

CEREBRAL ACTIVITY AND THE FREEDOM OF THE WILL

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Introduction

I have in my guest lecture given an account of the philosophical position which will form the basis of my discussion. I refer to the trialist philosophy of Sir Karl Popper in which everything in existence or experience is subsumed in one of the three worlds: World 1, the world of physical objects and states; World 2, the world of states of consciousness and subjective knowledge of all kinds; World 3, the world of man-made culture, comprising the whole of objective knowledge.

Fig. 1 indicates the three levels of World 2, outer sense, inner sense and central to these, the self or pure ego which for each of us is the basis of our unity as an experiencing being throughout our whole lifetime.

The ego and the freedom of the will

"An action to be free must be conscious, purposive, follow open alternative choices; and it by no means follows, as empiricist philosophers always maintain, that because it could be otherwise it need be arbitrary, or because it is not mechanically caused, it is not caused at all." (Polten, 1973).

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 moulded 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 counterconditioning -- 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?

The diagram of Fig. 1 gives the basis for defining the postulated mode of operation of free will, which is represented symbolically by the arrows stemming from the pure ego or self. Polten (1973) states:

"The pure ego is the necessary ingredient which changes determination to self-determination or libertarianism. If we did not have such an 'unmoved mover' (and it must be the core of that which makes up the self!) then we could not master our environment with science and technology, as we undeniably do. Far less would it be possible to give ourselves autonomously the moral law, and act with freedom of choice and responsibility. Both technologist and practical moralist can interfere with natural causal chains only because they themselves (i.e., their pure egos) are not pushed along these inexorable sequences; the pure ego rather impinges its own intentions upon the course of nature, and thus utilizes the laws of nature for its own ends. . . . Those who uphold free will need a pure ego, and the meaning and existence of free will has been so notoriously unclear and vexing largely because the meaning

and existence of the pure ego has so far been so unclear. Thus human reflex actions, such as a knee jerk, are unfree because the pure ego is not involved; but conscious thoughts and purposive actions are free because the pure ego directs them."

When discussing causality, Max Planck (1936) made a statement that is relevant in this context.

"The question of free will is one for the individual consciousness to answer: it can be determined only by the ego. The notion of human free will can mean only that the individual feels himself to be free, and whether he does so in fact can be known only to himself."

The neurological problems arising from the postulate of free will

My position is that I have the indubitable experience that by thinking and willing I can control my actions if I so wish, although in normal waking life this prerogative is exercised but seldom. I am not able to give a scientific account of how thought can lead to action, but this failure serves to emphasize the fact that our present physics and physiology are too primitive for this most challenging task of resolving the antinomy between our experiences and the present primitive level of our understanding of brain function. When thought leads to action, I am constrained, as a neuroscientist, to postulate that in some way, completely beyond my understanding, my thinking changes the operative patterns of neuronal activities in my brain. Thinking thus comes to control the discharges of impulses from the pyramidal cells of my motor cortex and so eventually the contractions of my muscles and the behavioural patterns stemming therefrom. A fundamental neurological problem is: how can willing of a muscular

ovement set in train neural events that lead to the discharge of pyramidal cells of the motor cortex and so to activation of the neural pathway that leads to the muscle contraction?

If we have not this ability to exercise a willed or voluntary control over our actions, if we are deluded in this belief, the logical consequences lead to a denial of all personal responsibility for actions no matter how clever the philosophical discussion. Praise or blame become but meaningless noises because all people would be trapped in an inexorable web of cause and effect. To claim freedom of will does not mean that actions are uncaused.-- It means that some are not caused or controlled solely by purely physical events in the neuronal machinery of the brain, ^{that} but the events in this neuronal machinery are to some extent modulated by the self or ego in the mental act of willing. It is postulated that there is a true interaction of the mental and the physical, and that mental events actually are causal agents in their modulating influence on the patterns of neuronal events that lead to the expression of willed movements.

I will not discuss the many philosophical theories that have been developed in order to evade the crucial and fundamental problems raised by the postulate of interaction -- that mental events can effectively interact with brain events both in giving and receiving. The existence of mental states is not denied in these various philosophies, but it is regarded as being ineffective -- a kind of spin-off from the neural events as in parallelism, epiphenomenalism ^{and} even in the more sophisticated version of the psychoneural identity hypothesis (Feigl, 1967). This philosophy is reducible to a materialist monism, but it accepts fully all varieties of conscious experience and explains them as being necessary components or aspects of brain states, there being strictly a

psycho-neural identity. It is postulated that every brain state has its counterpart in a conscious experience, the analogy being that the brain state can be recognized by external observation, and consciousness is the inner experience of that same state. Unfortunately the philosophical formulation is naive with respect to brain states.

I will not embark on a philosophical disputation, but recently there has been a most critical appraisal of the psycho-physical identity hypothesis by Polten (1973) who has demonstrated that it leads to paradoxes and contradictions and so stands refuted. My attack on the hypothesis is based on a consideration of the brain events and of the manner in which the identity hypothesis relates them to consciousness.

We are now in a position to consider the experiments of Kornhuber and associates (Deecke, Scheid and Kornhuber, 1969; Kornhuber, 1973) 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 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 it was possible to average 250 records of the potentials evoked at various sites over the surface of the skull, as shown in Fig. 2 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,

out there were small positive potentials of similar time course over the most anterior and basal regions of the cerebrum. Usually the readiness potential began almost as long as 800 ms 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 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 on to the pyramidal cells in the proper zones of the motor cortex (Fig. 3) for carrying out the required movement. I will later continue with the neurological problems arising from these remarkable experiments.

The unique areas of the cerebral cortex

The evolution of man's brain from primitive hominids was associated with an amazingly rapid increase in size, from 550g to 1400g in a million years. But much more important was the creation of special areas associated with speech. ^(Fig.3) We can well imagine the great evolutionary 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; Wada, 1972); and this enlargement is developed by the 20th week of intra-uterine 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.

Sperry's 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.

Fig. 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) ^(cf. Fig. 1) that is represented by the circular area above. It must be recognized that Fig. 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 Fig. 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 Figs. ^{and 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 hemisphere, 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 Fig. 4 that section of the corpus callosum gives a unique and complete cleavage of this unity. The neural activities of the minor hemisphere are 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.

Structural and functional concepts of the cerebral cortex

The modular concept

Physiological investigations by Mountcastle (1957) on the somesthetic 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 mm^2 in area. Recent investigations by Szentagothai (1969, 1972, 1973) have revealed that the column or module is the basic unit of the cortex and is a complex organization of many specific cell types (Fig. 5, 6). The modules represent what he calls the basic neurone circuits that in elemental form are constituted by input channels (afferent fibers), complex neuronal interactions in the module, and output channels, largely the axons of the pyramidal cells.

*Hungarian
nominal case*

In the first place the functional uniqueness of a module (Fig. 6) derives from the limited range of excitatory action by the specific and other afferent fibers -- in laminae III, IV and V -- no more than

500 μ -- and from the powerful and vertically localized excitation by the interneurons (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 IV. It should be noted in parenthesis that Szentagothai (1972) generalizes from the specific sensory areas to the neocortex in general.

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 (Szentagothai, 1972). In this way powerful excitation of a module will spread widely and effectively to other modules. 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. 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 neurones and in addition a mesh of feed-forward and feed-back excitatory and inhibitory lines overpassing the simple neuronal circuitry expressed in Fig. 5. 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

Fig. 7 is a diagrammatic attempt to illustrate in the limited time span of a fraction of a second the on-going 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 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 3 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. Fig. 7 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 Fig. 7 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 on-going background discharge. 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 Figs. 5, 6 and 7 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.

One can surmise that from the extreme complexity and refinement of its modular organization there must be an unimagined richness of properties in the active cerebral cortex. It is postulated that in situation where the pure ego is operative, there will be changed patterns of modular interaction leading eventually to a change in the spatio-temporal pattern of influences playing upon the pyramidal cells of the motor cortex. The "readiness potential" (Fig. 2) bears witness to this cortical activity preceding the pyramidal tract discharge.

Evidently we have here a fundamental problem that transcends our present neurophysiological concepts. Some tentative suggestions have been made (Eccles, 1953, 1970). It is necessary to take into account the evidence that the pure ego can act on cortical modules only when the cerebral cortex is at a relatively high level of excitation. If the neuronal activity of the cerebral cortex is at too low a level, the liaison between the pure ego and the brain ceases. The subject becomes unconscious as in sleep, anaesthesia, coma. Perception and willed

action are no longer possible. Furthermore, if a large part of the cerebral cortex is in the state of the rigorous driven activity of a convulsive seizure, there is a similar failure of brain-mind liaison. Originally it was suggested that the liaison between mind and brain depended on the "mind influences" being able to modify the discharge of neurones that were critically poised at firing level. In the light of the modular concept a more attractive hypothesis would be that the modules themselves are the detector units for causal input from the pure ego. We may give them a function analogous to radio-receiving units. However, evidence from patients with cerebral lesions reveals that only a special zone of the cerebral cortex would have this modular detector competence. Not only is it restricted to the dominant hemisphere, but it is further restricted to the linguistic and ideational areas as indicated in Fig. 4.

Thus, the neurophysiological hypothesis is that the causal action of the pure ego modifies the spatio-temporal activity in the modules of the liaison zone of the dominant hemisphere. It will be noted that this hypothesis assumes that the pure ego has itself some spatio-temporal patterned character in order to allow it this operative effectiveness.

This concept is closely related to those recently developed by Sperry (1969) who states:

"In the present scheme the author postulates that the conscious phenomena of subjective experience do interact on the brain processes exerting an active causal influence. In this view consciousness is conceived to have a directive role in determining the flow pattern of cerebral excitation."

"Conscious phenomena in this scheme are conceived to interact with and to largely govern the physiochemical and physiological aspects of the brain process. It obviously works the other way round as well, and thus a mutual interaction is conceived between the physiological and the mental properties. Even so, the present interpretation would tend to restore mind to its old prestigious position over matter, in the sense that the mental phenomena are seen to transcend the phenomena of physiology and biochemistry."

Just because World 2 is drawn located above the brain in Figs. 3 and 4, I do not wish to imply that World 2 is floating above the brain and has an autonomous existence and performance independent of the liaison area of the brain! On the contrary it is, so far as we can discover, tightly linked with neuronal activity there. If that stops, unconsciousness supervenes. As shown by the arrows in both directions in Fig. 4, there is an incessant interplay in the interaction between World 2 and the liaison brain, but we know nothing about its nature. This interaction is a tremendous challenge for the future. In this respect we can think of the whole range of psychiatry with such problems as those of the unconscious self, of sleep and dreams, of obsession. Despite our present ignorance of the precise neurological basis of all these problems of the psyche, we can have hope for some clearer understanding because it is now possible to define the liaison areas of the brain, and postulate that only in certain areas and in certain states of the brain does this relationship occur. This insight, limited as it is, provides hope for more understanding in this most fundamental problem.

Fig. 1. World of consciousness. The three postulated components in the world of consciousness together with a tabulated list of their components.

Fig. 2. 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 (Kornhuber and Deecke). 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. (Experiment of W. Becker, L. Deecke, B. Grözinger, and H. H. Kornhuber, presented at the German Physiological Society Meeting 1969, Pflügers Arch Physiol. 312:108).

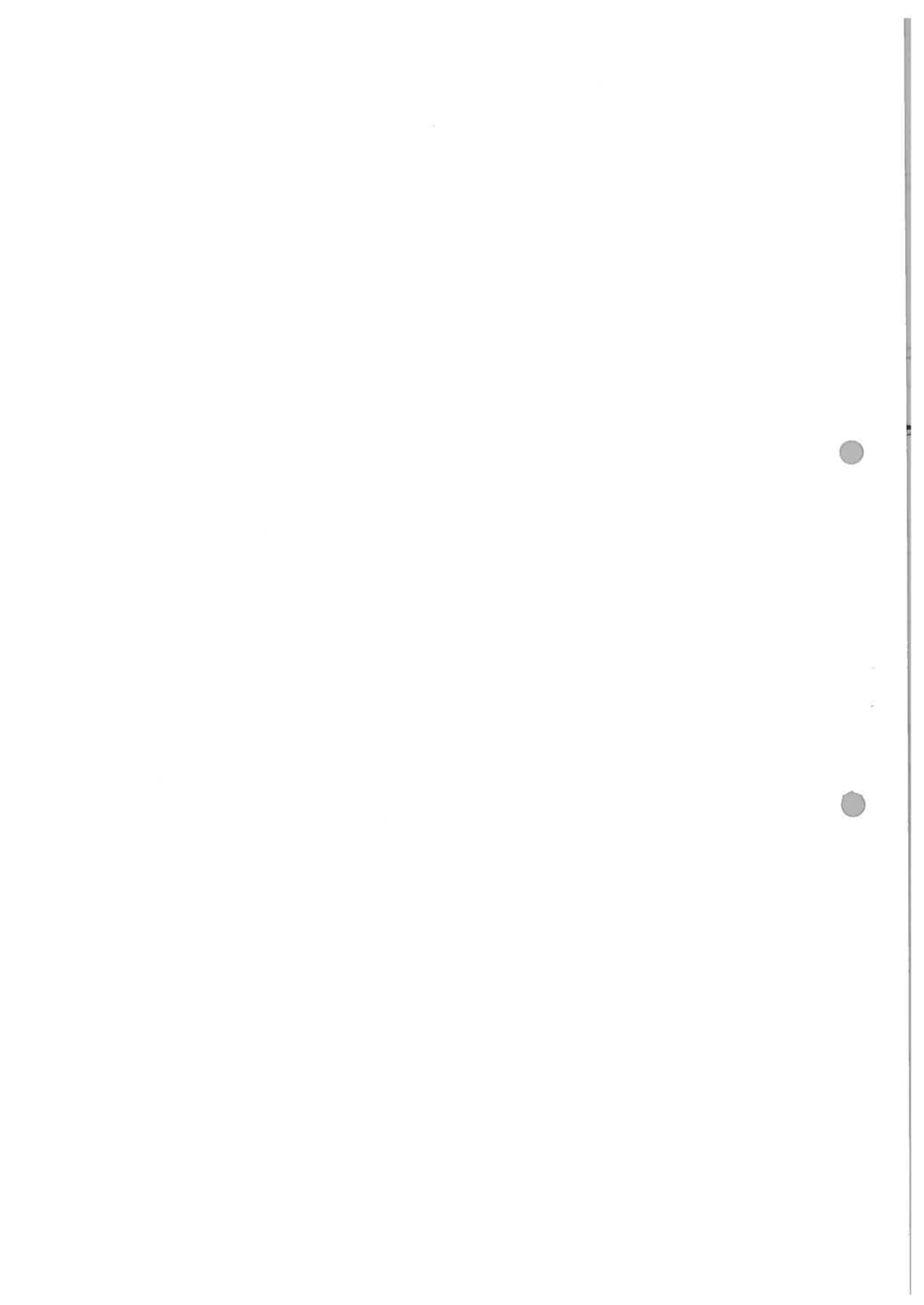
Fig. 3. The motor and sensory transmitting areas of the cerebral cortex. The approximate map of the motor transmitting areas is shown in the precentral gyrus, while the somatic sensory receiving areas are in a similar map in the postcentral gyrus. Other primary sensory areas shown are the visual and auditory, but they are largely in areas screened from this lateral view.

Fig. 4. 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, 2, and 3, as described in the text.

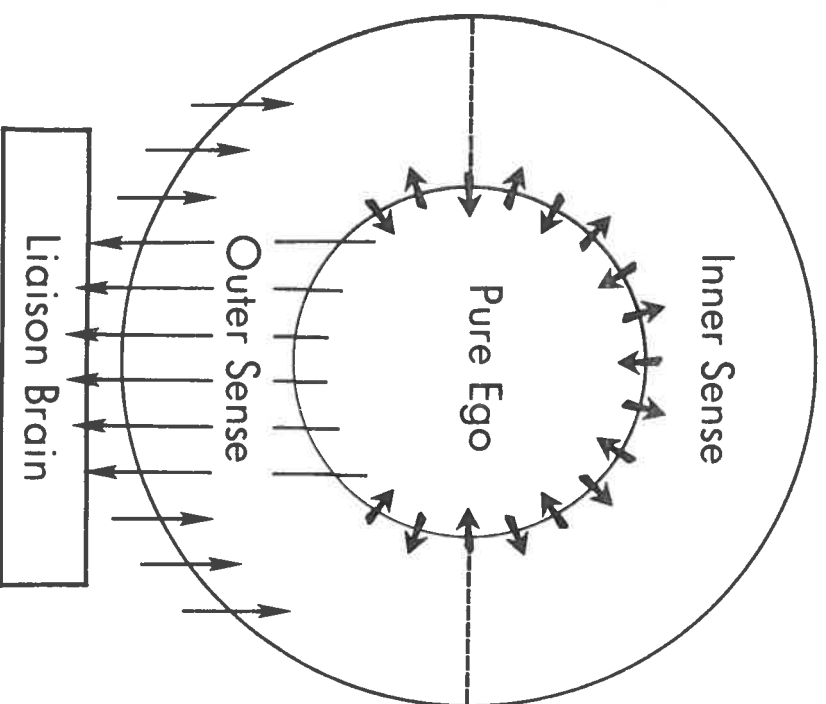
Fig. 5. Semidiagrammatic drawing of some cell types of the cerebral cortex with interconnections as discussed in the text. Two pyramidal cells are seen centrally in laminae 3 and 5. The specific afferent fiber is seen to excite a stellate interneurone S_1 (hatched) whose axon establishes cartridge type synapses on the apical dendrites of the pyramidal cells. 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 (a Martinotti cell) is shown in lamina 6 with ascending axon and S_5 is an interneurone also concerned in vertical spread of excitation through whole depth of the cortex. In layer 2 SP are ^{two}stellate pyramidal cells and S_2 is a locally acting inhibitory basket cell (Szentágothai, 1969).

Fig. 6. A perspective drawing of the cerebral cortex that is specially concerned with showing a column, or module that is partly drawn to the right in approximate dimensions, about 0.5 mm in diameter and 3 mm in depth. On each side are shown two plates of pyramidal cells (PC) that are inhibited by action of the inhibitory (S_3) cells of the column. To the left is shown in lamina 2 a small inhibited "box" with two stellate pyramidal (SP) cells and one locally acting inhibitory cell, S_2 . CC shows a special type of cell, possibly inhibitory, that acts locally on the apical dendrites of pyramidal cells (PC). (Szentágothai, personal communication).

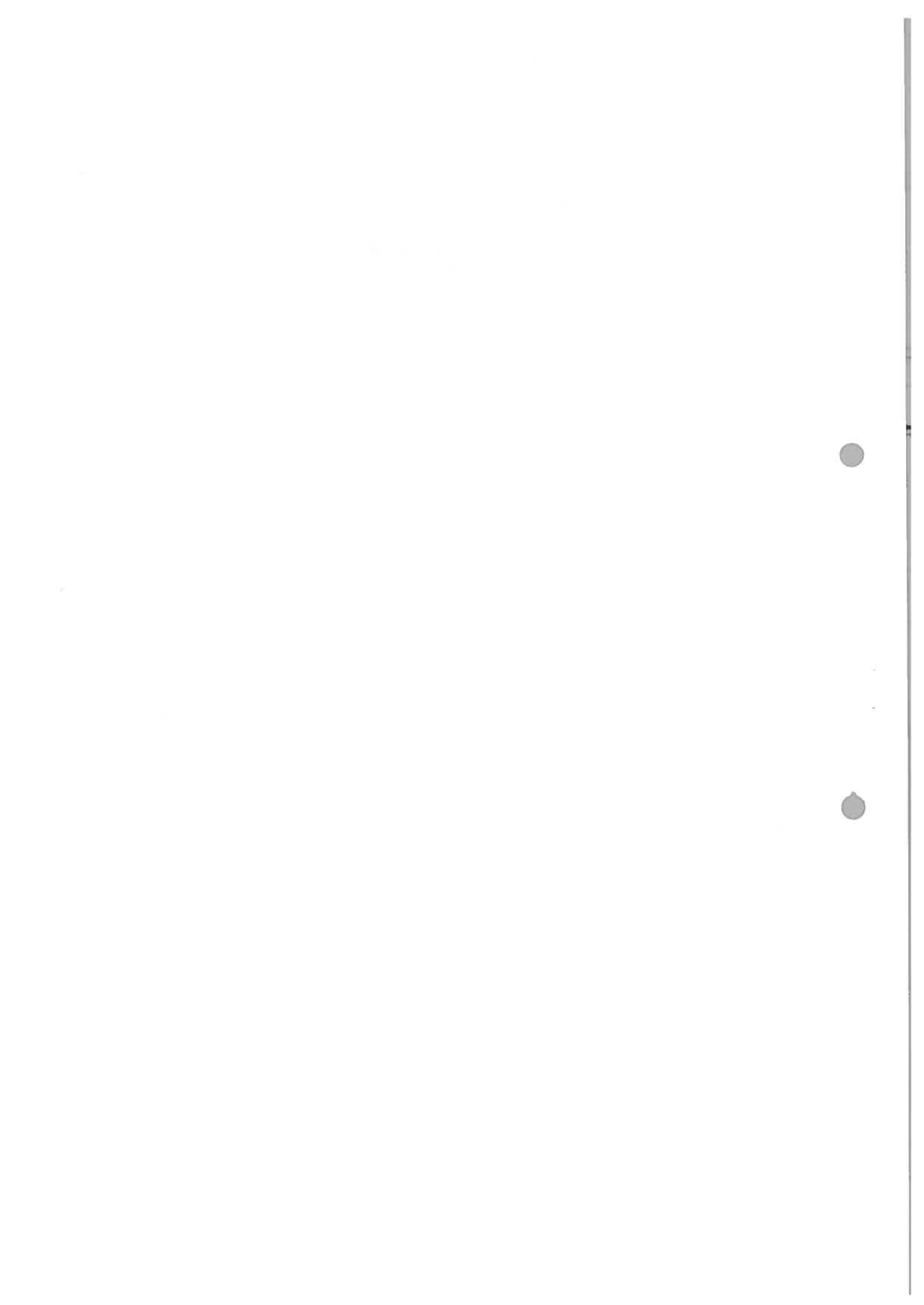
Fig. 7. In this schema of the cerebral cortex looked at from above, the large pyramidal cells are represented as circles, solid or open, that are arranged in clusters, each cluster corresponding to a column or module as diagrammed in Figs. 1, 2, where only ^{a few} large projecting pyramidal cells are shown of the hundreds that would be in the column. The large arrows symbolize impulse discharges along hundreds of axons 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.

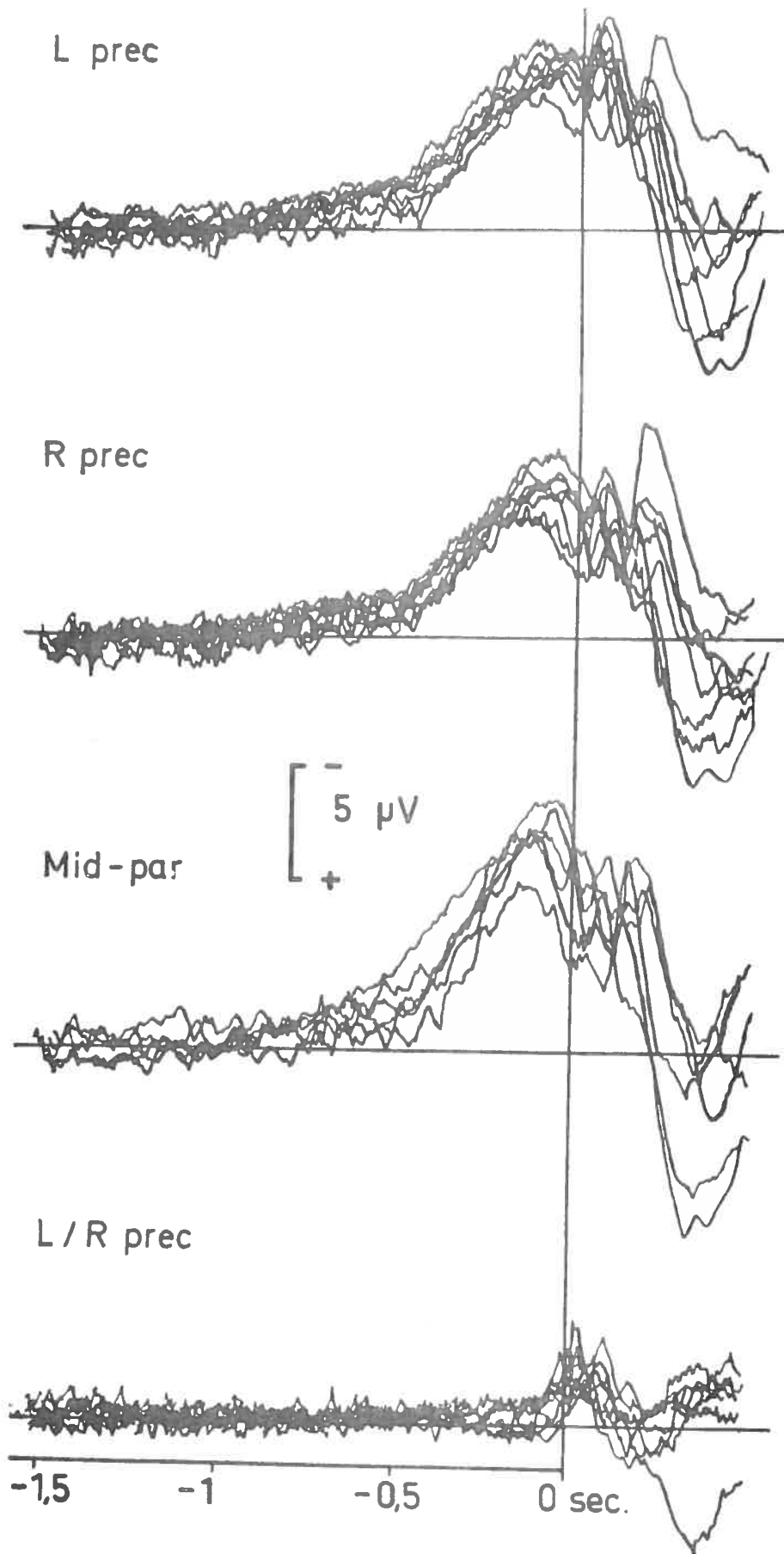


WORLD OF CONSCIOUSNESS

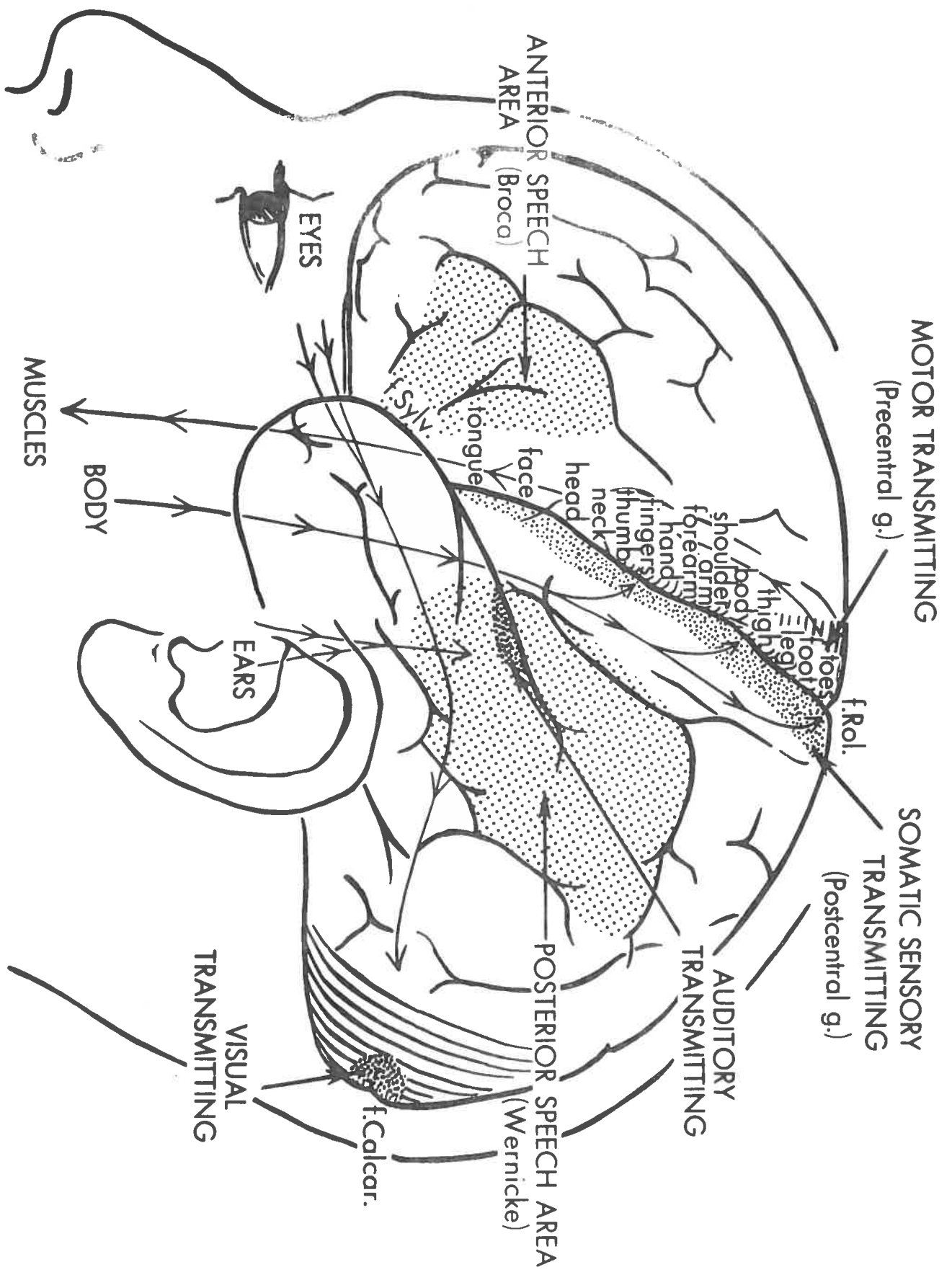


Outer Sense	Inner Sense	Pure Ego
Light Color Sound Smell Taste Pain Touch	Thoughts Feelings Memories Dreams Imaginings Intentions	The self The soul











MODES OF INTERACTION BETWEEN WORLD 1 : WORLD 2 : WORLD 3

