NEUROLOGY AND THE MIND-BRAIN PROBLEM

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THE discrepancy between physiological processes in the brain and the correlated psychic experiences to which they give rise in consciousness has ever posed a baffling puzzle to students of psychology, neurology, and the related sciences. Despite steady advancement in our knowledge of the brain, the intrinsic nature of mind and its relation to cerebral excitation remains as much an enigma today as it was a hundred years ago.

Interest in the problem of the mind-brain relationship extends far beyond the immediate concerns of neurology and psychology. Inability to comprehend the essence of mind has been a major obstacle to the progress of philosophy throughout its history. Questions such as those concerning scientific truth, the nature of reality, and the place of man in the cosmos require for their study some knowledge of the constitution, quality, capacities, and limitations of the human mind, through which medium all such problems must be handled. Much of man's religious dogma and his moral and even legal codes is deeply influenced in the final analysis by mind-matter concepts. In fact, all the ultimate aims and values of mankind could be profoundly affected by a thoroughgoing rational insight into the mind-body relationship. It was the broad significance of the problem as much as the difficulty of reaching a solution that prompted William James [1] to declare that the attainment of a genuine glimpse into the mind-brain relation would constitute "*the* scientific achievement before which all past achievements would pale."

The struggles of philosophy with psychophysical problems, although carried on over centuries and by some of the greatest thinkers in history, have as yet failed to produce anything of much satisfaction to the tough-minded scientist. Further progress from philosophical synthesis can be expected only after science has succeeded in furnishing philosophy additional data with which to work. For example, we shall be in a much better position to study mind-brain relations after we have attained some conception of the neural patterning involved even in such simple mental activities as the perception of color, time, pattern, size, and the like. Eventually it should be possible to list the special features which distinguish those brain excitations that are accompanied by consciousness from those that are not. Once this latter objective is achieved, it may be feasible, at last, to attack the mind-body problem with some effectiveness.

It is really the "brain" part of the mind-brain relation that most urgently needs clarification. Neurological science thus far has been quite unable to furnish an adequate description of the neural processes involved in even the very simplest forms of mental activity. Once the unknown neural events become sufficiently understood, it may be found that the mind-brain problem will tend to resolve itself. In any case, hope for progress now seems to lie entirely in this direction.

Accordingly we may by-pass many blind alleys of philosophical controversy, and turn immediately to the neural correlates of conscious experience. In the following discussion we shall be concerned principally with the nature of the neural processes themselves, keeping in mind questions such as the following: How do the brain patterns of visual sensation, for example, differ essentially from those of auditory or other modes of sensation? How does the pattern of brain excitation in the visual perception of a triangle differ from the excitation involved in perceiving a square or a circle? And so on. Thus, we propose to deal primarily with definite scientific questions subject to objective scientific answers in neurological terms.

Current Status of the Psychoneural Dilemma

Any immediate attempt to relate brain processes to psychic experience appears rather discouraging. To provide the colorful richness and infinite variation of quality and meaning in mental experience we find only a mass of brain tissue consisting essentially of closely packed nerve fibers and cell units roughly similar to one another in constitution, in structure, and in the physiological functions they perform. Such variation in size, shape, chemistry, conduction speed, excitation threshold, and the like, as has been demonstrated in nerve cells remains negligible in significance for any possible correlation with the manifold dimensions of mental experience.

Near the turn of the century it was suggested by Hering [2] that different qualities of sensation, such as pain, taste, and color, along with other mental attributes, might be correlated with the discharge of specific modes of nervous energy. Electronic methods of recording and analyzing nerve potentials, developed subsequently, have however failed to reveal any such qualitative diversity. It has been possible to demonstrate by other methods a refined constitutional specificity among neuron types [3, 4]. However, proof is lacking that this specificity influences in any manner the quality of impulse conduction. It seems rather to be operative primarily in the developmental patterning of the neural circuits. Although qualitative variance among nerve energies has never been rigidly disproved, the doctrine has been generally abandoned on a number of grounds in favor of the opposing view, namely, that nerve impulses are essentially homogeneous in quality and are transmitted as "common currency" throughout the nervous system.

Impulses traveling in the optic, auditory, proprioceptive, and other sensory pathways are, accordingly, believed to be similar in nature. "It is not the quality of the sensory nerve impulses that determines their diverse conscious properties but rather the different areas of the brain into which they discharge." This is the current point of view, and it seems to be warranted. When an electric stimulus is applied to a given sensory field of the cerebral cortex in a conscious human subject, it produces a sensation of the appropriate modality for that particular locus, that is, a visual sensation from the visual cortex, an auditory sensation from the auditory cortex, and so on [5]. When one looks for intrinsic differences in the matrix of these sensory fields that might account for qualitative psychic differences, there is disappointingly little to be found. Slight variations in the size, number, arrangement, and interconnections of the nerve cells have been demonstrated, but as far as psychoneural correlations are concerned, the more obvious similarities of these sensory fields to each other and to all other cortical fields, including the association and motor areas, seem much more remarkable than are any of the minute differences. Furthermore, sensations as diverse as those of red, black, green, and white, or of touch, cold, warmth, movement, pain, posture, and pressure apparently may arise through activation of the same cortical areas. For these and other reasons the reference of subjective quality to cortical locus, in itself, has little explanatory value. What seems to remain is some kind of differential patterning effects in the brain excitation. We may state, rather vaguely, that it is the difference in the central distribution of impulses that counts.

In short, current brain theory encourages us to try to correlate our subjective psychic experience with the activity of relatively homogeneous nerve-cell units conducting essentially homogeneous impulses through roughly homogeneous cerebral tissue. To match the multiple dimensions of mental experience we can only point to a limitless variation in the spatiotemporal patterning of nerve impulses. The difference between one mental state and another is accordingly believed to depend upon variance in the timing and distribution of nerve excitations, not upon differences in quality among the individual impulses.

On the foregoing points there is comparative agreement [6, 7, 8]. When we proceed to the question of exactly how conscious meaning is related to the spatiotemporal patterning of brain excitation, all certainty is lost and we enter an area of free speculation. The oldest, simplest, and still the most common notion on this matter holds that brain patterns resemble in form, and in a sense copy in miniature, outside objects and those of consciousness. For example, in the visual perception of a simple geometric figure like a triangle, the brain pattern is considered to be, at least roughly and with certain qualifications, triangular in form. This doctrine, formally called *psychoneural isomorphism* [9], has been extended to correlations in intensity, and in temporal organization as well as in spatial patterning. It appears to receive some direct support in the anatomical evidence that the sensory surfaces, such as the retina, skin, cochlea, and so on, are in fact projected onto the brain centers according to an orderly topographic plan.

In a corollary of this hypothesis adopted particularly by the Gestalt school of psychology [9, 10, 11, 12] it is contended that subjective experience is not correlated with the orthodox neural excitations traveling along fiber pathways, as commonly supposed, but rather with secondary electrical fields and currents which these excitations create in the brain tissue. The secondary electrical patterns, with their "field forces," are conceived to be massive and to spread through and between the nerve cells and fibers, pervading the cerebral tissue as a volume conductor. Unlike the scattered array of separated impulses from which they are generated, these mass patterns are unified and continuous in nature and therefore more like the patterns of subjective experience. This added correspondence in continuity and unity, along with the postulated similarities in form, intensity, and temporal patterning already mentioned, is believed to alleviate the discrepancy between neural and psychic processes.

Isomorphism, as has been stated by Boring [6], represents the most natural and naive way of dealing with mind-brain relations. It is implied unintentionally in a great deal of scientific as well as lay thinking about brain function, especially where perception, imagery, or memory is involved. For example, the neuroanatomist unwittingly works on this premise when he searches the brain for fiber pathways to unite the two halves of the visual field, which—inconveniently for the concept of isomorphism—are projected separately to opposite hemispheres of the cerebral cortex.

When the philosophic and logical basis of isomorphism is examined, its seeming metaphysical solace tends to dissolve, and it becomes difficult to see how anything is gained by having the neural processes copy the contents of consciousness. Furthermore, recent experiments designed specifically to test the importance of the postulated field forces in cerebral organization have failed to disclose any significant influence of such factors [13, 14]. Finally, it seems to me that our general knowledge of brain structure and physiology has for many years been quite sufficient to rule out any possibility that cerebral processes duplicate, even remotely, the patterns of subjective experience. This point is amplified in some detail below.

Other current theories of perception based more closely on the classical concepts of brain physiology ignore or deny any need for psychoneural isomorphism. In an effort to account for the retention of perceptual habits following destruction of major portions of the brain areas involved in learning, Lashley [15] has suggested that incoming sensory excitations may spread outwardly in waves that travel along the homogeneous fiber feltwork of the cortex. These spreading waves are presumed to set up widespread interference patterns such that any visual figure—a triangle, for example—becomes translated in the brain into a multi-reduplicated "scotch-plaid" type of pattern extending over the entire cortical area. All correspondence in shape with the original figure is lost in the reduplicated brain patterns.

Another hypothesis which has been proposed to account for our knowledge of universals and the perception of auditory and visual forms [16] postulates a scanning function to the alpha brain rhythm, which, as it passes up and down through the successive layers of the cortex, is supposed to bring about an enlargement and reduction inversely of the incoming sensory patterns. The authors of this theory expressly deny that the spatiotemporal distribution of brain excitations representing a given figure need resemble the actual figure in any simple way.

A third, rather different picture of the perceptual process is proposed by Hebb [17]. Convinced that visual perception occurs beyond the sensory receiving area of the cortex, he has attempted to follow the sensory pattern deeper into the brain. The type of excitation process arrived at, although vague in actual detail, retains even less resemblance to the original stimulus pattern than in the two foregoing theories.

In these and other hypotheses of perception it is assumed, in opposition to the tenets of isomorphism, that sensory stimuli become transformed in the brain into patterns of excitation that need not resemble in any way either the original stimulus or the contents of consciousness. The brain is presumed to work with a kind of code of its own, in which the symbols bear no direct correspondence to the mental experiences they represent.

With the doctrine of psychoneural isomorphism rejected along with that of specific nerve energies, some such codal scheme has seemed to be the only remaining alternative. The problem is thereby reduced to that of discovering the correct nature of a brain code based on the patterning of homogeneous nerve impulses. Even these restrictions have continued to leave a wide range for speculation. Advancements in neurology and psychology in the past several decades have tended progressively to limit this range, but its boundaries have again been widened of late by contributions from the field of computing-machine and signal engineering. Again one can find estimations of the contents of consciousness based on the total number of possible combinations and permutations of neuron elements. Other writers would code mental information into individual neurons, and still others into their protein molecules. The scope and diversity of opinion to be found in the current literature reflect our general confusion and almost complete lack of guiding principles.

Whereas the doctrine of psychoneural isomorphism has purported to bridge the mind-brain gap through principles of similarity and correspondence, the various "coding" schemes leave one with no basis whatever for resolving the problem. Even the most neurologically sophisticated of these latter hypotheses, as now stated, seem only to exaggerate rather than to minimize the mind-brain dichotomy. Perhaps as a hang-over from early behaviorism, many investigators have continued to pride themselves on a deliberate policy of ignoring entirely any questions that touch upon the relation of subjective experience and neural activity.

The following comment of Charles Sherrington [18] remains as valid today as when he wrote it more than eighteen years ago: "We have to regard the relation of mind to brain as still not merely unsolved, but still devoid of a basis for its very beginning." It is not a solution we aspire to but only a basis on which to begin.

A Different Approach to the Problem

A tentative attempt is made in the following discussion to point out and to justify another approach to the interpretation and understanding of mental activity. So far, only the vague outlines of the scheme are discernible. Even these outlines, however, if they could be verified, would help considerably to orient our efforts and would automatically eliminate much misguided speculation.

The proposed scheme rests on a view of brain function which was most nearly approximated in the old motor theory of thought, now largely abandoned. Despite its recognized shortcomings and errors, this forsaken offspring of behaviorism taken in combination with the pragmatism of C. S. Pierce [19] possibly holds the key to a comprehension of brain function far advanced beyond anything developed subsequently. An analysis of our current thinking will show that it tends to suffer generally from a failure to view mental activities in their proper relation, or even in any relation, to motor behavior. The remedy lies in further insight into the relationship between the sensori-associative functions of the brain on the one hand and its motor activity on the other. In order to achieve this insight, our present one-sided preoccupation with the sensory avenues to the study of mental processes will need to be supplemented by increased attention to the motor patterns, and especially to what can be inferred from these regarding the nature of the associative and sensory functions. In a machine, the output is usually more revealing of the internal organization than is the input. Similarly in the case of our thinking apparatus an examination of its terminal operations and finished products may be more enlightening than any amount of analysis of the transport of raw materials into it.

Only after we have attained some understanding of the way in which the sensory and thought processes become transformed into motor activity, can we hope to comprehend their meaning and plan of organization. Only then can valid working principles be found to curb and to guide future theorizing.

Utilization of this motor approach immediately helps us to view the brain objectively for what it is, namely, a mechanism for governing motor activity. Its primary function is essentially the transforming of sensory patterns into patterns of motor coordination. Herein lies a fundamental basis for the interpretation, direct or indirect, of all higher brain processes including the mental functions. At first thought such statements will probably seem most short-sighted and unsatisfactory. Nevertheless, for purposes of scientific analysis, a perspective of this kind seems necessary, and we may turn now to an attempt to justify it.

Partial support is found in phylogenetic considerations which indicate that the vertebrate brain was designed primitively for the regulation of overt behavior rather than for mental performance. As one descends the vertebrate scale, purely mental activity becomes increasingly insignificant compared with overt response. Among the salamanders and lower fishes, where thought processes are presumably negligible, the bulk of the nervous apparatus is clearly concerned with the management of motor activity. To the extent that sensation and perception are evident, these would appear to serve directly for the guidance of response. From the fishes to man there is apparent only a gradual refinement and elaboration of brain mechanisms with nowhere any radical alteration of the fundamental operating principles. In man as in the salamander the primary business of the brain continues to be the governing, directly or indirectly, of overt behavior.

Overt behavior, upon analysis, we find to be constituted almost entirely of patterns of muscular contraction. It follows that the principal function of the nervous system is the coordinated innervation of the musculature. Its fundamental anatomical plan and working principles are understandable only on these terms.

Further support for this point of view may be found in the study of brain architecture. One searches the cerebrum in vain for any structures that seem to be designed for the purpose of forming, cataloguing, storing, or emanating copies or representations of the outside world (see p. 303). If any scheme or plan at all is evident in the complicated fiber associations and nuclear interconnections of the brain, it is a design patterned throughout for governing excitation of the "final common (motor) pathways." Such information as is now available regarding physiological functions of the various brain centers correlates with the anatomical data to support the same thesis.

To the neurologist, regarding the brain from an objective, analytical standpoint, it is readily apparent that the sole product of brain function is motor coordination. To repeat: *the entire output of our thinking ma-*

chine consists of nothing but patterns of motor coordination. The neurohumoral and glandular components may be disregarded in this discussion. We may also disregard the various by-products of brain activity such as heat, electric potentials, carbon dioxide, and other metabolites released into the blood stream, cerebrospinal fluid, and surrounding tissues.

This classification of the electric potentials as an irrelevant by-product rather than an important end-product of brain activity requires some comment, inasmuch as certain authors have considered these to be the essential correlates of consciousness. It is well established that brain activity generates electrical currents and potential changes which vary greatly in rate and amplitude. These phenomena extend well beyond the confines of the brain and may be recorded readily at the surface of the scalp. It would be difficult or impossible at this point to furnish irrefutable proof that the manufacture of these electrical changes is not a major object of cerebral activity. However, many reasons for doubting it, both direct and implied, will be found throughout the present discussion.

In our scheme these stray mass potentials have no more special function or meaning than have the similar electrical currents that pervade the entire body whenever the heart beats, muscles contract, and so on. There is no evidence that they react back upon the processes that produce them nor otherwise influence these processes in any significant fashion. Brain organization, we suspect, is maintained in spite of these secondary electrical effects, not because of them. In a conscious patient with brain exposed under local anaesthesia it should not be difficult to pass electric currents through a sensory field of the cortex during perceptual tests. We would anticipate no functional disturbance provided the currents were maintained within the normal physiological limits. In so far as electrical changes do operate directly in the conduction of nerve impulses, synaptic transmission, maintenance of excitatory thresholds, and so forth, they constitute an essential part of the brain function itself and are not to be classed as one of its end-products.

The layman naturally assumes the major work of the brain to be the manufacture of ideas, sensations, images, and feelings, the storage of memories, and the like, and often expects the physical correlates of these to be some kind of aural end-product phosphorescing within the cortex or emanating from its convolutions. These subjective phenomena may, however, be regarded as phases of brain function itself, not products of it. Scientific analysis has failed to disclose any output at the cerebral level other than the miscellaneous by-products mentioned above. Excepting these, the entire activity of the brain, so far as science can determine, yields nothing but motor adjustment. The only significant energy outlet and the only means of expression are over the motor pathways.

Thus, whether accompanied by consciousness or not, all brain excitation has ultimately but one end, to aid in the regulation of motor coordination. Its patterning is determined throughout on this principle. It follows that efforts to discover the neural correlates of consciousness will be more successful when directed on this basis than when guided by arbitrary correlations with psychic experience, stimulus patterns, or outside reality, or by analogies with various types of thinking machines.

The above approach to mental functions may require some shift in our customary perspective on the interrelation of cerebral and motor processes. Instead of regarding motor activity as being subsidiary, that is, something to carry out, serve, and satisfy the demands of the higher centers, we reverse this tendency and look upon the mental activity as only a means to an end, where the end is better regulation of overt response. Cerebration, essentially, serves to bring into motor behavior additional refinement, increased direction toward distant, future goals, and greater over-all adaptiveness and survival value. The evolutionary increase in man's capacity for perception, feeling, ideation, imagination, and the like, may be regarded, not so much as an end in itself, as something that has enabled us to behave, to act, more wisely and efficiently.

Perceptions and ideas are found, upon analysis, to have their factual significance and meaning in terms ultimately of overt operation. Their meaning derives from the potential effect, that is, the difference they make or may make in behavior. In both its phylogenetic and ontogenetic histories, mental activity develops out of, and in reference to, overt action.

Actually the interrelation of motor and mental activity is one of cyclic and reciprocal interdependence. However, the nature of the problem and current trends in our thinking make it necessary at this time to emphasize particularly the dependence of the mental upon motor activity.

Any separation of mental and motor processes in the brain would seem to be arbitrary and indefinite. Mental processes are intimately associated with other integrative mechanisms which we are accustomed to recognize as serving for the regulation of motor adjustment. Sensory and associative processes, conscious and unconscious alike, are obliged to merge and interlace in the brain with the motor patterns. There are no boundary planes in the cerebrum to keep the two apart. In many or most situations overt response is guided closely and directly by the excitation patterns of thought and perception. Temporally, therefore, as well as spatially, the mental and the motor patterns must integrate, mesh, and interlock.

The same relationship is indicated in more specific anatomical and physiological observations. The great pyramidal motor pathway from the cerebral cortex is constituted of fibers which arise from many cortical areas, sensory as well as motor. Motor responses may be elicited directly by electrical stimulation of sensory areas, as, for example, the visual and the somesthetic cortex. The extrapyramidal motor outflow from the cerebral cortex likewise arises from associative and sensory cortical fields as well as from those traditionally designated as motor. Excitation patterns in the sensory and associative areas, therefore, have to integrate with patterns in the subcortical motor systems as well as with those in neighboring motor fields.

In brief, we conclude that the unknown cerebral events in psychic experience must necessarily involve excitation patterns so designed that they intermesh in intimate fashion with the motor and premotor patterns. Once this relationship is recognized as a necessary feature of the neural correlates of psychic experience, we can automatically exclude numerous forms of brain code which otherwise might seem reasonable but which fail to meet this criterion.

It follows further that the more we learn about the motor and premotor mechanisms, the more restrictions we add to our working picture of the unknown mental patterns and hence the closer our speculation will be forced to converge toward an accurate description of their true nature.

Implications for a Theory of Perception

Past theory and speculation concerning the neural correlates of subjective experience have been based to a large extent upon phenomena of visual pattern perception. For the sake of comparison some further implications of the present thesis may also be illustrated most effectively with reference to the same material. Consider the cerebral excitations which take place, for example, during the visual perception of a simple geometric figure, say a triangle. Of what exactly does the brain process consist, and how is it patterned?

A satisfactory explanation of the neural events involved in this one simple example of visual perception would carry us a long way toward an understanding of cerebral organization and mind-brain relations in general. Several possible types of answer as suggested in isomorphic theory and in other recent theories of perception have already been mentioned above.

By comparison, one arrives at a quite different kind of picture by utilizing the approach advocated earlier in this paper (pp. 296–300). This approach does not lead us to expect in the cerebral process any kind of triangularity, linearity, nor even a unity corresponding to that of the perceived triangle. Nor are we led to seek any kind of codal representation of these. What we are prompted to search for, primarily, is an excitation process so patterned as to bring about a central adjustment that will put the premotor and motor systems into readiness for adaptive response to the given triangle. Reasoning on this principle from the motor mechanism backward, step by step, into the association and sensory centers, one is able to construct a working picture of the brain pattern which, although necessarily vague in the present state of our knowledge, differs significantly in principle from anything obtained by tracing the retinal triangle centralward or by attempts to translate the subjective triangle directly into neural patterns.

If there be any objectively demonstrable fact about perception that indicates the nature of the neural process involved, it is the following: In so far as an organism perceives a given object, it is prepared to respond with reference to it. This preparation-to-respond is absent in an organism that has failed to perceive. In the case of the triangle, a person who perceives it, is ready to point to it, to outline it with his finger, to show its location and orientation in space, to pick it up, describe it, etc. Animals lacking the verbal and symbolic capacities of man illustrate the principle more simply. The perceiving animal is able to avoid or to approach the triangle, to run under it or up one edge of it, to leap to a corner of it or to pick it up in its mouth by one of the points, etc. The presence or absence of adaptive reaction potentialities of this sort, ready to discharge into motor patterns, makes the difference between perceiving and not perceiving.

The preparation-to-respond in perception is a demonstrable fact. All that need be questioned is whether it may not be a consequence of, rather than a part of, the cerebral process which actually constitutes the perception itself. In this regard we may emphasize again that the structure of the brain, as well as what is known of its physiology, discourages any effort to separate the motor from the sensory and associative processes. To the best of our knowledge there is only a gradual merging and transformation of the one into the other, with nothing to suggest where perception might end and motor processes begin. That the preparation for response *is* the perception is suggested by further considerations.

Perception is not correlated with the immediate arrival of stimulus patterns in the sensory receiving areas of the cortex. Compare two persons gazing at the same visual field in which lies a triangle, with only one of them perceiving the triangle. (Failure to perceive elements of the visual field is common enough with respect to ordinary scenes or pictures but is more strikingly illustrated in the case of hidden figures in picture puzzles, *trompe-l'oeil* paintings, ink blots, etc.) In both persons the retinal pattern and its transmission into the visual receiving areas of the brain are essentially identical. Therefore, the mere transmission of sensory patterns into the visual cortex does not, in itself, constitute perception nor is it sufficient to bring it about. This is also suggested in the fact that many of our perceptions involve the combined influence of afferent patterns from more than one sense modality. In the case of vision, postural and kinesthetic factors are regularly involved along with the retinal cues in determining the spatial orientation and stability of "visual" perception. Since these different afferent influences are projected to separate cortical fields, the combined perceptual effect must lie deeper.

Perception is more than the mere passage of sensory patterns into passive brain protoplasm. In the nonperceiving subject the stimulus pattern of the hidden figure may pour into the brain for seconds or even minutes, producing widespread secondary and tertiary effects throughout the nervous system, without the figure's being seen. Something else is needed, something that approaches an active and specific adjustment on the part of the brain.

This fact is indicated in our ability to see the same stair diagram as if from above or below, or a cube diagram with first one corner extending toward us and then another. The stimulus pattern during the perceptual shift remains constant, as does its projection into the brain. The perceptual shifts must therefore depend on active changes within the brain itself. It should be noted also that these perceptual shifts involve changes in the tendency to respond. When one corner of the cube is nearest, we are ready to react to the cube, to reach for it, handle it, deal with it in these terms. When the other corner seems nearest, our reaction tendencies shift accordingly.

Many other examples can be cited to illustrate the same fact, namely, that perception is basically an implicit preparation to respond. Its function is to prepare the organism for adaptive action. The problem of what occurs in the brain during perception can be attacked much more effectively once this basic principle is recognized.

It follows that it will be necessary to learn something about the nature of those central integrative mechanisms that lead into motor adjustment before we can picture in any detail the neural processes of perception or of other mental activities. Knowledge of the stimulus pattern and its projection into the cerebral cortex is not enough. The patterning of the perceptual process is determined as much by the organization of the central mechanisms as it is by the sensory influx. This is evident in the general tendency to perceive selectively what one is already looking for and expects to see. Carried further this may lead to visual illusions or, in the extreme, to hallucinations. In the latter case, almost the entire organization is determined centrally. Hallucinations constitute further evidence that the psychic experience is not correlated with the discharge of the retinal image into the visual cortex, but depends on subsequent and more complex operations.

It is common to think of visual hallucination and visual imagery as dependent on some kind of central rearousal of an essentially sensory pattern. In the case of the visual image of a triangle, for example, we might postulate a re-excitement in the visual cortex of a triangle or whatever coded pattern—according to our favored theory of perception—the sensory stimulus is presumed to establish there. This would demand the dispatch from somewhere in the centers of an array of discharges patterned somewhat like the original sensory influx. It is difficult to see how such a pattern could be dispatched from anywhere other than from the retina itself. This difficulty is not encountered when we conceive of perception as an incipient preparation for action, with the brain excitation taking the form of a central adjustment leading into response to the figure. Rearousal of this type of pattern from central sources is neurologically feasible.

Isomorphism and Topographic Projection in Sensory Pathways

The rejection of isomorphism obliges us to find another explanation of the orderly topographic projection of sensory surfaces in the brain. Actually, further thought on the problem will reveal that an orderly anatomical projection fails anyway, under most conditions, to insure even a rough similarity between the brain pattern and that of the perceived figure. To illustrate, consider further the visual perception of a triangle. The brain pattern, in the first place, is split in two because the two halves of the visual field are projected to opposite hemispheres of the brain. The two halves are not neatly drawn apart with a gap between them, but instead the mid-plane of each is reflected laterally away from the other. This is the primitive condition; in man the mid-planes tend to be twisted posteriorly. Although fiber pathways that would serve to unify the visual areas of the two hemispheres have been sought, none has been found.

The triangular pattern is equally divided in the cortex only while the gaze is perfectly centered in the mid-plane of the figure. When the fixation point shifts to either side, the fragments of the triangle projected to each hemisphere change accordingly. As the eyes rove over the triangle from apex to base and from side to side, the shape and also the position of the cortical patterns change radically in each hemisphere. One can compare the effect photographically to a series of multiple exposures of various fragments of a triangle flashed successively with erratic shifting of the center of the figure in each hemisphere.

While this kaleidoscopic series of excitatory changes is taking place in the visual cortex of the brain, the figure of subjective experience remains constant, a unified whole, with a fixed orientation in space. If exactly the same retinal projection patterns were produced, not through eye and head movements but by actual movement of the figure itself while the gaze is kept fixed (as might be done with cinema projection methods), the subjective effect would, of course, be entirely different. With the projection to the visual cortex identical in each instance, the difference in "visual" sensation must be attributed to the difference in the proprioceptive influx from the eye muscles. The importance of proprioception in vision is only mentioned in passing because it illustrates further the impossibility of correlating perceptual experience with the immediate projection of the retinal image to the sensory cortex, as well as the lack of similarity between the form of the perceived triangle and that of the excitatory process in the brain.

Additional dissimilarity is caused by the enlarged cortical representation of the macula of the retina [20]. The portion of the figure that falls on the macular area becomes magnified in the brain relative to the rest of the triangle. The resultant warping differs from moment to moment with each change of fixation. And, of course, the flat two-dimensional triangle becomes irregularly folded and twisted when projected upon the fissures and convolutions of the cortex. These latter spatial distortions also are subject to variation with each shift of fixation.

In summary, the topographic projection of the retina upon the cerebral cortex fails to insure any significant similarity in form between the figure of perceptual experience and that of the brain excitations. The possibility of psychoneural isomorphism is even more remote with respect to the other senses. Consider, for example, stereognosis and the perception of the three-dimensional form of a triangular block of wood placed in the hands. The cutaneous discharges projected to the cortex from the palms of the hands and the moving fingers as they explore the surface contours, already lacking any resemblance to triangularity, must further be integrated and interpreted at each instant with reference to the train of postural and kinesthetic cues entering from each of the many moving joints. The result is a brain process the configuration of which is hopelessly removed from that of the object perceived.

Topographic projection is explainable on other bases than that of mediating isomorphic representation. It is significant that the same type of fiber projection is found in the motor and associative parts of the brain and also in nonspatial sensory systems like that of smell and possibly taste. Certainly topographic projection is quite comprehensible as a reflection of the developmental processes of neurogenesis [3, 4] and would seem to be a simple framework on which to build more refined structural organization.

If topographic projection could be eliminated by random displacement of the nerve cell bodies, at the same time maintaining all the original synaptic connections and conduction-time intervals, complete functional disorganization should follow according to isomorphic field theory. On the other hand, little or no disturbance would be expected from the standpoint of orthodox circuit theory.

Impressed Sensory Patterns versus Operational Adjustment

The major fluctuations in the excitation patterns of the visual cortex caused by ocular movements in perception are accompanied by simultaneous shifts in the nonvisual kinesthetic influx. These two inputs integrate with activity already going on in the brain centers to produce a relatively stable over-all adjustment to the perceived triangle. The constancy of the subjective experience derives, not from any constancy in the sensory patterns impressed on the cortex, but from the integrative effect of their more central resultant. This does not mean that the subjective constancy depends strictly upon the excitation of a final invariant group or pattern of central neurons. It is the functional, or operational, effect of the input patterns upon the dynamics of cerebral adjustment that counts. The over-all adjustment might have a constant functional or subjective value even though the particular neurons excited and the spatial and temporal patterning were to vary from experience to experience or to fluctuate radically during a single perceptual span. Waning in one part of the pattern, for example, might be compensated by increased intensity in another, or by the entry of new excitatory elements, to preserve the over-all effect.

It must be emphasized that the constancy and other subjective properties of the brain process are not to be evaluated in terms of sensory geometry or of even a closely related frame of reference as is our usual inclination. An entirely new frame of reference applies, one that is based ultimately on motor adjustment.

We may arrive at a better conception of the neural events in visual perception if we imagine our sample triangle as being constructed gradually in time out of dots and dashes that are passed successively into the brain to produce each its individual vertical effect. This may seem contradictory to demonstrated Gestalt principles in perception but actually it is contradictory only to some of the secondary inferences drawn therefrom regarding brain physiology. It is well established by tachistoscopic studies that a complicated pattern is not perceived in full detail with the initial projection of the pattern into the brain. The total picture comes gradually; at first the broader and bolder features are seen and then, by steps, further details. The perception of simultaneous *spatial* relations thus commonly depends upon *temporal* organization in the brain processes.

Consider the neural adjustments involved in perceiving a single dot on the wall before you. The stream of impulses entering the midbrain and cortex will first set up responses that tend to center the eye on the dot. This may involve head as well as eye movements and possibly the entire musculature. Immediately with perception of the dot comes readiness to locate it and to respond to it. Widespread facilitating and inhibiting effects are invoked in many parts of the brain. The cerebral mechanisms have become set for a certain class of reactions. This particular set will automatically exclude an infinite number of other reaction possibilities. Probably your eyes will not remain fixed upon the dot but will stray around the wall in its vicinity. As a result the stream of excitations in the brain will drift about the visual cortex. Nevertheless the dot appears to stay fixed meanwhile, and you remain oriented with reference to it.

Now suppose another dot is added in the neighborhood of the first. This sets up another stream of impulses which in turn arouses responses somewhat similar to those of the first dot. The adjustments from the first largely remain, however, and essentially the result is an additional adjustment superimposed upon the first.

The addition of a third dot sets up other reactions that further modify the adjustments already present. There are now three streams of impulses passing through the striate cortex. As the eyes move about from one dot to another and to neighboring points on the wall, the spatial patterning of the three streams of impulses through the cortex varies greatly. Not only do the three foci of excitation flash about in different positions in the cortical field, but the number projected in each hemisphere will fluctuate from none to three. The simultaneous spatial interrelationships thus undergo continuous variation in the cortex so that it is impossible to think of any type of horizontal "field" force binding these streams of impulses together in the constant pattern that is perceived.

To the three dots may be added two more, and so on. Then the dots can be closed gradually by dashes and more dots until the triangle is completed. The cerebral adjustment to a single dot meanwhile will have been built upon and modified into an adjustment to respond to a partial and finally a whole triangle. The sensory input must be pictured throughout as influencing and modifying premotor and motor patterns of excitation that are already present. One may say that the sensory input is perceived and acquires conscious meaning only in so far as it modifies preceding patterns of central activity. The foregoing approach to the perceptual process is suggested merely to aid in visualizing the neural events as an active meaningful adjustment, rather than as simply an impression or passive registration in brain tissue of a pattern of sensory excitation.

By the same procedure one might build a square or a hexagon. Although the first several dots in each case might be identical and arouse the same response, the final adjustment will differ according to the pattern completed. As emphasized by the Gestalt school, it is the over-all pattern that counts, both in the perceived figure and in the brain process; but this is no reason for inferring isomorphic correspondence between the two, nor for assuming that it is the secondary mass electrical disturbances that constitute the important phase of the brain process.

Unity, Number, and Size in Psychoneural Correlation

When a visual figure is perceived as a unified whole, it is natural to suppose that the brain pattern also possesses a corresponding unity. In theories of the codal as well as of the isomorphic type a given unit in brain process is commonly supposed to represent a given unit of psychic experience.

We must, however, ask in what manner the brain process, as in the perception of a triangle, should be unified. Must the discharging neurons be side by side, unseparated by resting or inhibited cells? Or is it enough if their fiber processes link with one another? Or perhaps it is only the electric potentials they generate that must meet or overlap? Reference has been made above to the suggestion that conscious experience is correlated with secondary electrical changes that are massive, field-like, and continuous in nature. These very properties which would appear to preserve physiological unity, however, would at the same time seem to preclude any finely etched perceptual effects involving thin lines, abrupt contrasts, and sharp boundaries. The concept also fails to account for the unity of the visual scene, the projection of which is split in half in the cortex with the mid-lines directed outwardly and posteriorly. Discovery of duplicate projections of the retina via the pulvinar, colliculus, and so on, will hardly simplify matters. Actually we have yet to find any satisfactory criterion of unity in the neural processes that can account for the unity in psychic experience.

In the scheme proposed here it is contended that unity in subjective experience does not derive from any kind of parallel unity in the brain processes. Conscious unity is conceived rather as a functional or operational derivative. In perception it means only that the brain becomes adjusted to deal with the perceived object as a unit. There need be little or nothing of a unitary nature about the physiological processes themselves. The essential parts of the preparation-for-response may be rather widespread through the brain with nowhere a compact unified pattern of discharge that represents "triangle." The retention of perceptual and other habits following extensive brain lesions [15] and the seeming "equipotentiality" of cortical areas become less difficult to account for with such a concept of cerebral organization.

Closely related to the problem of unity is that of number. Consider the perception of two, three, or more triangles present in the visual field simultaneously. The brain process might be pictured as a corresponding number of excitation patterns each representing "triangle," in either isomorphic or signal-code terms. Actually, in the cerebral preparation for response to a number of items there is no need for a corresponding number of unitary excitation processes. Three triangles viewed simultaneously tend to be perceived together as one larger unit. The extent to which this unification occurs will vary, of course, with many factors, but in any case the brain process will not be found to be anything like a mere tripling of that which occurs in the perceiving of a single triangle.

Consider the motor patterns involved in handling one tennis ball compared with those used in handling three tennis balls—or to be consistent, make it triangular blocks instead of spheres. A comparison of these motor processes at the cerebral level, even though vague, will be more suggestive of the principles of neural patterning involved in perceiving groups of items than will inferences based on attempts to trace the stimulus figures centralward.

The same principles apply to the perception of size. Compare the brain processes involved in perceiving a large and a small triangle. Are we to infer that the two are similar except that the former is larger? According to our present thesis there need be little or no correlation between the size of an object in perception and the size of the correlated brain pattern. The adjustment of the brain to deal with a large triangle will differ in certain respects, but it need not cover a larger volume of cerebral tissue. The nature of the differences is perhaps better indicated again by comparing the motor patterns involved in handling a small and a large triangular block. The motor-pool discharge in the two cases will differ with respect to timing and intensity in an extremely complex fashion but the size of the triangles is not reflected in any direct way in the extensity of the central excitations. This applies as well to the premotor firing and to all excitation following the initial sensory projection into the brain.

Sensory Equivalence

Sensory equivalence is illustrated in the ability of an animal to recognize and to respond similarly to patterns of the same configuration even though these differ markedly in size from the one used in training. It has been almost universally inferred that some kind of brain mechanism is needed such that the equivalent sensory patterns, after filtering through the cerebral cortex, become funneled in one way or another into a given invariant central excitation regardless of their starting size and position at the sensory surface. Similar reasoning has been applied to problems of generalization and abstraction.

According to our present scheme, brain function is not organized on these principles at all. Psychic meaning is not so direct a reflection of corresponding properties in the brain mechanisms. Subjective meaning depends on the over-all *functional* effects of the physiological processes, not upon their copying or representing in code form the attributes of the stimulus. Further, the brain process must be viewed basically as an *adjustment to* a perceived or imagined item, not a reduplication or representation of it.

The "equivalent" responses of the rat to a large and to a smaller triangle, for example, whether it be jumping at doors or selecting alleys, may have little in common as far as the physiological details of the motor discharge are concerned. The same is true of the more central or perceptual part of the brain process. It is only in the over-all functional or operational effect that their essential similarity resides. In the centers as well as at the sensory surfaces the patterning counts. In the centers, however, it is not a copy-type or geometrical kind of pattern that is involved, but a much more intricate one fashioned in accordance with the complex web of brain pathways and designed to work through this medium into motor adjustment. The central excitation may vary considerably in its geometric, spatiotemporal, and other properties while maintaining invariant or equivalent functional value as measured with reference to motor adjustment. In other words the same functional effect and the same psychic meaning *may* be obtained from brain patterns the neuronal details of which differ considerably on different occasions. Not only may different neurons be involved, as many configurationists would agree, but more than this, the configuration of neurons may vary.

In the above examples, the visual perception of a triangle is assumed to be built up in the nervous system as an active operational adjustment that puts the brain in readiness to respond to the triangle. Although the general adjustment may involve actual motor changes, the core of the perceptual process in the higher centers is not itself a motor pattern. It is more premotor or better pre-premotor in nature, owing to the hierarchical plan of neural organization. This continued emphasis on the motor approach to mental activity should definitely not be taken to imply that subjective experience resides within any motor reaction or within the motor system. If obliged to localize the conscious experience, we could only suggest vaguely those brain centers midway functionally between the sensory input and motor output, where the coordinated action of the entire motor system may be governed as an integrated whole through the combined influences of most of the sensory excitations and mnemonic traces. This vital focus of neural organization might possibly be centered in the brain stem primarily, as suggested in the observations of Bailey [21], Penfield [5], and others, rather than in the cerebral cortex itself.

It has been indicated repeatedly that the brain excitation is neither a copy nor a codal representation of subjective experience. Psychic meaning is presumed to be intrinsic in the brain organization itself, such that once the brain patterns are fully understood, no additional "key" should be necessary to interpret the subjective meaning.

Much of what has been said above with reference to pattern perception applies to other forms of mental activity. Thinking itself may be regarded as a prolongation and elaboration of perception embodying additional factors such as insight, trial-and-error processes, reasoning, and especially the use of symbols. Essentially it is implicit, symbolic preparatory adjustment without commitment in overt action. The cerebral excitations are presumed to be patterned throughout with ultimate—

but not necessarily direct—reference to the motor and premotor systems. This holds even where the thought process is entirely symbolic. In the person "thinking out loud," in whom we get some indication of the nature of the inner activity, it is noteworthy that the overflow into the motor periphery is clearly of such pattern as to effect coordinated innervation of the musculature.

Perhaps the mental experiences most difficult to account for in the terms proposed here are the immediate sensory qualities. We have no satisfactory explanation of these on any basis as yet, and it is not easy at present to see how the conscious qualities of sensation relate to their operational effects in the motor system. Of all psychic functions, the sensations are farthest removed from the motor side. They are genetically predetermined and involve a detector and discriminatory type of cerebral adjustment that has little direct commitment in motor activity.

Particularly in the case of sensory qualities it is tempting to have recourse to some form of specific nerve energies. For the present, however, it would seem more fruitful to assume that the difference between, for example, taste and tactile sensations does not derive from any difference in the quality of the individual impulses but rather from differences in the way in which the two afferent systems are linked into the central organization, and from the differential dynamic effects thereby secured. That the sensations have emerged in the course of evolution as attributes of mere complexity alone in neural organization seems less likely than that each sense modality depends upon a specific design the meaning of which may become apparent once the neurological analysis is carried far enough. Sensations certainly appear to function directly in the guidance and control of motor adjustment, and we can only hope that when the sensory regulation of motor coordination becomes more thoroughly understood, it will be possible to see where the sensory qualities fit into the rest of the scheme.

One need not feel distressed at the suggestion that all our noblest and most aesthetic psychic experiences may be found, on analysis, to consist merely of brain patterns designed, directly or indirectly, for the adjustment of muscular contraction and glandular secretion. This detracts nothing from their meaning and importance. In the same way our finest deeds consist only of patterns of muscle-fiber twitches, our greatest printed passages only of ink marks on paper, while our most ravishing music, as pointed out by William James, is but the rasping of hairs from a horse's tail on the intestines of a cat. Significance and meaning in brain function do not derive from the intrinsic protoplasmic or other analytic aspects of neural excitation, but rather from their higher-order functional and operational effects as these work upon successive brain states, upon the motor system, and thereby into the environment, and back into the brain. We should not expect to find that a single neuron or an isolated patch of neurons, or even a cortical center, could sense, feel, experience, or think anything in isolation. These psychic properties we envisage as depending upon a specific design and complexity in the vortex of neural activity, generally involving a reciprocal interplay of many parts.

It will be evident that our scheme leaves much unanswered. It is inevitable that the reader, like the writer, will find it wanting and unsatisfactory in many respects. At best it can only be offered tentatively as a possible basis on which to begin to describe the neural events of mental experience.

Summary

At the core of all metaphysical problems stands the mind-brain relationship, real understanding of which could have vast influence on all the ultimate aims and values of mankind. The logical, philosophic, and semantic approaches to the question, though employed intensively by some of the greatest of human minds, have repeatedly failed to yield a satisfactory resolution of the problem. Hope for further progress is seen to lie in a scientific analysis of the neural correlates of psychic experience, and the present discussion has been restricted primarily to this essentially neurological problem.

Present-day science is quite at a loss even to begin to describe the neural events involved in the simplest forms of mental activity. Conjecture has been vague and varied, ranging from theories in which the brain patterns are supposed to parallel and to copy roughly the contents of consciousness, to a series of codal schemes in which psychic experience is represented by implication in various brain codes with no other meaningful psychoneural relation indicated.

An approach to the interpretation of higher brain functions is here suggested in which motor adjustment, rather than stimulus patterns or the contents of subjective experience, figures predominantly as a proper frame of reference for understanding the organization, meaning, and significance of brain excitation. Such an approach would seem to guarantee at least a better understanding of the brain processes themselves. Whether this in turn may help to resolve the baffling mind-brain enigma remains to be seen.

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