4   Brain and Free Will

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PHILOSOPHICAL INTRODUCTION

That we have free will is a fact of experience. Furthermore, I state emphatically that to deny free will is neither a rational nor a logical act. This denial either presupposes free will for the deliberately chosen response in making that denial, which is a contradiction, or else it is merely the automatic response of a nervous system built by genetic coding and molded by conditioning. One does not conduct a rational argument with a being who makes the claim that all its responses are reflexes, no matter how complex and subtle the conditioning. For example, one should not argue with a Skinnerian, and moreover a Skinnerian should not engage in argument. Discourse becomes degraded into an exercise that is no more than conditioning and counter-conditioning—what we may characterize as Skinnerian games!

      Nevertheless, despite these logical problems, it is widely held that free will must be rejected on logical grounds. The question can be raised: can free will be accommodated in a deterministic universe? That this may be possible has been shown by philosophic arguments developed initially by Popper (1950a, 1950b) and later very extensively elaborated by MacKay (1960, 1966, 1967, 1971a, 1971b).

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In 1950 Popper considered the behavior of calculating and predicting machines operating according to the laws of classical physics. He showed that in principle there are certain predictive tasks that cannot be carried out. For example, such a machine cannot predict its future states, because an attempted prediction based on the situation up to the time of prediction would be outmoded by the introduction of the additional information embedded in the prediction, and the updated prediction would similarly be again outmoded, and so on indefinitely. In the case of two such machines, A and B, A many be able to predict the future states of B, given full information of B, but only if B is not informed in advance of A's prediction.

In a series of publications MacKay (1960, 1966, 1967, 1971a, 1971b) has discussed the freedom of action of human agents in a mechanistic universe, substituting conscious human agents for the calculating and predicting machines considered by Popper. However these human agents are controlled by brains that are assumed to be "as mechanical as clockwork," and that are immersed in a deterministic physical environment. The special feature introduced by MacKay is that an observer is equipped with a "cerebroscope" (cf. Feigl, 1967; Pepper, 1960), a mythical and absurd scientific instrument giving a complete description of the ongoing brain states of subject A, and also of the environment! Armed with these devices and with a Laplacean intelligence, it is postulated by MacKay that the observer can predict with certainty the behavior of A, for example the making of a decision between alternative choices that A believed were open to him. Thus, at the time A believes that he is acting freely in coming to a decision, this decision has already been predicted by B. MacKay argues that A was correct to believe that he was acting freely, even though he was carrying out the predictions of the omniscient observer. MacKay's point is that if A had been informed of the prediction before his decision, he could have altered his decision and thus falsified the prediction.

For example, MacKay (1967) states:

If the brain were as mechanical as clockwork, no completely detailed present or future description of a man's brain can be equally accurate whether the man believes it or not. (a) It may be accurate *before* he believes it, and then it would automatically be rendered out of date by the brain-changes produced by his believing it; or (b) it might be possible to arrange that the brain-changes produced by his believing it would bring his brain into the state it describes, in which case it must be inaccurate *unless* he believes it, so he would not be in error to *disbelieve* it.

Notice that we are not saying only that the subject cannot *make* or

discover a prediction of his future brain-states, but that there *exists* no definitive prediction that could claim his assent.

MacKay calls this the Principle of Logical Indeterminacy. MacKay (1971*b*) has succinctly summarized his philosophical position on free will as follows.

> Many arguments against free will from deterministic brain theory fail at just their point. Their advocates successfully prove *(ex hypothesi)* that *brains* are not free; but they seem unaware that what was at issue was a different question: namely, whether *people* are free; and that freedom is something it would not even make sense to attribute to brains as physical objects. But, you may ask, does not this create difficulties for the view that the personal story of mental activity and the physical story of brain activity reflect complementary aspects of our human nature? If the stories in "agent-language" and "observer-language" are supposed to be correlates, how can one be deterministic and the other indeterministic? The answer is that if the two were simply *translations* of one another, as in some "identity theories", they could not differ in determinateness; but as *correlates,* even if the correlation were one-to-one, they suffer no such restriction.

In general I find myself in agreement with this summary statement of MacKay on free will. But I have grave misgivings to the effect that this very clever sophistry has side-stepped the central problem of free will because it has avoided any consideration of what is going on in one's brain when one is carrying out an action that has been freely chosen—such as bending a finger in the case illustrated in Figure 5 *intra.* If in willing an action one does not *effectively* influence the patterns of neuronal activity in the cerebral cortex and so bring about the desired discharge of motor pyramidal cells, then free will is an illusion, however subtle the philosophical arguments. Reference should be made to recent critical discussions of MacKay's contribution to the free-will problem (Landsberg and Evans, 1970; Evans and Landsberg, 1972; Watkins, 1971; McDermott, 1972). McDermott (1972) concludes that MacKay "has substituted for the old: 'I'm free because I feel free' the more cumbersome cry: 'I'm free because I know that I don't yet know what I'm going to do.' "

In order to come to grips with this problem of mind–brain interaction it is essential to study as far as possible the recent scientific discoveries on the microstructure and mode of neuronal operation in the neocortex. It will then appear that "cerebroscopes" are magical devices from science fiction—as also are Laplacean intelligences. Furthermore, it is absurd to state that the brain is as "mechanical as clockwork."

STRUCTURAL AND FUNCTIONAL CONCEPTS OF THE CEREBRAL CORTEX

The Modular Concept

Physiological investigations by Mountcastle (1957) on the so-mesthetic cortex and by Hubel and Wiesel (1962) on the visual cortex revealed that the pyramidal cells of small, sharply defined areas exhibited an approximately similar response to specific afferent inputs. The cells were located in cortical zones forming columns orthogonal to the cortical surface. In fact the primary sensory areas are composed of a mosaic of such columns with irregular cross sections averaging about 0.2 mm² in area. Recent investigations by Szentágothai (1969, 1972, 1973), Colonnier (1966, 1968), and Colonnier and Rossignol (1969) have provided important information on this columnar concept by revealing its structural basis. There is now an identification of many specific types of neurones in the columns and of their probable role in the processing of information in respect both of their synaptic connectivities and of their nature as excitatory or inhibitory cells. As a consequence, we are becoming aware that the column is a complex organization of many specific cell types. Szentágothai (1973) therefore develops the concept that, in both structure and function of the cerebral cortex, the column or module is the basic unit. He goes so far as to postulate that the modules are comparable to the integrated microcircuits of electronics (Szentágothai, 1973, personal communication). The modules represent what he calls a basic neurone circuit that in its elemental form is constituted by input channels (afferent fibers), complex neuronal interactions in the module, and output channels, largely the axons of the pyramidal cells. Despite the diversity of the structure obtaining in different regions of the neocortex, Szentágothai (1972) finds five basic similarities:

(1) A fairly uniform principle of lamination, (2) a relatively uniform main cell type: the pyramids, (3) certain characteristic types of interneurons or Golgi 2nd type cells, (4) an essential similarity in the organization of input channels: association afferents, commissural afferents, specific and non- (or less) specific subcortical afferents, and (5) an essential similarity in the organization of the output lines, mainly the axons of pyramid neurons. This gives us the confidence that in spite of obvious differences in detailed structure and even more in connexions with other regions of the CNS, certain "units" of neocortical tissue might be built on the basis of the same fundamental principle, i.e., they might be essentially similar as devices for processing neural information.
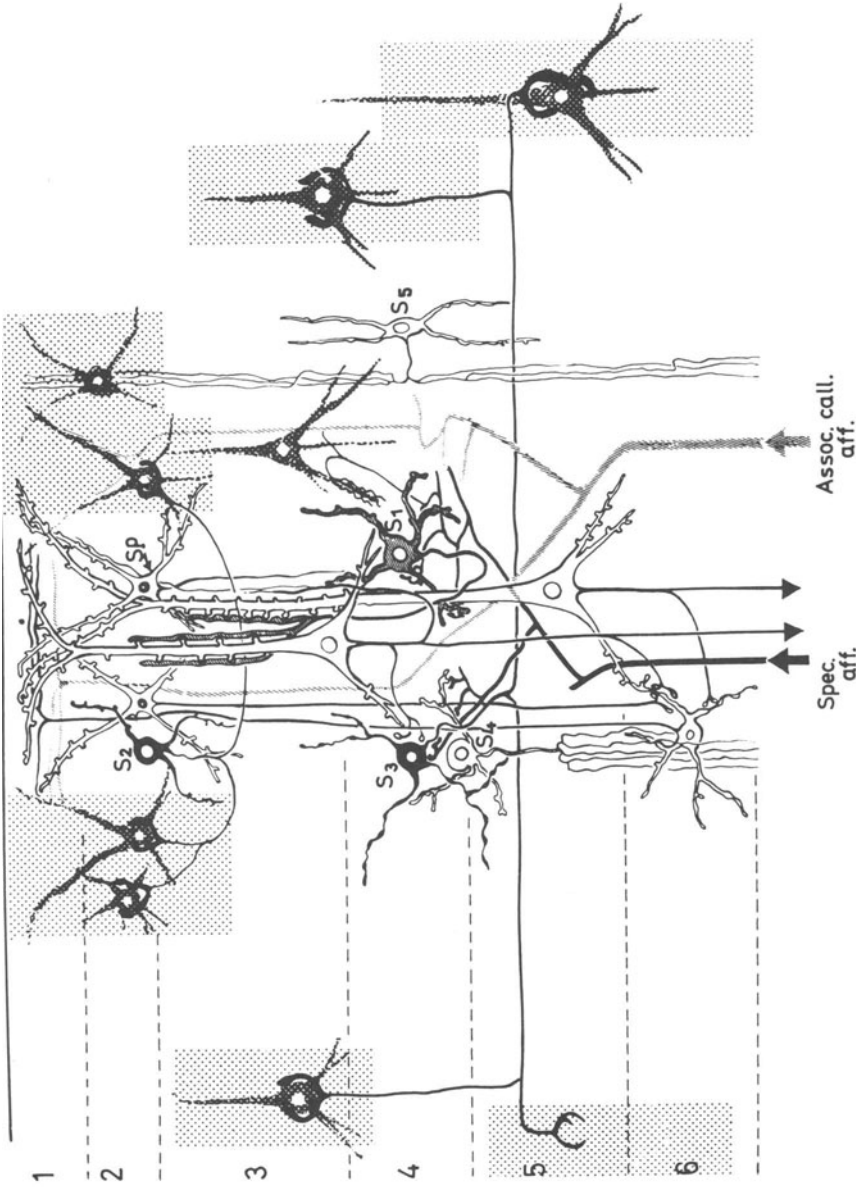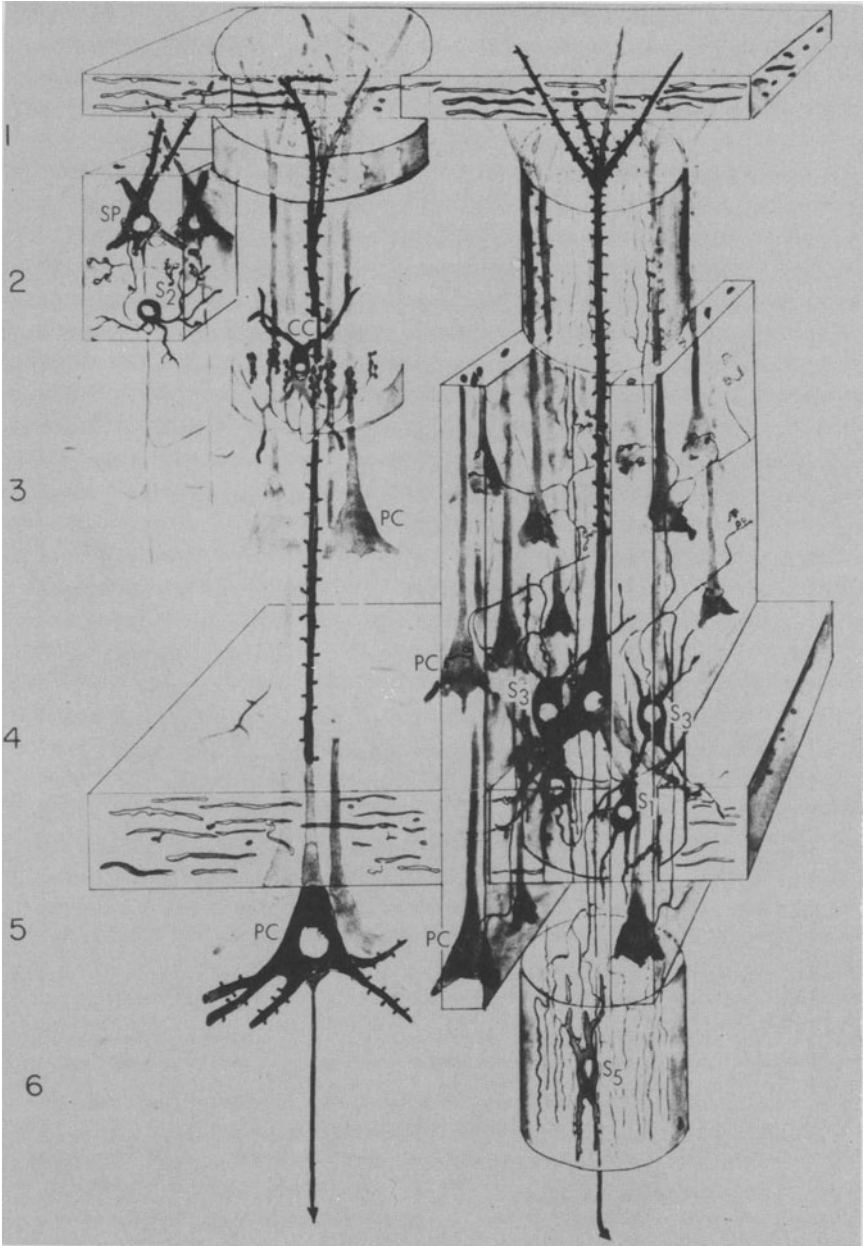
Figure 1. Semidiagrammatic drawing of some cell types of the cerebral cortex with interconnections as discussed in the text. Two pyramidal cells are seen centrally in laminae 3 and 5. The specific afferent fiber is seen to excite a stellate interneurone S_1 (cross-hatched) whose axon establishes cartridge-type synapses on the apical dendrites. The specific afferent fiber also excites a basket-type stellate interneurone S_3 that gives inhibition to pyramidal cells in adjacent columns, as indicated by shading. Another interneurone is shown in lamina 6 with ascending axon, and S_5 is an interneurone also probably concerned in vertical spread of excitation through the whole depth of the cortex (Szentágothai, 1969).

Figure 2. Semidiagrammatic drawing as in Figure 1, but with a more realistic represen-
tation of a column on the right with two vertical inhibitory slabs on either side. Details of
the more superficial laminae are shown to the left. CC is a recently recognized inhibitory
cell, the so-called chandelier cell (Szentágothai, 1972).

Some basic patterns of operations within and around the module are shown diagrammatically in Figures 1 and 2. These figures give greatly simplified pictures of the neuronal composition of a module and its surround. According to Szentágothai there is a major functional subdivision between the neuronal connectivities in laminae 3, 4, and 5 and those in laminae 1 and 2.

Figure 1 shows that in laminae 3, 4, and 5 there are the endings of the specific and nonspecific afferent fibers on the basal dendrites of pyramidal cells, on the dendrites of several species of excitatory interneurones, and on the dendrites of inhibitory interneurones (S_3). Also the association and commissural fibers give branches to cells in the deeper laminae on their way to their principal terminations in laminae 1 and 2 (Heimer, Ebner, & Nauta, 1967). Some of the excitatory neurones (S_1) of lamina 4 (cellule à double bouquet, S_5, of Ramón y Cajal) are powerfully excitatory to the apical dendrites of pyramidal cells by the so-called cartridge type of synapse in which the axon of this Golgi type II cell runs along the dendrites forming hundreds of synapses in a manner comparable to the climbing fiber synapses on Purkyně cells. Other interneurones (not illustrated) more widely distribute their excitatory synapses, both vertically and transversely. Others again (S_4 of Figure 1) are more localized. These last two types give very few synapses to any particular interneurone or pyramidal cell. The convergent action of many is required for an effective excitation. The overall result of the sequences of synaptic excitation by all of these excitatory cells is a powerful excitation of pyramidal cells within the column that is illustrated in Figure 2. There is a kind of amplification process. On the other hand the inhibitory neurones (S_3 in Figure 1 and 2) of laminae III and IV of the module are excited by specific afferents either directly or indirectly by mediation of the excitatory interneurones, and exert their inhibitory influence on pyramidal cells in vertical slabs shown in Figure 2 (Marin-Padilla, 1969, 1970) immediately adjacent to the columnar module, i.e., to the somata of pyramidal cells of laminae 3, 4, and 5 of adjacent modules (cf. Figures 1 and 2). There is convergence of several basket cells onto any one pyramidal cell soma, on which there are 50 to 100 inhibitory synapses (Colonnier and Rossignol, 1969).

In contrast to the powerful localized action of specific afferent fibers in laminae 3, 4, and 5, there is in laminae 1 and 2 the less concentrated action of the other main input lines to the module, the association fibers from other regions of the cortex and commissural fibers of the corpus callosum (cf. Figures 1, 2). These fibers, as well as the ascending axons of the Martinotti type cells of laminae V and VI, branch to form in laminae I and II tangentially running axons which are

up to 5 mm in length for the Martinotti cells. These axons form crossing-over synapses (at about 45° angle) with ascending dendrites of pyramidal cells of the deeper laminae (cf. Figure 1, 2) and also of the star–pyramid cells of laminae 2 (SP in Figure 1, 2). It is assumed that any one afferent fiber exerts such a limited synaptic excitation by these crossing-over synapses that the summation of very many callosal or association fiber inputs is required for effective action. Thus laminae 1 and 2 are zones of diffuse mild excitatory action on pyramidal cells. In addition, in lamina 2 there are small varieties of basket cells (S_2) with a much more limited axonal distribution to the star–pyramidal cells (SP in Figures 1, 2) than occurs for the basket cells of the deeper laminae. This finer pattern of inhibitory action as well as the more diffuse milder excitation of laminae 1 and 2 lead to the postulate that in these superficial laminae there is a mild and fine-grain modulation of pyramidal cells. However, Szentágothai (1972) states that much more systematic study is needed in order to discover if the association and callosal afferents also establish a high level of synaptic connectivity with cells in the deeper laminae, which presumably would be much more limited in tangential spread than occurs in the superficial layers.

These considerations reveal that in the first place the functional uniqueness of a module derives from the limited range of excitatory action by the specific and other afferent fibers—in laminae 3, 4, and 5—no more than 500 μ—and from the powerful and vertically localized excitation by the interneurones (S_1, S_5) giving the cartridge-type synapses. A further defining factor is the inhibitory surround built up by the basket cells in laminae 4. It should be noted in parenthesis that Szentágothai (1972) generalizes from the specific sensory areas to the neocortex in general. One can assume that nonspecific afferents from the thalamus, for example, have the same distribution as the specific afferent in Figure 1. These modules of the neocortex are embedded, as it were, in the much more diffuse and mild excitatory and inhibitory actions of laminae 1 and 2, which span many modules with what we may suppose to be a general modulating influence, though a finer grain may be given by the very localized basket cell action on the star–pyramidal cells of lamina 2.

The excitatory level built up in a module is communicated from moment to moment by the impulse discharge along the association fibers formed by the axons of pyramidal cells and of certain large stellate cells (Szentágothai, 1972). In this way powerful excitation of a module will spread widely and effectively to other modules, but of course principally to laminae 1 and 2 of these modules. Less powerfully excited modules will be less effective in intermodule transmission, and

of course there will be zero action by those modules effectively inhibited by basket-cell action. There is as yet no quantitative data on module operation. However the number of neurones in a module is surprisingly large—up to 10,000, of which there would be some hundreds of pyramidal cells and many hundreds of each of the other species of neurones. Other operative features not mentioned and as yet but little understood are the axon collaterals of pyramidal cells which would give positive feedback circuits. In fact the operation of a module can be imagined as a complex of circuits in parallel with summation by convergence of hundreds of convergent lines onto neurons and, in addition, a mesh of feed-forward and feed-back excitatory and inhibitory lines overpassing the simple neuronal circuitry expressed in Figures 1 and 2. Thus we have to envisage levels of complexity in the operation of a module far beyond anything yet conceived and of a totally different order from any integrated microcircuits of electronics, the analogous systems mentioned earlier. Moreover there will be an enormous range in the output from a module—from high frequency discharges in the hundreds of constituent pyramidal cells to the irregular low-level discharges characteristic of cerebral cortex in the resting state (Evarts, 1964; Moruzzi, 1966; Jung, 1967). The range of projection of the pyramidal cells is enormous—some go only to nearby modules, others are remote association fibers, and yet others are commissural fibers traversing the corpus callosum to areas of the other side, which tend to be in mirror-image relationship.

The Patterns of Module Interaction

Figure 3 is a diagrammatic attempt to illustrate in the limited time span of a fraction of a second the ongoing module to module transmission. It attempts to show the manner in which association fibers from the pyramidal cells in a module can activate other modules by projections of many pyramidal axons in parallel. These other modules in turn project effectively to further modules. In this assumed plan of a small zone of the neocortex the pyramidal cells of the modules are represented as circles, solid or open, according as they participate in one or another class of modality operation, e.g., to one type of sensory input for A and to another for B. Main lines of communication between successive modules are shown by arrows, and there is one example of a return circuit giving a loop for sustained operation in the manner of the closed self-reexciting chains of Lorente de Nó. In addition, convergence
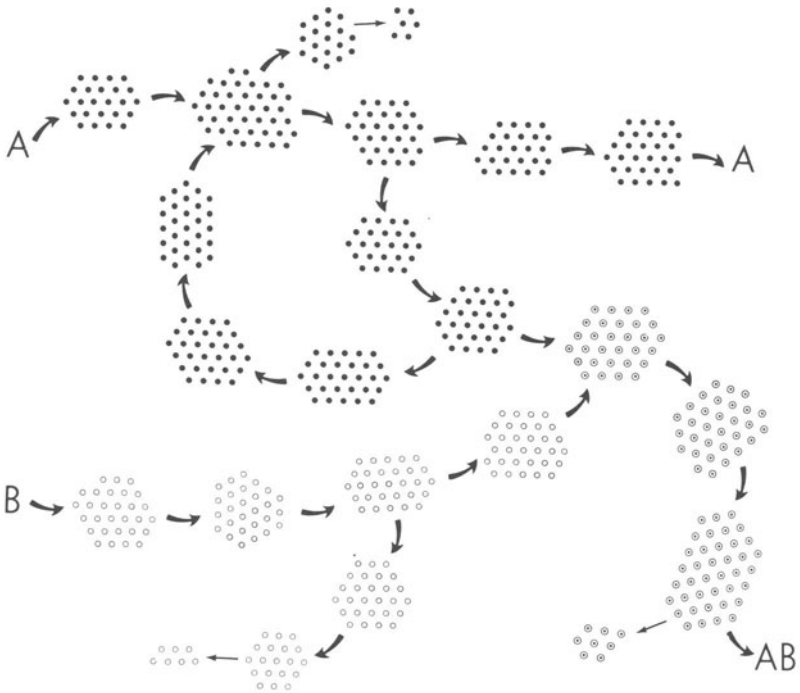
Figure 3.   In this schema of the cerebral cortex looked at from above, the large pyramidal cells are represented as circles, solid or open, that are arranged in clusters, each cluster corresponding to a column as diagrammed in Figure 1, where only two large projecting pyramidal cells are shown of the hundreds that would be in the column. The large arrows symbolize impulse discharges along hundreds of lines in parallel, which are the mode of excitatory communication from column to column. Two inputs, A and B, and two outputs, A and AB, are shown. Further description in text.

of the modules for A and B modalities gives activation of modules by both A and B inputs with a corresponding symbolism—dense-core circles. The diagram is greatly simplified because in it one module at the most projects to two other modules, whereas we may suppose it to be to tens or hundreds. There are three examples where excitation of modules was inadequate for onward propagation. Thus in the diagram two inputs, A and B, give only two outputs, A and AB. Figure 3 represents the kind of patterning of neuronal activation in the cerebral cortex that was imagined by Sherrington (1940). He likened it to "an enchanted loom, weaving a dissolving pattern, always a meaningful pattern, though never an abiding one, a shifting harmony of subpatterns."

The diagram of Figure 3 is particularly inadequate in that there is no representation of the irregular background discharge of all types of cortical neurones. The modular activation and transmission must be imagined as being superimposed upon this ongoing background noise. Effective neuronal activity is ensured when there is in parallel activity of many neurones with approximately similar connections. Signals are in this way lifted out of noise. Thus instead of the simplicity indicated in Figures 1, 2, and 3, we have to envisage an irregular seething activity of the whole assemblages of neurones, the signals being superimposed on this background by phases of collusive activity of neurones in parallel either within modules or between modules.

As Szentágothai (1972) points out, we recognize in the modular concept many species of neurones, each type having its characteristic connectivities both in its synaptic input and output. Furthermore, we can envisage patterns of modular interaction, as in Figure 3. We have progressed far from the quasi-random connectivity postulated by Utley (1955) and Sholl (1956) for the neocortex. This modular structure with all its detailed connectivity would be built by genetic coding and all the secondary instructions, the specific chemical specificities, in a manner as yet only dimly understood in a few special sites in the central nervous system (cf. Sperry, 1971). The more comprehensive connectivities of modules would also be built by similar instructions. All that happens in the learning process is presumed to be changes in microstructure at the synaptic level, particularly in the synapses on dendritic spines which provide the principal sites for excitatory synapses on both pyramidal and stellate cells (cf. Eccles, 1972).

The Unique Areas of the Human Neocortex

Thus far we have been considering the structure and functioning of the mammalian neocortex as studied in a few zones at a level which is still woefully inadequate. The modular concept was developed originally for primary sensory areas, but may now be extended to the whole neocortex on the basis of the finding that the same neuronal species are of general occurrence, particularly the interneurones giving the cartridge type of synapse (Szentágothai, 1972).

The evolution of man's brain from primitive hominids was associated with an amazingly rapid increase in size, from 550 g to 1400 g in a million years. But much more important was the creation of special areas associated with speech. We can well imagine the great evolution-

ary success attending not only the growth of intelligence that accompanied brain size in some exponential relationship, but also the development of language for communication and discussion. In this manner primitive man doubtless achieved great successes in communal hunting and food gathering, and in adapting to the exigencies of life in linguistically planned operations of the community. We now know that special areas of the neocortex were developed for this emerging linguistic performance, which in 98% are in the left cerebral hemisphere (Penfield and Roberts, 1959). Usually (in 80% of brains) there is a considerable enlargement of the planum temporale in the left temporal lobe and in the areas bordering the sulcus in the inferior frontal convolution (Geschwind, 1972), and this enlargement is developed by the 28th week of intrauterine life in preparation for usage some months after birth. Its development represents a very important and unique construction by the genetic instructions provided for building the human brain.

It would appear that the cerebral cortex in the linguistic areas has some unique properties. When the speech areas are damaged in children up to 5 years of age, there is evidence that in some cases there is transfer to mirror areas of the undamaged hemisphere. However this evidence is derived from such doubtful criteria as are provided by the Wada test with intracarotid injection of sodium amytal on each side in turn. There is reliable evidence that in some cases the speech centers are not switched, even with severe damage at birth, as for example in the case reported by Nebes and Sperry (1971). We can envisage that very special cerebral actions would be required in the decoding of the neural signals generated by sounds in order to give meaningful sentences. Unique patterns of neuronal connectivities must have been developed. As yet there have not been any attempts to study the speech centers at an adequate level of electromicroscopy. It would be expected that very special structural and synaptic relationships would have to be evolved for carrying out this neuronal performance at the requisite level of subtlety and complexity; and superimposed on these elemental operations there would be hierarchies of spatiotemporal patterns in an as yet unimaginable manner. It is postulated that, in the speech and related ideational areas of the brain, hierarchies of neuronal performance were evolved in the emergence of man's brain with its transcendent performance in language and ideation. And from this stems the cultural heritage of man that has been the theme of recent philosophical contributions by Popper (1972). He shows that culture can properly be given status in his trialist world, as World 3. World 3 was made by man, and

the World 3 in which he develops makes man in each successive generation.

Furthermore, Sperry's (1968, 1970a, 1970b) investigations on commissurotomy patients have shown that the dominant linguistic hemisphere is uniquely concerned in giving conscious experiences to the subject and in mediating his willed actions. It is not denied that some other consciousness may be associated with the intelligent and learned behavior of the minor hemisphere, but the absence of linguistic or symbolic communication at an adequate level prevents this from being discovered. It is not therefore "self-consciousness." The situation is equivalent to the problem of animal consciousness, to which we should be agnostic.

Figure 4 shows in diagrammatic form the association of linguistic and ideational areas of the dominant hemisphere with the world of conscious experience. Arrows lead from the linguistic and ideational areas of the dominant hemisphere to the conscious self (World 2) that is represented by the circular area above. It must be recognized that Figure 4 is an information-flow diagram and that the superior location adopted for the conscious self is for diagrammatic convenience. It is of course not meant to imply that the conscious self is hovering in space above the dominant hemisphere! It is postulated that in normal subjects activities in the minor hemisphere reach consciousness only after transmission to the dominant hemisphere, which very effectively occurs via the immense impulse traffic in the corpus callosum, as is illustrated in Figure 4 by the numerous arrows. Complementarily, as will be discussed in full later, it is postulated that the neural activities responsible for voluntary actions mediated by the pyramidal tracts normally are generated in the dominant hemisphere by some willed action of the conscious self (see downward arrows in Figure 4). When destined for the left side, there is transmission to the minor hemisphere by the corpus callosum and so to the motor cortex of that hemisphere.

It must be recognized that this transmission in the corpus callosum is not a simple one-way transmission. The 200 million fibers must carry a fantastic wealth of impulse traffic in both directions. In the normal operation of the cerebral hemispheres, activity of any part of a hemisphere is as effectively and rapidly transmitted to the other hemisphere as to another lobe of the same hemisphere. The whole cerebrum thus achieves a most effective unity. It will be appreciated from Figure 4 that section of the corpus callosum gives a unique and complete cleavage of this unity. The neural activities of the minor hemisphere are
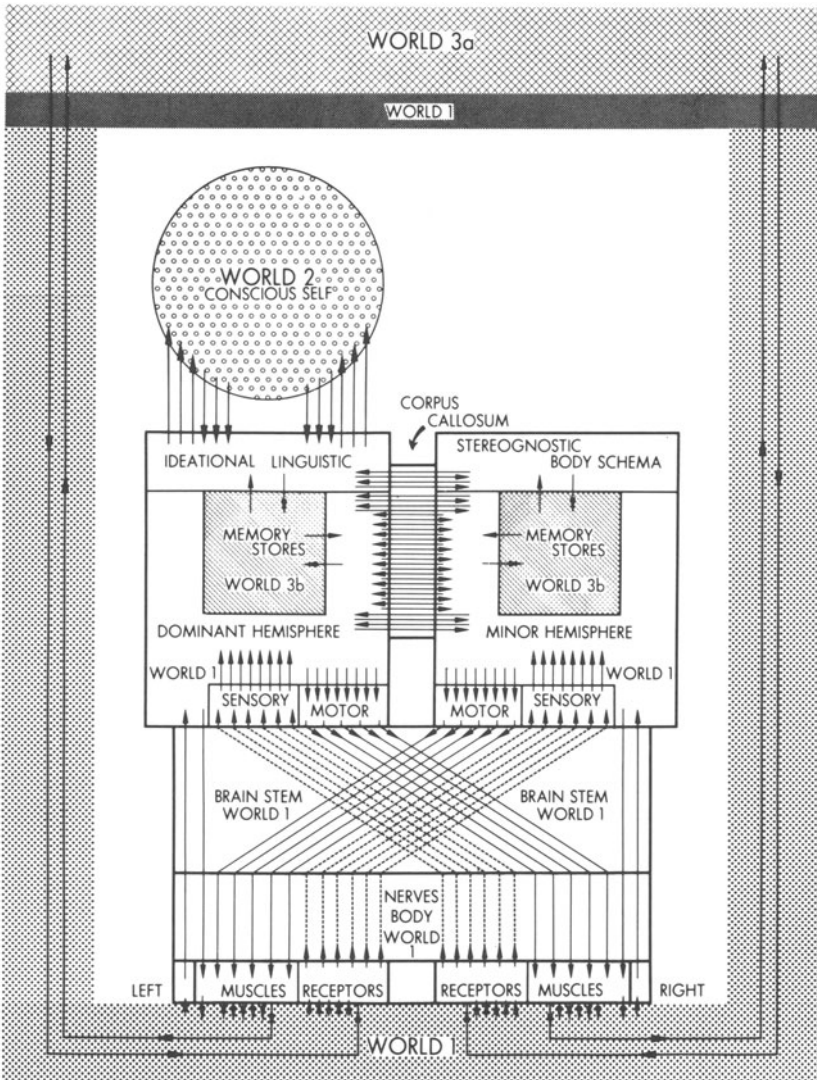
Figure 4. Modes of interaction between hemispheres: Communications to and from the brain and within the brain; diagram to show the principal lines of communication from peripheral receptors to the sensory cortices and so to the cerebral hemispheres. Similarly, the diagram shows the output from the cerebral hemispheres via the motor cortex and so to muscles. Both these systems of pathways are largely crossed as illustrated, but minor uncrossed pathways are also shown. The dominant left hemisphere and minor right hemisphere are labeled, together with some of the properties of these hemispheres. The corpus callosum is shown as a powerful cross-linking of the two hemispheres and, in addition, the diagram displays the modes of interaction between Worlds 1 and 2, as described in the text.

isolated from those cerebral areas that give and receive from the conscious self. The conscious subject is recognizably the same subject or person that existed before the brain-splitting operation and retains the unity of self-consciousness or the mental singleness that he experienced before the operation. However, this unity is at the expense of unconsciousness of all the happenings in the minor (right) hemisphere.

CEREBRAL RESPONSES DURING WILLED ACTION

We are now in a position to consider the experiments of Kornhuber and associates on the electrical potential generated in the cerebral cortex prior to the carrying out of a willed action. The problem is to have an elementally simple movement executed by the subject entirely on his own volition, and yet to have accurate timing in order to average the very small potentials recorded from the surface of the skull. This has been solved by Kornhuber and his associates (Deecke, Scheid, & Kornhuber, 1969; Kornhuber, 1974) who use the onset of the movement to trigger a reverse computation of the potentials up to 2 sec before the onset of the movement. The movement illustrated was a rapid flexion of the right index finger. The subject initiates these movements "at will" at irregular intervals of many seconds. In this way is was possible to average 250 records of the potentials evoked at various sites over the surface of the skull, as shown in Figure 5 for the three upper traces. The slowly rising negative potential, called the *readiness potential*, was observed as a negative wave with unipolar recording over a wide area of the cerebral surface, but there were small positive potentials of similar time course at the most anterior and basal regions. Usually the readiness potential began almost as long as 800 msec before the onset of the movement, and led on to sharper potentials, positive then negative, beginning about 90 ms before the movement. Finally, as shown in the lowest trace, at 50 ms a sharp negativity developed over the area of the motor cortex concerned in the movement, the left precentral hand area in this case. We can assume that the readiness potential is generated by complex patterns of neuronal discharges that eventually project to the appropriate pyramidal cells of the motor cortex and synaptically excite them to discharge, so generating this localized negative wave just preceding the movement.

These experiments at least provide a partial answer to the question: What is happening in my brain at a time when a willed action is in process of being carried out? It can be presumed that during the readiness potential there is a developing specificity of the patterned
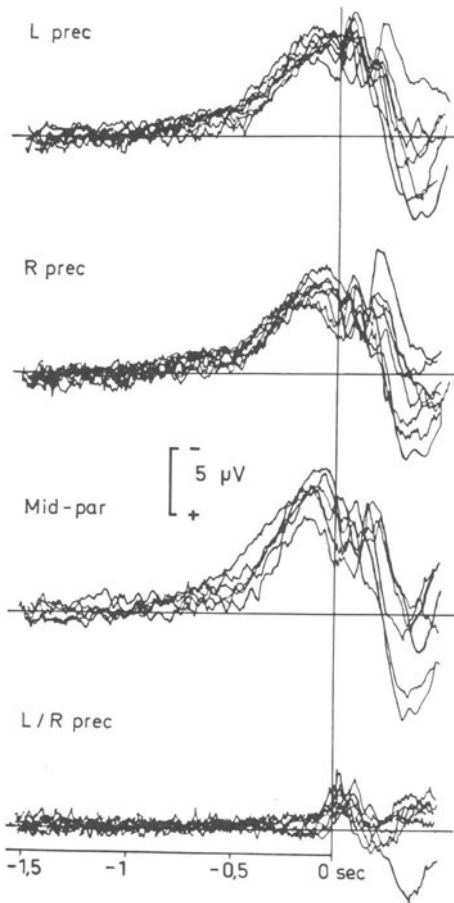
Figure 5. Cerebral potentials, recorded from the human scalp, preceding voluntary rapid flexion movements of the right index finger. The potentials are obtained by the method of reverse analysis. Eight experiments on different days with the same subject; about 1000 movements per experiment. Upper three rows: monopolar recording, with both ears as reference; the lowermost trace is a bipolar record, left versus right precentral hand area. The readiness potential starts about 0.8 sec prior to onset of movement; it is bilateral and widespread over precentral (L. prec, R. prec) and parietal (Mid-par) areas. The premotion positivity, bilateral and widespread, too, starts about 90 msec before onset of movement. The motor potential appears only in the bipolar record (L/R prec); it is unilateral over the left precentral hand area, starting 50 msec prior to onset of movement in the electromyogram (Kornhuber, 1974).

impulse discharges in neurones so that eventually there are activated the correct motor cortical areas for bringing about the required movement. It can be regarded as the neuronal counterpart of the voluntary command. The surprising feature of the readiness potential is its wide extent and gradual build-up. Apparently, at the stage of willing a movement, there is very wide influence on the patterns of neuronal operation, or, as we will consider below, on the patterns of module operation. Eventually this immense neuronal activity concentrates onto the pyramidal cells in the proper zones of the motor cortex for carrying out the required movement. My hypothesis would be that the highly specialized modules in the regions of the brain in liaison with the conscious self (the ideational and linguistic areas of Figure 4) can

function as extremely sensitive detectors of consciously willed influences, at least when they are poised at special levels of activity (cf. Eccles, 1970, Chap. 8). As a consequence, the willing of a movement produces the gradual evolution of neuronal responses over a wide area of frontal and parietal cortices of both sides, so giving the readiness potential. Furthermore, the mental act that we call willing must guide or mold this unimaginably complex neuronal performance of the liaison cortex so that eventually it "homes in" on to the appropriate modules of the motor cortex and brings about discharges of their motor pyramidal cells (cf. Eccles, 1973, Chapters 4, 6).

Free will is often denied on the grounds that you can't explain it, that it involves happenings inexplicable by present-day physics and physiology. To that I reply that our inability may stem from the fact that physics and physiology are still not adequately developed in respect to the immense patterned complexity of neuronal operation that can be imaginatively appreciated to some small degree from the tremendously simplified illustrations of Figures 1, 2, 3, and 4. The subtlety and the immense complexity of the patterns written in space and time by this "enchanted loom" of Sherrington's and the emergent properties of this system are beyond any levels of investigation by physics or physiology at the present time, as I have argued in my book *Facing Reality* (Eccles, 1970)—and perhaps for a long time to come. I would postulate that in the liaison areas these neuronal patterns of module activity are the receiving stations or antennae for the ongoing operations in the consciousness of World 2, as illustrated in Figure 4.

Even after this transmission from World 2 to the liaison brain, we still have to consider the further neuronal pathways thence to the motor cortex. Movements on the right side would result from some complex patterns of neuronal action, first in the liaison areas and then through unknown pathways to the motor cortex, the whole procedure occupying as long as 800 msec as defined by the average duration of the readiness potential. The situation is similar for movements on the left side except that there is in addition the crossing to the minor hemisphere via the corpus callosum. Since the calculated time for such a crossing is no more than 10 msec, motor actions voluntarily carried out by the minor hemisphere carry no more than a negligible temporal penalty. Again it must be recognized that in the ordinary performance of voluntary movements both the minor and dominant hemispheres are involved, and doubtless there is much to-and-fro communication across the corpus callosum during the readiness potential, which in its initial stages is bilateral even during the programming of a strictly unilateral action such as the flexion of one finger.

UNCONSCIOUS ACTIONS EMANATING FROM THE HUMAN CEREBRAL CORTEX

In order to define the special status of actions regarded by the subject as freely initiated by him, reference will be made to two types of actions that are sharply distinguished by the subject.

It has been known for many years that electrical stimulation of the motor cortex of conscious subjects evokes actions which are disowned by the subject. As Penfield reports: "When a subject observes such an action, he remarks, 'that is due to something done to me and is not done by me.'" Evidently a motor action emanating from the motor cortex in response to a voluntary command has some concomitants that are not present when a similar action is artificially evoked from the motor cortex.

The remarkable finding after the operation of sectioning the corpus callosum (Sperry, 1968, 1970a, 1970b) is that all of the actions programmed from the right cerebral hemisphere (the minor hemisphere) are not recognized by the conscious subject as being instituted by him. These actions would, of course, be on the left side, and the left hand is used in the tests. His conscious awareness of actions is restricted to those programmed from the left cerebral hemisphere, though, of course, through his sense organs he is informed, as it were indirectly, of the actions of the left hand that are programmed by the right hemisphere. Strictly speaking, therefore, we can state that the actions effected by the right cerebral hemisphere are unconscious actions.

The conscious subject, who is, recognizably, the same subject that existed before the brain-splitting operation, complains about the left hand, which is, of course programmed from the unconscious right cerebral hemisphere. He makes various statements such as "I cannot work with that hand," that the hand "is numb," that "I just can't feel anything or can't do anything with it," or that "I don't get the message from that hand." If the subjects perform a series of successful trials and correctly retrieve a group of objects which they previously stated they could not feel, and if this contradiction is then pointed out to them, we get comments like "Well, I was just guessing," or "Well, I must have done it unconsciously."

As illustrated in Figure 4, after section of the corpus callosum, there is no neural pathway from the conscious subject via the liaison brain to the right motor cortex. It would be of great interest to investigate the distribution of the readiness potential over the cerebral

hemispheres in commissurotomy patients. It would be predicted that, for willed movements of the right hand, the readiness potential would have a distribution corresponding to its generation only in the left hemisphere. Necessarily the experiment cannot be done when the subject is attempting to carry out willed movements of the left hand. Since these movements do not occur, it is not possible to carry out the recording procedures, which necessitate a backward computation triggered by the initiation of the movement.

These two examples of unconscious actions emanating from the cerebral cortex serve as a reminder that, in a less dramatic manner, the great majority of actions initiated from the human cerebral cortex via the pyramidal tract are not consciously willed—at least in all their diverse details. At most, consciousness comes in to issue general commands for complex actions, the detailed execution being left to the neural machinery of the cerebral cortex with all the ancillary machinery of the brain stem, cerebellum, and spinal cord.

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