nodes of excitation which develop in the vibrating surface (the "strings") account for the piano-keyboard-like qualities described by Helmholtz.

Bekesy further developed his model by actually constructing a multiply vibrating surface which he placed on the forearm of a subject. When the phase relationship between the vibrators (there were five in the original model) are appropriately adjusted, a single point of excitation is tactually perceived (Bekesy, 1967). It was then shown that the cortical response evoked by such vibrations is also single: the percept rather than the physical stimulus (Dewson, 1964) is reflected in the cortical response. Somewhere between skin and cortex, inhibitory interactions among neural elements had produced a transformation. Bekesy went on to show that by applying two such "artificial cochleas," one to each forearm, and once again making the appropriate adjustments of phase, the subject was made to experience the point source alternately on one arm, then on the other, until after some continued exposure, the source of stimulation was projected outward into space between the two arms. Bekesy noted that we ordinarily "project" our somato-sensory experience to the end of writing and surgical instruments; the novelty in his experiments was the lack of solid physical continuity between the experienced source and the actual physical source. In the auditory mode this is, of course, the principle upon which stereophonic high fidelity music systems are based: by appropriate phase adjustment the sound is projected to a location between and forward of the acoustical speakers, away from the physical source of origin.

Another line of support favoring some sort of wave-form operation of the brain cortex comes from the observation that specific engrams or memory traces are not lost when brain tissue is injured. Whatever the nature of memory traces, they must become distributed over some considerable part of the brain to resist disruption. An effective method of distributing information was invented by Dennis Gabor, a mathematician, who suggested that storing the wave forms generated by energies reaching a recording surface rather than their intensities would provide better resolution in image reproduction (1948). Each electron or photon reaching a film creates ripples much as pebbles thrown into a pond. The ripples form wave fronts which intersect, producing nodes of reinforcement and interference. Mathematically, the point energies composing an image are transformed into a frequency, i.e., a wave-form representation, and by performing the inverse transform, the image can be readily reconstructed. Gabor christened the method "holography" because the entire image becomes distributed, i.e., represented, in each part of the hologram record.

In a hologram each quantum of light acts much as a pebble thrown into a pond. The ripples from such a pebble spread over the entire surface of the pond (the mathematical expression for this is in fact called a spread function of which the Fourier transform is a prime example). If there are several pebbles, the ripples produced by one pebble originate in a different location from those produced by another pebble, thus the ripples intersect and form interference patterns with nodes where the ripples add, and sinks where they cancel. The nodes can be captured on film as oxidations of silver grains if the ripples are produced by light falling on film instead of pebbles falling into water. Note that the information from the impact of each and every pebble or light ray is spread over the "recording" surface, thus the property that each portion of that surface is encoding the whole. And as noted earlier, performing the inverse transform reconstructs the image of the origin of that information. Thus the whole becomes enfolded in each portion of the hologram because each portion "contains" the spread of information of the entire image.

The holistic principle of the hologram is totally different from earlier views that wholes develop properties different from their parts. The emergence of properties from appropriate combinations was expressed in the Gestalt principle that "the whole is greater and different from than the sum of its parts." The holistic properties of holograms are expressed in the principle that "the whole is contained or enfolded in its parts" and the very notion of "parts" is altered because parts of a hologram have no specifiable boundaries.

The properties of holograms that are important for brain functioning are (1) the distribution of information which can account for the failure of brain lesions to eradicate any specific memory trace (engram); (2) the tremendous readily retrievable storage capacity of the holographic domain—the entire contents of the Library of Congress can currently be stored on holofiche (microfilm recorded in holographic form) taking up no more space than an attaché case; (3) the capacity for associative recall which is inherent in holograms because of the coupling of inputs when they become distributed; and (4) the powerful technique for correlating provided by this coupling—cross correlations and auto correlations are accomplished almost instantaneously. This is why the Fast Fourier Transform (FFT) is so useful in computer operations when statistical correlations are needed or when image construction, as in X-ray tomography, is required.

The step from showing that cortical cells encode frequencies to viewing the cortical surface as a holographic distributing device for encoding memory is not a completely simple one. The receptive field of each cell may encode holographically, i.e., in the waveform domain, but such receptive fields are small—for example, in the visual system they subtend at most some 5° of visual angle. But, as has been shown by engineers using holographic techniques, such patch holograms—also called "strip" or "multiplex" holograms—have all the image-reconstructing properties of global holograms. Further, when the patches encode overlapping but not identical patterns, movement can be recorded. Global holograms show the property of translational invariance which allows object constancy to result; but this is at the sacrifice of an explicit encoding of space and time which are enfolded into the *wave number*, as physicists term the two-dimensional *spatial frequency* of neurophysiologists.

There are other problems such as the amount of information that can be encoded in wave lengths recorded from neural tissue. But if the wave form is spatially related to dendritic hyper- and depolarizations these can occur angstrom units apart. Furthermore, the wave mechanical treatment of neural holography may not be the most propitious; suggestions have been made to use modified cable theory (Poggio & Torre, 1980); to treat the dendritic net as a manifold in which each polarization point is considered a cell in a lattice of a Lie group (Hoffman, 1970); or to use other mathematical approaches developed in quantum mechanics. Whatever the best quantitative description turns out to be, the current facts are that the dendritic receptive field does encode in such a way that a Fourier-like Gabor transform is appropriate at one level of description (see DeValois et al., 1978a,b), and the

Fourier transform has the advantage of being readily invertible so that encoding and subsequent image reconstruction are easily achieved.

The reason for looking at quantum mechanics for mathematical treatments of neural holographic processes is that the issues faced at the microphysical level are in many respects similar to those encountered in current neurophysiology. Thus David Bohm (1971, 1973) has suggested that a holographic-like order which enfolds space and time underlies the observations of quantum physics. Bohm calls this an implicate order to distinguish it from such explicate, explicit orders as those represented by Euclidean geometry and Newtonian physics.

On the basis of these results and formulations, the problem of brain-percept isomorphism takes on added complexity. The brain cortex resembles a spatial filter (Movshon et al., 1979), resonator or interferometer (Barrett, 1969), a musical instrument, or hologram constructing percepts. Such an instrument is not a geometric isomorph of the percepts it constructs. Rather, the isomorphism is seen to be between the brain as an instrument and the arrangement of physical energies elsewhere in the universe. The isomorphism is between two "physical" entities, "brain" and "world," rather than between either of them and our percepts!

Were the Gestalt psychologists wrong therefore in their proposal of psychophysical isomorphism? I do not believe so—only the locus of the isomorphism was misplaced. A possible resolution of the complexities introduced by the recent findings of how the brain cortex operates comes from an observation made by David Bohm with regard to current physics: he suggests that all of our conceptualizations in physics (as opposed to experimental manipulations and their formal mathematical treatment) are based on the use of *lenses*. We have telescopes and microscopes which contain lenses which objectify. Objects are particulate, separated from one another and can thus move with respect to one another to create the appearance of space, time, and causality, i.e., the explicate domain. Take away lenses and one is immersed in the implicate order.

Apply this reasoning to the perceptual isomorphism problem. Our percepts provide us with a Euclidean and Newtonian mechanistic order in which there are objects separated from one another, in which there is space, movement, time, causality. This is the explicate order. Take away our lenses—in this case the lenses and retinal structure of our eyes, the cochlea of the ear, and the tactile senses which, as we have seen, Bekesy showed in a carefully conducted series of experiments to be lens-like due to sensory, i.e., lateral inhibition—and we might well be left with an implicate order much as was Helen Keller before she learned to objectify.

Isomorphy, according to this analysis, is between percept and *sensory* mechanism. Contrary to James Gibson's pronouncements (1979), the lens of the eye does focus an image on the retina which is viewed by most students of comparative neurology when they are given an ox eye to dissect. The eye is, of course, not stationary. Thus the "image" of perception must be composed from a retinal figure which is in continual motion. This is accomplished in two ways. First, the retinal mosaic is anatomically re-presented isomorphically in the gross structure of the cortex. There is a more-or-less point-to-point connectivity between groups of cells in the retina and groups in the cortex. Thus the sensory order is maintained in the macrostructure—the between-receptive-field organization—of the sensory projections to the cortex.

Second, *within*-receptive-field organization of these projections is, as detailed above, holographically organized. The focused retinal image is analyzed into wave forms by the motion of the retina as shown by the "Mexican hat" configuration of the receptive field recorded from the fibers of the optic nerve (Rodieck, 1965). This results in the microstructure of the sensory projections (Pribram, Lassonde, & Ptito, 1981).

Now under intense study in our laboratory (Spinelli & Pribram, 1967; Lassonde, Ptito, & Pribram, 1981) are the relationships between the macro- and microstructures of the cortical sensory receiving areas, and of both to the mechanisms (located in the intrinsic "association" systems of the brain) which are responsible for linguistic logicality and objectivity (Pribram, 1981a,b, 1983). Objectivity apparently results not only from the lens-like structures of the senses but also from the constancies, the invariances, culled from the variegated interactions between the senses and the sensed which result from *movement*. Correlations, facilitated by the holographic microstructure of the sensory systems, play a critical role in establishing invariances. Objective invariance (e.g., experienced event, numerosity) must then be operated upon to produce logos and ratio, and there is evidence that in man these operations are performed to some extent by different hemispheres. Thus the left hemisphere appears to specialize in logical linguistic operations; the right hemisphere (at least in musically untrained subjects) in the rational tonal operations basic to music and perhaps some aspects of mathematics.

The issue of brain-percept isomorphism is thus complex. Basically, however, one can make the statement that phenomenal experience is the result of the operations of the sensory-motor apparatus. *Brain* function is involved only inasmuch as the sensory-motor apparatus is represented in the macrostructure of the sensory and motor systems of the brain. But there is much more to brain function than this sensory-motor re-presentation. The operations of the holographic microstructure and the mechanisms that lead to linguistic logic and musical and mathematical rationality were considered here, but there is also the entire neurochemical apparatus which is involved in the organization of mood-states, the apparatus that organizes emotional and motivational feelings and expressions, to name the most important. Again, these mechanisms show isomorphy with experience only to the extent that they represent the organization of bodily functions (Pribram & McGuinness, 1979; Pribram, 1977, 1981c).

These observations do not mean that the brain remains uninvolved in the organization of experience and behavior. The phenomenon of phantom limbs is but one outstanding example which demonstrates the intimate relationship of brain to psychological processes. This same example shows that the body per se becomes unnecessary to experiencing it once its representation has become imprinted in brain. The converse has also been demonstrated: certain brain lesions result in "neglect" of the part of the body on the side opposite to the lesion. Such body parts are simply not experienced as existing even when they are pointed out to the patient.

In summary then, it is the body and its senses and receptor functions, its glands, and the muscles that beget movement that are *ontologically* responsible for perceptual-brain isomorphism. To the extent that these body functions become represented in the brain, to that extent isomorphism occurs. But the brain has other alternative processing systems which are anisomorphic with experience, though they may correspond to nonsensory aspects of physical reality. It is these alternatives that provide a current frontier for exploration, both in physics and in psychobiology.

The Eternal Verities

Subjectivity, holograms, musical ratios, and harmonies as rational operations; all have become counterintuitive to our contemporary scientific culture. For a century we have been steeped in the virtues of "logical" positivism and "logical" mathematics to the exclusion of "rational" forms of thought. Thus, right or wrong, a Euclidean logic of isomorphy between brain processes and perception comes all too easily while a Gaborian and Bohmian rationality is appreciated with only the greatest of difficulty. The difficulty is compounded for scientists because they have been trained to be "objective" and thus they objectify before all else; because proximate causality is a necessity in performing and interpreting experiments; and because the implicate and rational orders are so closely aligned with subjective, religious, and mystical, i.e., nonlogical, experience.

If, however, the analysis presented in this essay is correct, the evidence gathered in the physical, brain, and psychological sciences will right the current cultural imbalance between *logos* and *ratio*. As noted, physicists have already come to grips with the limitations of objectifying. As the data from the neuro- and behavioral sciences indicate, these physicists are about to be joined by their biological and psychological colleagues. A paradigm shift, to use Kuhn's well-worked phrase, is in the making. But, of course, the shift will be, as revolutions so often are, a return to knowledge and wisdom established long, long ago in the prehistory of mankind. But the scientific mode should add its own luster to these eternal verities. Psychologists especially should benefit from this turn of the scientific weal. A precise, observationally based approach to such problems as aesthetics, ethics, spiritual values, freedom, dignity, religious beliefs, and mystical and other "paranormal" phenomena ought to result. At the moment these problems can be tackled from a social-psychological standpoint, but understanding which might come from an analysis of process and mechanism—especially neural mechanism—appears beyond reach. If, however, the twenty-first century continues the incredibly fruitful course charted by the nineteenth and twentieth, there is every promise that we will look at "psychology's first hundred years as an experimental discipline" with a quiet humor encompassed in phrases such as "and they thought they were psychologists"!

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