

Scientific Basis of Clinical Practice

Organization of Cerebral Cortex for Perception

S. R. BUTLER

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The pathways by which sensory information is relayed as far as the projection areas of cerebral cortex are relatively well established. We know much less about what happens to the information once it has reached the brain, though the process is important since it results in the perception of meaningful objects in the world around us.

Classically a distinction is made between projection and association areas of the cerebral cortex. Sensory projection areas such as the calcarine and postcentral gyri receive their input from third-order sensory neurons, whereas association areas receive their input from other areas of the cortex or the association nuclei of the thalamus. Even though association cortex does not receive information directly from the sensory pathways, its importance in analysing sensory information is evident from the disturbances of perception which result when it is injured. Lesions in posterior association areas frequently impair the ability to make use of familiar patterns of sensory stimulation or to distinguish new ones. Such perceptual disturbances are distinct from the simple sensory losses which are characteristic of damage to the projection areas.

In any attempt at understanding the organization of cerebral cortex it is tempting to look for an anatomical localization of function. In this way we might expect different aspects of perception to be carried out in different parts of association cortex. The evidence for such a view is not entirely favourable. Very small lesions often produce no symptoms and when the damage is more extensive it seldom affects abilities singly. Further, lesions in a given region may produce different effects in different individuals. It has been argued that perceptual processes may be diffusely represented in the association areas.¹ Since no part would be irrevocably specialized other regions could take over and compensate for a limited amount of damage, and indeed there is often a partial recovery of function in the weeks after experimental cortical ablations. The recovery can be shown to be dependent on postoperative experience, as though the work of lost neurons were being redistributed among those remaining. The facility for this reorganization is referred to as equipotentiality.

The controversy between localization of function and a diffuse, equipotential representation provided much of the excitement in the early years of neurobiology. As with so many debates the truth seems to lie somewhere between the two positions. In animals it is now possible to recognize cells concerned specifically with early steps in visual analysis, and beyond these functionally discrete areas of association cortex; yet within these areas diffuseness and equipotentiality are the rule.

Visual Analysis

Thus in the cat the first step in visual analysis can be observed in and near the projection area itself and takes the form of detecting the contours by which shapes may ultimately be recognized. Recordings of the electrical activity in this region show some cells which respond selectively to the presence of lines and edges oriented at specific angles in the visual fields. Any shape may be defined in terms of many short segments arranged spatially at various angles, and it seems clear that the brain begins to sort out the pattern of excitation on retinal receptors first into groups representing short sections of the whole, and then, perhaps, into groups of these corresponding to complete shapes.

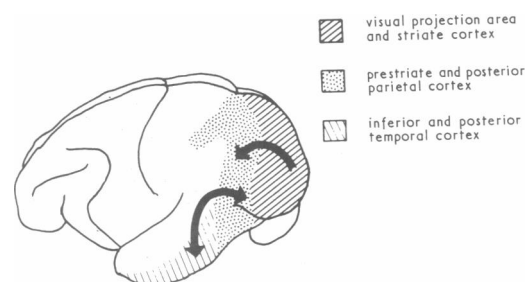


FIG. 1—The shaded areas indicate regions of cerebral cortex important for visual perception in the monkey. Visual information is passed from the projection area across the cortex in the manner suggested by the arrows.

By studying the effects of ablations in animals it is possible to deduce the organization of the association cortex for further steps in the perceptual analysis. This has been best worked out in connexion with vision, and in monkeys two areas seem to be of particular importance: the prestriate and posterior parietal region, and parts of the temporal cortex. Lesions in both these areas interfere with visual discrimination and recognition. Probably the prestriate and posterior parietal cortex are important for distinguishing simple visual patterns and shapes, while the temporal cortex is concerned with the abstraction of more complex features and concepts. It is as though there were a hierarchy in processing visual information, with information being passed from projection area, through prestriate to temporal regions. This spread of information (Fig. 1) from region to region has been shown in the monkey in a series of elegant behavioural experiments² involving combinations of surgical ablations. In man evidence for a similarly hierarchical system comes from stimulating cerebral cortex in the conscious neurosurgical patient. Stimulation evokes progressively more complex images as cells are excited further from the projection areas and into the temporal cortex.^{3 4}

Tactile Discrimination

Similarly there are well-defined regions of cortex essential and specific to tactile discrimination. In the monkey tactile discrimination of shape is selectively impaired by ablation of small areas of parietal cortex, well beyond the primary projection cortex. But, as with visual association areas, representation of function within the region is diffuse, and apparently equipotential. There is no record of a partial lesion impairing the ability to discriminate one shape, for example, while sparing the discrimination of others. At the same time recovery of function after partial ablations is often complete given the appropriate postoperative experience; notably so after prestriate lesions⁵—a fact which caused considerable difficulty in early attempts to define the function of this area.

In man the picture becomes more complex by the inclusion of language among the functions mediated by the association cortex. Language allows a ready exchange of information between sensory modalities. This affects the manner in which sensory information is processed and also enables the patient to compensate to some extent for limited perceptual disabilities. Accordingly, the effects of brain damage become more difficult to fit into a simple theoretical framework and it is hard to recognize the organization of even the visual system in the form it takes in the monkey. The most conspicuous difference in the organization of the system is that language is usually represented in the left cerebral hemisphere, while the other becomes highly specialized for visuospatial perception. This is the case in at least 95% of right-handed people.

The asymmetry was noted during the first half of the 19th century, through the association of left-sided brain damage with aphasia. It became apparent that both receptive and expressive aspects of language were represented in the left hemisphere, which also controls the preferred hand in right-handers. By playing the leading part in both manual and cognitive processes, the left hemisphere earned its title of "dominant," or "major," hemisphere. The term cerebral dominance is still in current usage, though it is now clear that the right hemisphere plays a leading part too, in other types of mental activity.

Effects of Local Lesions

The differences between the organization of the two hemispheres become clearer if we consider the effects of local lesions. Since language depends upon sensory, cognitive as well as motor processes it is not surprising to find aphasias related to lesions in many parts of cerebral cortex. These processes are not always affected simultaneously and so in the sensory aphasias only the ability to read or understand spoken language is disturbed, while the ability to formulate sentences is retained. In these cases the lesion is often located in a part of the association cortex consistent with some degree of localization of perceptual function. Thus in pure word deafness as well as Wernicke's aphasia the inability to understand speech is frequently caused by a lesion in posterior superior temporal cortex, the auditory association area, or its connexions.⁶ Similarly, alexia is associated with lesions in the visual cortex of the occipital lobe.

Lesions of the right hemisphere in right-handers seldom affect linguistic abilities. Instead, the patient is unable to recognize complex patterns or to use visuospatial information. There is some indication that the effect holds for tactile and auditory pattern recognition too. Most of the evidence, however, concerns the performance of visually guided tasks and the causative lesions are frequently in prestriate, posterior parietal, posterior temporal, and inferior temporal cortex—the regions recognized to be important in visual perception in lower primates. Thus the patient may lose the ability to recognize faces (prosopagnosia), to find his way across town, to work machinery or assemble objects in an appropriate

sequence (constructional apraxia), or to recognize inconsistencies in the juxtaposition of familiar objects. These tasks call for analytical processes quite unlike those of the verbal left hemisphere. Just how unsuitable language is for these tasks is evident when one attempts to describe routes and faces; indeed, people employ elaborate strategies to avoid using descriptive language in such matters by drawing maps or by wearing some outstanding clothing which can be described in order to be identified by someone they have not seen before.

Functions of Right Hemisphere

The association between lesions of the right posterior association cortex and visuospatial disturbances is now generally accepted but the functions and organization of the right hemisphere are still something of a mystery. In the first place, there is no consistent relation between specific impairments and the locus of the lesion. Indeed, it has been suggested that the perceptual analysis carried out by the right hemisphere does not lend itself to a localization of function—it calls for the integration of too many sources of information to benefit from local specialization.⁷ Secondly, we cannot be sure that "visuospatial" is an accurate or complete description of what concerns the right hemisphere. Not only may we have missed some important clues, but the effects of cortical damage are not always a reliable pointer to what the injured area did when it was intact.⁸ Accordingly, other, independent techniques are needed to evaluate the nature of the right hemisphere's specialization.

The Waja procedure, involving the injection of amytal into one carotid artery at a time, makes it possible to examine for a few moments the abilities of a single conscious hemisphere. It is used to determine the hemisphere concerned with language in a given individual. It has also been employed to investigate the ability of the right hemisphere to recognise musical patterns,⁹ but it is unsuitable for routine experimental investigation. Tachistoscopic methods involving the brief exposure of pictures in left and right halves of the visual field may be used to compare the efficiency of opposite sides of the brain in comprehending different kinds of visual information, since each half of the visual field is represented in only one cerebral hemisphere—the contralateral one. But the corpus callosum and anterior commissure enable visual information to be exchanged rapidly between the two sides and so far the technique has proved of limited value.

Nevertheless, a unique opportunity to study the abilities of left and right hemispheres separately is provided when the forebrain commissures, including the corpus callosum and anterior commissure are surgically transected in the midline. This operation is performed in California by Professor P. J. Vogel and Dr. J. Bogen to alleviate certain forms of epilepsy. Several of their patients have been studied postoperatively by Professor Roger Sperry and his team at the California Institute of Technology.

ROLE OF COMMISSURES

The forebrain commissures provide pathways for the exchange of perceptual and cognitive information between the two hemispheres. In the absence of these pathways each hemisphere remains in ignorance of the sensory input to its partner. Accordingly, information may be restricted to a single hemisphere by the tachistoscopic presentation of pictures in one half of the visual field or by permitting the patient to touch objects with one hand while they are hidden from view (Figs. 2 and 3). Under these conditions one can examine the ability of each hemisphere separately to perceive different kinds of information.¹⁰

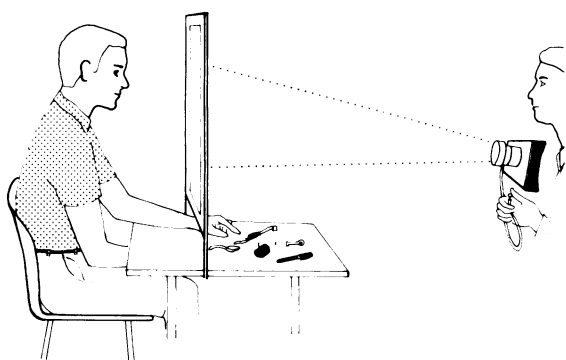


FIG. 2—Images are briefly exposed on the screen to the left or right of a central fixation point. Since each half of the visual field is projected to the contralateral hemisphere alone, information can be restricted to one half of the brain by exposing it on the appropriate half of the screen. The patient can reach under to the screen where he has to identify by touch, and with one hand at a time, objects whose pictures he has seen on the screen.

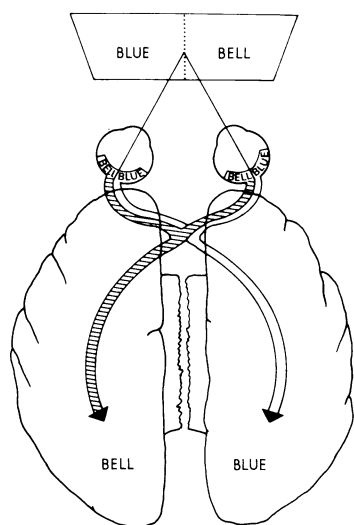


FIG. 3—Information about objects seen in one half of the visual field or felt in one hand is relayed to the contralateral half of the brain. In patients with bisection of the brain each hemisphere is in ignorance of sensory input to the other.

When words are displayed on the tachistoscope screen, the subject can read them aloud only if they are seen in the right half of the visual field—that is, if they reach the left hemisphere. Parts of words which extend across into the left visual field are apparently ignored, so in Fig. 3 the patient would read out only “bell.” Similarly he cannot name objects placed in his left hand. Yet he perceives well enough with the right hemisphere; any object felt with the left hand or seen in the left visual field, can be retrieved when the left hand has to pick it out from a collection of similar items.

Testing a range of abilities in this way shows that the right hemisphere is better at recognizing abstract shapes, both visually and tactually. The patient shows other signs of the differential specialization of the hemispheres. He sketches better with the left hand but has the greatest difficulty copying even simple drawings with the right, often giving up before completing the task. He draws successfully with the right hand only if words are used to help him, such as “Now make a vertical stroke”. At the same time he has lost the ability to write with the left hand, even allowing for its usual clumsiness in right-handers. Thus his reactions to visual images, to tactile information, and his attempts at visually guided manual skills all confirm the differences between left and right hemispheres which were deduced from the effects of cortical lesions.

Not all the findings are in accord with earlier ideas. For example, though the patient may be unable to read aloud

what is presented to the right hemisphere, the words are evidently understood. Objects can be picked out with the left hand when only their names have been seen in left field, and even when phrases are used to describe the object indirectly.¹¹ Paradoxically, the right hemisphere—which is so far superior in the recognition of complex, abstract patterns—is not able to read script. This ability is the province of the left hemisphere, which is not normally very good at recognizing complex patterns.

As the studies of patients with bisected brains progressed it seemed that the right hemisphere was by no means illiterate but limited chiefly by its failure to identify script and to execute orders, of which the instruction to read aloud was only one. It occurred to me that the failure to read aloud or follow commands might indicate not so much an absolute inability, but a higher threshold for initiating action. This would be desirable in any case to avoid conflict in the cerebral control of actions. If that were the case, the right hemisphere might be induced to “get a word in edgeways” if the instructions were persistent enough and the left hemisphere had nothing to talk about or was preoccupied. Accordingly a colleague, Dr. Ulf Norrsell and I designed an experiment¹² in which we presented words in the left visual field for long periods of time—up to half a minute. This was accomplished with the aid of the device shown in Fig. 4. It comprised a pair of spectacles equipped with a lens so that the patient could focus upon a transparency fixed in a holder. Words printed upon

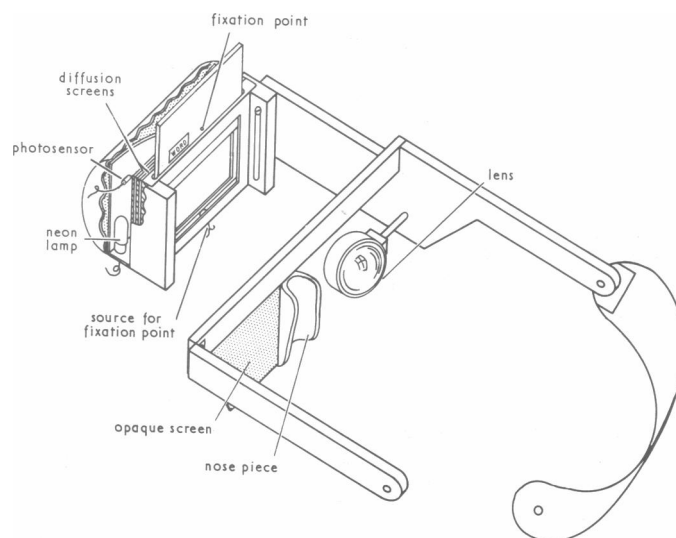


FIG. 4—Spectacle frames carrying the arrangement for exposing visual information to the right hemisphere for long periods of time. A transparency bearing a word to be exposed in the left visual field is shown partially inserted in its holder in front of the light source, which transilluminates it. The slide carries its own fixation point, which remains alight even when the main illumination is extinguished by eye movements to the left. The patient must look at the fixation point or to the right of it to keep the main illumination on.

the transparency were visible only by transillumination from a miniature light source, since the room was in darkness. The direction in which the patient was looking was measured by nystagmography. The recorded signals were used to extinguish the lamp automatically if the word on the transparency came within view of the right visual field. The patient could keep the image alight in his left visual field for long periods simply by looking a few degrees to the right of it. Meanwhile the left hemisphere, seeing nothing, was kept occupied by having the right hand palpate some heavy object.

Under these conditions patients were sometimes able to vocalize letters of the alphabet, numbers, and even the occasional word. This was in contrast to their performance when similar images were presented tachistoscopically. On one occasion a patient began tapping with her left index

finger when the word "tap" was shown on the screen. She could not vocalize the word. Indeed, her left hemisphere had no idea what her left hand was up to in the dark but some excitement had communicated itself, and she said "I'm doing it, Doc. What am I doing?" The interhemispheric transfer of emotional reactions, incidentally, persists in spite of section of the forebrain commissures; thus when erotic pictures are exposed to the right hemisphere, the verbal hemisphere is excited, too, but cannot relate why.

PERCEPTION OF WRITTEN LANGUAGE

In addition to its visuospatial accomplishments, then, the right hemisphere can perceive written language and even act upon it in certain circumstances. If this reflects abilities which are normally held in check by the opposite hemisphere, as our hypothesis predicted, it has a bearing on the prognosis for patients whose aphasia is caused by left-sided lesions. Nevertheless, the results may be interpreted in another way. These patients presented in the first instance with epilepsy, and the associated brain damage may have resulted in an atypical, bilateral distribution of cerebral functions. There is evidence that epileptic lesions in rats result in a reorganization of cerebral function, profoundly modifying the effects of subsequent cortical ablations. The bilateral representation of language in patients with bisection of the brain has not been observed in otherwise healthy individuals in whom the commissural pathways have been traumatically interrupted. Thus, while brain bisection presents a most elegant opportunity to study differences between left and right hemispheres clearly we can extrapolate the findings only with caution.

The phenomenology of perception has been the subject of intensive investigation by psychophysicists and psychologists ever since the emergence of their subject more than a hundred years ago. To the early gestalt psychologist the problems were largely solved by envisaging a representation of the outside

world on the substance of the brain. We now know a great deal about the almost point-to-point representation of receptor fields upon the projection cortex. But clearly the interpretive processes only begin here and we must look to the association cortex to discover the highest levels of perceptual analysis. Our opportunities to gain insight into this system are rare, and more often as a result of malfunction than as chances to observe the system working normally. We are at present attempting to interpret the electrical activity of the normal brain as it appears in the electroencephalogram in terms of perceptual processes in the underlying cerebral cortex. We can already use these techniques to distinguish both the semantic specialisation of the left hemisphere and visuospatial activity in the right.^{13 14}

We hope that techniques like these will enable us to gain further insight into the organization of the brain for perceptual processes.

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Problems of the Newborn

Less Urgent Problems and Minor Abnormalities

DAVID G. VULLIAMY

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Relatively trivial disorders of the newborn infant may be magnified in a mother's mind to cause intense worry and suffering, which often remain unvoiced unless the opportunity is given. Only recently I had to spend some time assuring and reassuring one mother that the minimal webbing of her baby's second and third toes would not cause him to be a permanent cripple. Even when no abnormality is visible there may be an irrational feeling of apprehension about the baby—especially if there is a family history of some disorder in a previous child. Hence the value of carrying out the full neonatal examination

in the mother's presence, so that she may express any doubts or fears and so that any disorder which is found may be put in its right proportion.

In the first few weeks of life the newborn infant continues a process of adjustment to independent existence, which began abruptly at the moment of birth. Some of the problems of this period are due to this incomplete adaptation to the new environment.

The Skin

COLOUR CHANGES AND RASHES

Cyanosis of the hands and feet is often visible in the first few days owing to sluggish peripheral circulation in the skin. It need not signify any abnormality, but since peripheral cyanosis

Dorset County Hospital, Dorchester
DAVID G. VULLIAMY, M.D., F.R.C.P., Consultant Paediatrician