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Chapter VII

PERCEPTION IN THE ABSENCE OF THE NEOCORTICAL COMMISSURES[1]

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The following is centered mainly around some changes produced in visual perception by surgical division of the forebrain commissures in man. Early efforts to correlate visual experience with the underlying cerebral events encountered a major setback when it became known that the optic image on its way to the brain gets split down the middle, one-half being projected to the right hemisphere and the other half to the left hemisphere. The ensuing search for cross-connecting fiber systems that could serve to unite the separate cortical half fields into a single cerebral image still continues.

As our knowledge of the cerebral pathways and centers for vision increases, however, so also it seems does the problem of trying to correlate the experienced unity of visual perception with any underlying unity in cerebral physiology. The same holds for other basic properties of the visual image like its constancy, for example, in the presence of erratic movements of the head and eyes, or its smooth continuity especially that across the vertical midline. The underlying cerebral events do not seem to possess these same kinds of properties. The following observations are concerned with these and related problems.

During the past 6 years through the courtesy of Drs. Philip Vogel and Joseph Bogen of Los Angeles my colleagues and I have had an opportunity to do follow-up behavioral studies on some patients of theirs in whom an extensive midline section of the cerebral commissures had been carried out at the White Memorial Medical Center in Los Angeles in an effort to help control advanced intractable epilepsy. The surgery in all of these patients included complete division of the corpus callosum in its entirety plus complete section also of the smaller anterior and hippocampal commissures. The variable massa intermedia also was divided in several cases where it was seen to be present. All of these sections were carried out in a single operation. The therapeutic outcome continues predominantly good at 5 and 6 years after the surgery in the earlier cases and has been reviewed elsewhere as have also the more general be-

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havioral and numerous neurological symptoms produced by this surgery (1–5, 15–17). Our concern in the following will be focused selectively on those effects that relate to perception. Rather than attempt a comprehensive coverage of the perceptual effects in general, I try to concentrate on some of the main features and recent developments, illustrating these with specific reference to vision and visually guided functions.

What most impresses one at first about the vision of these people after recovery from the surgery is the seeming absence of any visual symptoms so far as ordinary behavior goes. No consistent visual complaints are heard, nor do the patients' comments indicate that they are bothered by or even notice any changes or peculiarities in their visual experience. There is no reference, for example, to any halving or doubling in their vision, nor to any imperfections or irregularities at the vertical midline.

VISUAL SYMPTOMS

In contrast to this deceptive normality under ordinary conditions, marked abnormalities in vision and visually dependent activities are very evident when more rigorous testing conditions are imposed. With controlled visual input, lateralized and directed separately to right and left hemispheres, the patients behave after the surgery as if they now see things through two quite separate and distinct perceiving systems, one in each hemisphere and neither having any conscious connection with the other.

After commissurotomy these patients are unable, for example, to recognize or remember stimulus items that they have just been shown only a moment before when these items are presented in the opposite half of the visual field from which the initial exposure was made. In other words, the usual perceptual transfer that one normally expects to find between left and right halves of the visual field fails with the neocommissures divided. The testing procedure used here requires the patient with one eye covered to fix his gaze on a point near the middle of a projection screen close in front of him, whereupon visual material on 2 × 2 inch slides is flashed tachistoscopically at one-tenth of a second or less to right, to left or to both visual half fields, usually on a prearranged pseudorandom schedule (see fig. VII.1).

Whereas the commissurotomy patients regularly name and describe material that is flashed to the right half field of vision under these conditions, they fail regularly when the same material is presented in the left visual field. When words, numbers, letters, pictures, colors or geometric patterns are exposed in the left half field, with or without a right field stimulus, the subject consistently denies having seen anything on the left side except perhaps a flash of light. In the example shown in figure

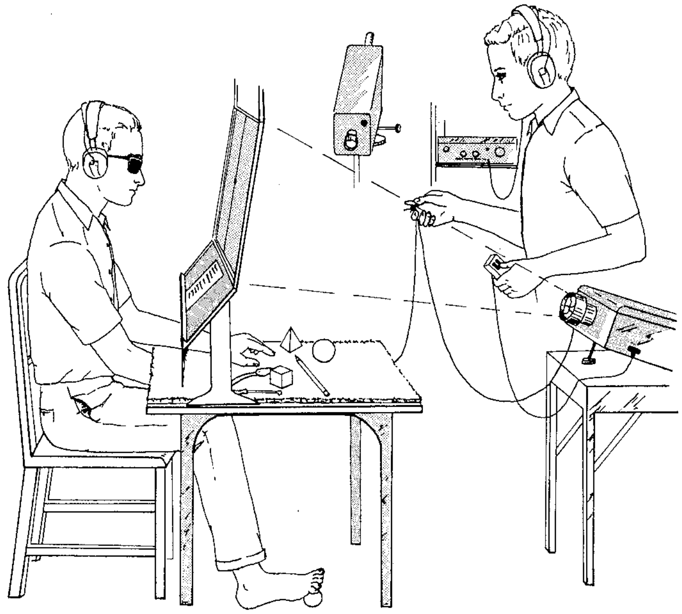

Fig. VII.1. Arrangement of general testing unit used in demonstrating commissurotomy symptoms.

VII.2 if the subject is asked what kind of "band" he has in mind he may answer "rubber," "robber," "rock and roll" or other, but any reference to hatband will be purely coincidental. That is, there is no carry-over here between the left and the right field. The verbal reports obtained under these conditions give the impression that the subjects are almost totally blind in the left half field.

In contradiction to what the patients *tell* us they see, however, good perception of the left field stimuli is demonstrated when we change the testing procedure to utilize nonverbal instead of verbal readout. For example, the commissurotomy patient can select by hand from a collection of test objects the specific item that matches or corresponds to the same left field stimulus that the subject still insists verbally he did not see. If the collection of test objects, instead of being screened from sight, is lined up in full view, the subject can point to the correct item using either hand, in this test, with the help of bilateral orientational cues and because of the considerable ipsilateral as well as contralateral motor control in each hemisphere. When the collection of test items is screened from sight, however, and has to be identified by blind touch, then the left hand must be used with the left visual field and the right hand with the right visual field. Crossed interhemispheric combinations fail and

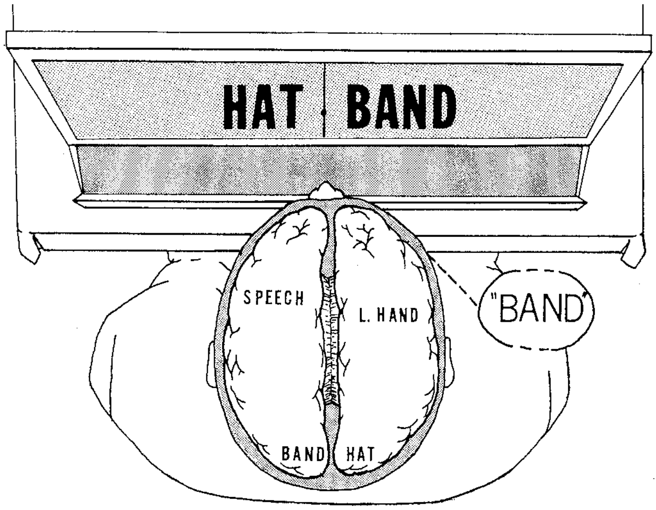

Fig. VII.2. Left and right parts of a word extending across midline are projected into right and left hemispheres respectively.

the same holds for perceptual associations that combine visual with auditory or visual with olfactory input (6, 10).

In the example illustrated in figure VII.3, if the subject is asked at the completion of his response what he has selected and is holding in the left hand, he can only guess with the verbal hemisphere what the other hemisphere has chosen and usually will assume incorrectly that it is the item that was flashed in the right half field of vision. In examining these people, one must always remember that when they talk to you it is the major hemisphere only that is doing the talking and, furthermore, that this talking hemisphere in the absence of the forebrain commissures speaks for itself alone. The talking hemisphere is not in touch with nor party to the perceptual experiences of the opposite minor hemisphere.

Visuomotor combinations proceed on the same principle. That is, intrahemispheric combinations succeed whereas interhemispheric combinations fail. The interhemispheric breakdown is manifest in dyspraxias of hand and finger movements when visual control is lateralized to the hemisphere opposite that containing the primary motor centers for the responding hand. In a nonverbal task that I devised for testing the degree of manual dyspraxia (fig. VII.4) the subject tries to copy with the right or left hand screened from sight, the sample hand poses flashed one at a time to right or left visual field. Gross movements such as opening or closing the whole hand can be achieved through ipsilateral control systems but usually not movements requiring differential posturing of the fingers.

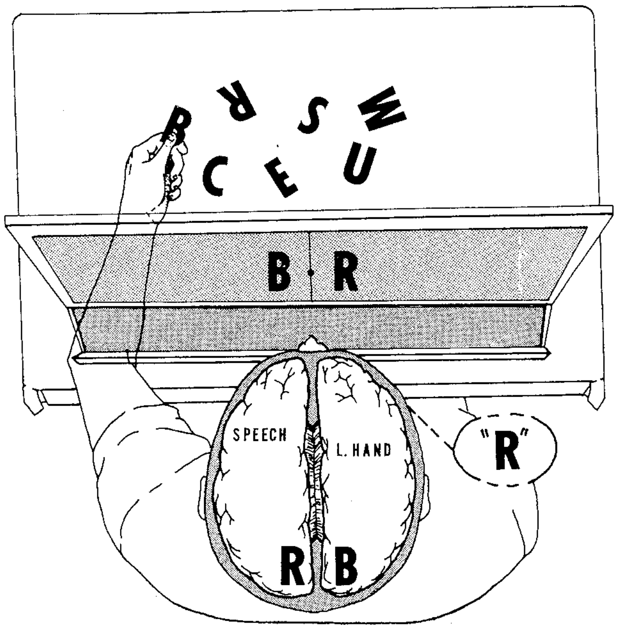

Fig. VII.3. Manual identification of stimuli in left visual field is successful with left hand although subject is unable to name the object.

Double retrieval of two objects simultaneously can be performed with the two hands working in parallel. Each hemisphere is given simultaneously a separate goal object to search for. Pictures of the goal objects may be flashed to the visual half fields, or the objects may be named through auditory instructions via earphones with competing dichotic input, or the objects themselves may be placed in the hands for identification by touch. The two goal objects are then taken and scrambled for tactual retrieval among a collection of other items screened from sight. In searching through the collection of test objects each hand consistently comes up with the stimulus item perceived in its own hemisphere. Frequently one hand will encounter first an object that the subject is searching for with the other hand. If so, the item is simply rejected as incorrect and the same hand goes on searching for its own thing; that is, neither hand seems to know what the other is looking for. It is almost like two separate people searching through the collection of objects with no communication between them. Auditory and other cues, including speech, of course, must be controlled.

These and related findings are summarized schematically in figure VII.5. They all add up to the conclusion that each of the disconnected hemispheres has its own private sensations and perceptions, and

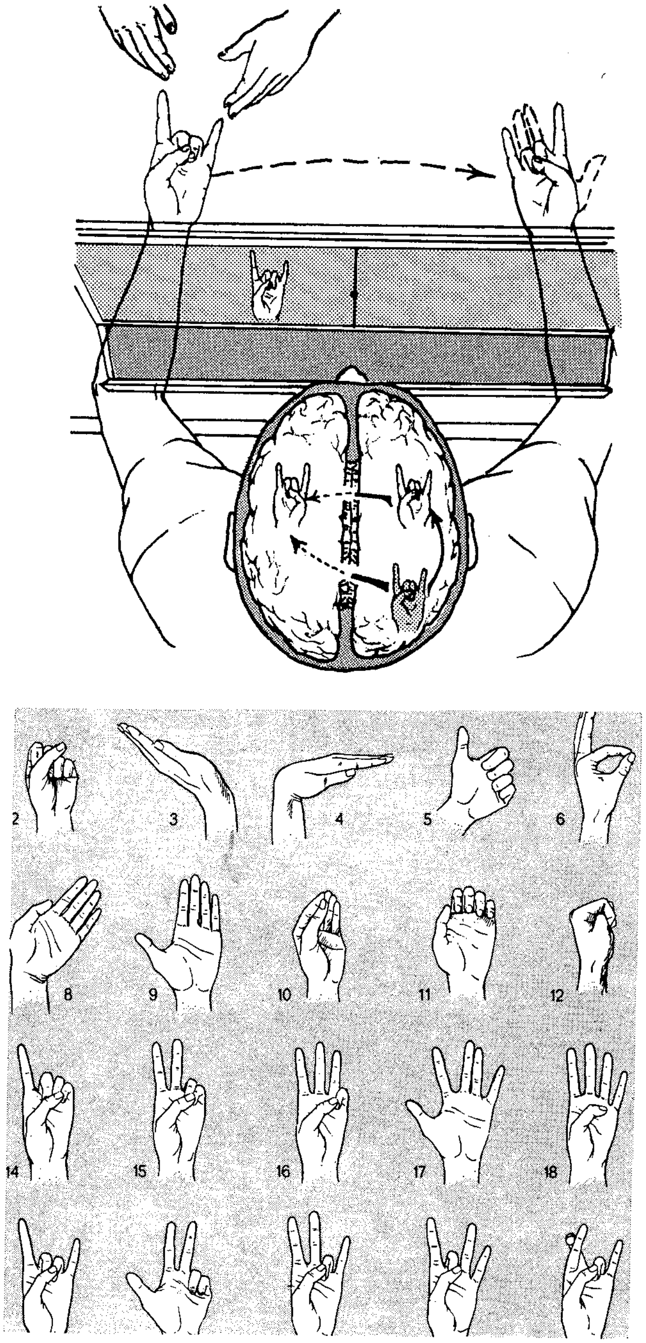

Fig. VII.4. A sample digit pose is flashed in left, right or both visual half fields and subject tries to copy the posture with the homolateral or contralateral hand.

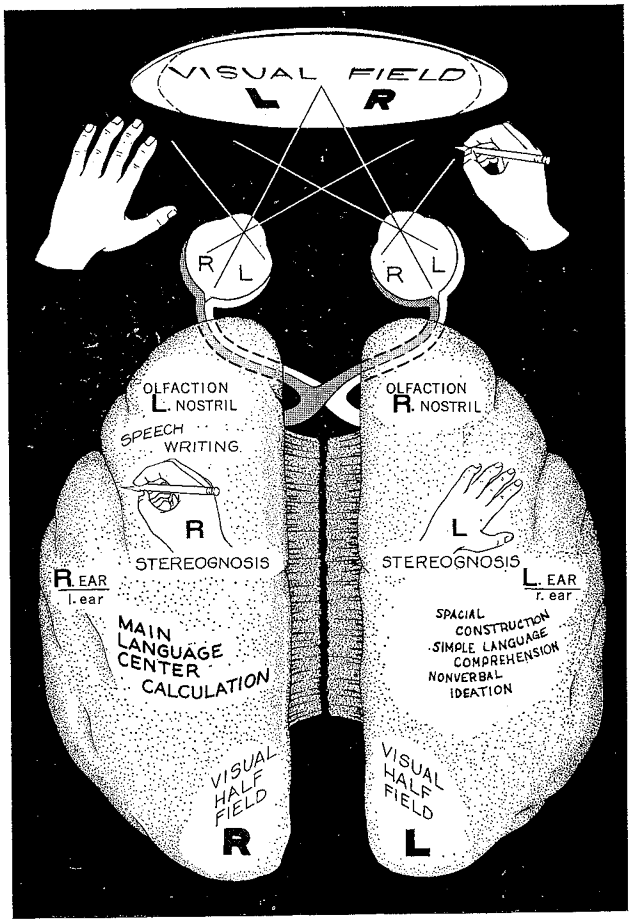

Fig. VII.5. Scheme of functional lateralization demonstrated by separate testing of right and left hemispheres after section of forebrain commissures.

also its own private images and memory, as well as its own mental associations, ideas and other gnostic experiences. Recent observations on the emotional reactions evoked by pleasant and unpleasant olfactory stimuli suggest that the related feelings and emotions also may be included as being lateralized in man by forebrain commissurotomy (6). Apparently the great bulk of conscious experience in man does not descend below the forebrain level, at least it does not seem to cross the midline below this level.

DUAL PERCEPTUAL PROCESS

With respect to visual perception specifically it would seem that these people have not one but two largely separate inner visual worlds, neither of which has any direct conscious awareness of the other, and we can look a little further at this situation wth respect to some possible implications for neural mechanisms in perception. Although each of these visual realms gets its input from only half of a retinal field, scanning movements of the eyes under ordinary conditions of free vision would have the effect of bringing into both hemispheres rather full coverage of the outside scene. From the patient's verbal accounts one would judge that the dominant speaking hemisphere does not notice any incompleteness about its own visual experience, and there is no reason to think any different for the minor hemisphere. Thus the inner visual experience of each hemisphere would seem to be comparable to that of the hemianopic patient with occipital lobe damage or hemispherectomy who has failed to notice the loss of an entire half field of vision until this is brought to his attention by special optic tests. An impression of full visual experience in each hemisphere may be further reinforced by the additional ipsilateral projection into each hemisphere of some of the cruder midbrain components of vision as discussed below.

Consider now the effect for any given object of visual attention that is being examined, not tachistoscopically but with the usual exploratory eye movements. Scanning movements of the eyes from the left to the right edge of a perceived object or a pattern would be sufficient (see figure VII.6) to get the image projected into both hemispheres. The well known constancy of the visual percept in the presence of eye movements along with gestalt completion and closure effects should then further reinforce the development of two full-blown right and left perceptual representations of the same given object in each hemisphere. The right and the left perceptual image would be largely identical to the extent included within the overlap sector of the eye movement span.

This kind of right-left doubling of the perceptual process would seem to be more the rule than the exception for most sensory input, with the notable exception of the limb extremities, perhaps, that seem to lack bilateral representation. The functional value of this extreme right-left redundancy in perceptual activity is not entirely clear, although one can see a possible basis for it in the differential processing of these percepts in the right and the left hemispheres that is considered in another context below.

In respect to the role of the normally intact corpus callosum in this situation, it would seem that information carried by the corpus callosum would serve to further enhance and complete the forementioned right-left reduplication in the perceptual machinery. For example, cues from the ipsilateral half field of vision passed across through the callosum from the prestriate to prestriate cortex should help to complete the whole

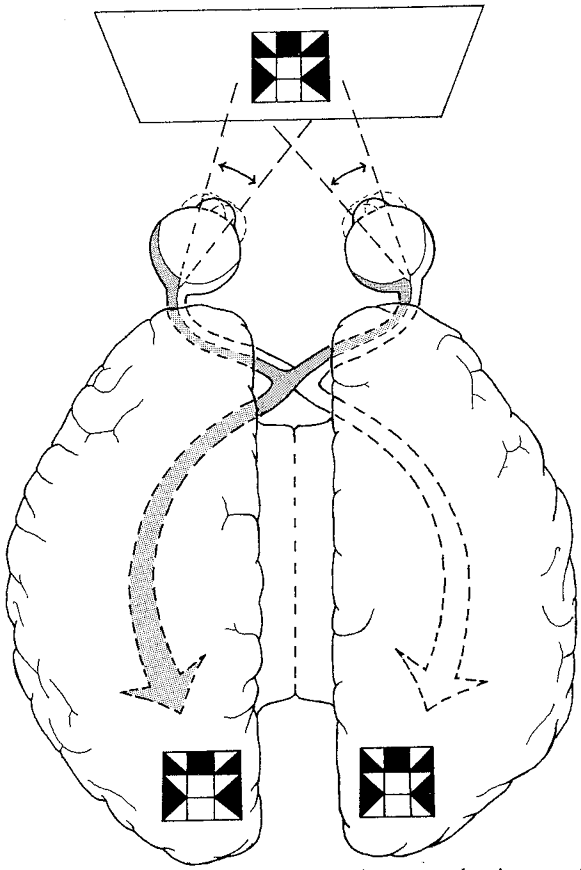

Fig. VII.6. Through scanning movements of the eyes, the image of an object of visual examination may be projected in full to both hemispheres.

visual scene or its image within both hemispheres. Similarly, in bimanual identification of an object or its surface through stereognosis the corpus callosum would appear to carry cues from the ipsilateral hand in each direction, thereby bringing together the full supply of information from both hands into both hemispheres.

It has been proposed recently (11) that proneness to right-left mirror image errors in behavior, as occurs frequently for example in dyslexia, may be explained by the fact that the half of the visual field transmitted indirectly to a hemisphere via the corpus callosum is a mirror image reversal of the same pattern projected directly from the lateral geniculate nucleus. This interpretation presumes a bisymmetric, homotopic rather than a complemental pattern for callosal integration (13) and ignores the effect of eye movements. Equally plausible behavioral explanations for the phenomenon should be ruled out before remedial reading clinics begin to make investments in this simplistic anatomical interpretation.

AGENESIS OF CORPUS CALLOSUM

In a recent study Dr. Ronald Saul and I ran a series of perceptual and related tests for right-left cross-integration on a 19-year-old girl diagnosed to have a complete congenital absence of the corpus callosum (12). This was one of those very rare "asymptomatic" cases that usually are not discovered until autopsy, and who in this case for 19 years had been presumed by herself and her family to have been entirely normal. Her condition was discovered when X-rays were taken following an attack of severe headaches later attributed to an acute hydrocephalus that responded promptly to treatment. At present she is a sophomore in college maintaining an average scholastic record of C+ or so.

During the past year we put this person through the entire battery of tests that we had worked out in the laboratory for detecting basic cross-integrational deficits in the commissurotomy patients. The tests were similar to those described above for vision but extended into somesthetic, auditory, olfactory, motor, verbal and various transmodal functions (15–17). To make a long story short she performed throughout essentially like normal controls exhibiting none of the impairments that remain prominent in the surgical patients 4 to 7 years after the surgery. This is a tribute of course to the much greater functional plasticity of the still developing, still growing nervous system as compared to the fully grown mature system.

She could read words presented in either left or right visual half fields, for example, and did so promptly with no hesitation. This was true also for words that extended across the vertical meridian. I arranged lists of words that contained many syllables in common such that one could not guess the whole word from the syllables that fell in either half field alone. In many cases even the pronunciation of the syllables falling in either field depended on integration with those across the midline.

With the idea that it might be possible to separate a direct projection of one half field, from a weaker ipsilateral projection of the other, we had the subject perform these word reading tasks with small thin letters at a distance close to her acuity threshold. Even under these conditions, her responses with the divided input were as good as for those with the unified input to either half field alone and were of the same order as for normal controls. Similarly she was able to read off promptly the sum or the product of two numerals flashed simultaneously into right and left fields. The contrast between her performance and that of the surgical patients was most striking throughout the entire battery of tests.

We still lack any satisfactory explanation for the very remarkable degree of functional compensation seen in this agenesis patient. The anterior commissure appears to be present and perhaps slightly enlarged but it is difficult to imagine one hemisphere reading word syllables from the other through the anterior commissure at the level exhibited in the above tests. The most promising explanation that I can see at present is in terms of a developmental elaboration, reinforced by function, of the ipsilateral sensory, motor and associated systems of the brain. These ipsilateral systems normally are weak by comparison with the main contralateral systems, but they are known to be potentiated by conditions like brain damage at birth.

The presence of some ipsilateral projection in the visual pathways is indicated in the ability of patients with commissurotomy to verbalize some of the more gross and crude aspects of visual stimuli presented in the left half field of vision. Nearly all of the commissurotomy subjects have been able to report the onset or offset of a light and some of its cruder variables, like larger or smaller, brighter or dimmer, for gross size and intensity changes. Tests for transfer of static color have given ambiguous results, but more recently Trevarthen and I (19) have found that color and other features of vision may transfer in the split brain subject at a higher level when presented with movement and in the peripheral field. This accords with Trevarthen's concept of midbrain mediation of ambient vision (18) and favors the possibility that ipsilateral information reaching the cortex from midbrain centers and extrageniculate pathways might undergo compensatory development under the conditions of agenesis of the corpus callosum.

CALLOSAL FUNCTIONS NOT COMPENSATED

There is another side to this story, however, in that functional compensation seems not be have been achieved in certain other respects. Results of additional tests aimed at different kinds of activity including more general, complex and abstract mental functions suggest that the absence of the callosum in this person remains in many activities a definite handicap not successfully compensated. This college sophomore is not an exception to the general doctrine that persons with agenesis of the callosum do not, at best, develop more than a mediocre intellect. She is in the city, not state, college system and is majoring in something that demands no more than average intelligence.

A distinction in the functions of the corpus callosum is thus pointed up here between those functions that can, and those that cannot, be compensated for under the conditions of its total agenesis. In the later category I tentatively include that class of higher functions that is associated with cerebral dominance and lateral specialization of function in the human brain. These "noncompensatables" are largely, perhaps uniquely, human functions of the neocortical commissures and especially those that involve cooperation between qualitatively specialized mental faculties on the right and left sides.

The resultant deficits show up in the agenesis case in her performance on block design tasks, in drawing and in working spatial puzzles. Although she scores above normal in verbal reasoning, she is very low in nonverbal reasoning. She is also poor in mathematics, particularly so in geometry, and has trouble with geography. As in agenesis patients studied by Jeeves (7), her scores are subnormal in a variety of perceptuomotor tasks like stringing beads, putting pegs in holes with forceps and buttoning clothes, all scored for speed. All the foregoing can be inferred to be dependent on functions that seem to be specialties of the minor hemisphere in the highly specialized skilled brain. The subnormal achievement in the foregoing activities is to be contrasted with the above normal verbal score of 112 on the Wechsler's Adult Intelligence Scale "I.Q." test.

The verbal functions thus seem to be favored in at least one, and possibly both, hemispheres in this person. It follows that the nonverbal minor hemisphere faculties must accordingly remain either underdeveloped, through having to share a hemisphere committed primarily to verbal performance, or poorly integrated with the other hemisphere for lack of the corpus callosum. Either way, the person with agenesis of the callosum is bound to be handicapped on these terms.

Much of the same reasoning applies, also, to the commissurotomy patients. Studies in progress along with many incidental observations indicate that the same functional syndrome that we see in the agenesis patient is present also, in exaggerated form, in the surgical patients. They too show marked impairment in nonlateralized unrestricted performances on the same kinds of perceptuomotor, nonverbal and spatially oriented tasks. Their achievement is markedly impaired on tests involving deductive reasoning, maze learning, digit span, arithmetical problem solving, drawing, recent memory, topographic perception and orientation, picture completion and logical arrangement. By contrast they tend to be near average on tests for vocabulary, digit symbol association, simple calculation, object assembly, and in immediate and remote memory, reading and writing.

Thus the syndrome of the neocortical commissures, the very existence of which in any form was long in doubt, still continues to grow in ever-increasing complexity the more that we look at it. No doubt remains today that two hemispheres are "good for you" and that two hemispheres united are better than two hemispheres divided.

New evidence for differential perceptual and cognitive capacities in right and left hemispheres has been found recently by Levy-Agresti (8, 9). A modification of the Space Relations subtest of the Differential Aptitude Tests was designed to include transmodal transformations in a form that could be administered to the surgically separated hemispheres. The results show a distinct superiority of the disconnected minor over the major hemisphere. Basic qualitative differences are also suggested in the kinds of perceptual processes present in right and left hemispheres and in the associated reasoning techniques and performance strategies employed by the verbal and the nonverbal hemisphere. The one is described as being verbal, sequential, detailed, analytic and computer-like; the other, non-verbal, synthetic, coherent and spatial.

The test involved presentation of a wooden block, unseen into right or left hand for identification through stereognosis by left or right hemisphere respectively. Different blocks were of different shapes and had special features like grooves, holes and sandpaper surfaces placed in distinguishing positions. The subject had to mentally unfold the tactual percept of the block in the hand and visualize what the block would look like as an unfolded two-dimensional pattern in order to select on a card exposed in free vision the one of three similar such patterns matching exactly the block in the hand. Thirteen cards were included each with a set of three similar but different blocks. There was evidence in the results for the presence of interference effects between the two different performance techniques and this has been advanced as a possible primary factor behind the evolution of cerebral dominance and lateral specialization. A significant operational advantage can be seen to having the two different methods for processing sensory information set off in separate hemispheres.

MODIFIED CONCEPT OF CONSCIOUSNESS

Another thing to come out of all this, that perhaps is as important with respect to perception as any of the foregoing, is a modified concept of the nature of mind and consciousness. In the course of trying to deal with questions concerning the quality and the distribution of conscious awareness in the split brain, I find that my interpretation of consciousness has gradually undergone a considerable swing back in the direction of mentalism to settle on a view that is at least distinctly different from the conventional materialist approach on which most of us in behavioral research have been raised in this century.

This is a view that postulates the presence in the brain of mental as well as physiological forces, and contends further that the phenomena of conscious awareness play an important active role in shaping and directing the flow pattern of cerebral excitation (14). 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.

Let me try to spell out these statements just a little further now to see if they can be made at least remotely convincing. In brain research we customarily visualize an ebb and flow of excitation in which one set of electrophysicochemical events leads to the next and so on. That this causal sequence is in any way influenced by conscious or mental forces is violently resisted, of course, by most brain researchers. It is the working faith in neuroscience that a full explanation of brain activity can be found in the analysis of nerve impulse traffic and related neural events with no reference to conscious phenomena being necessary.

Thus excluded from an active role in the material brain process, conscious experience gets relegated by many in experimental neurology to the status of an epi- or paraphenomenon of some sort that is supposed to run along in parallel with the material process but not to act back upon it. These epiphenomena are noninterventionist. Other researchers alternatively prefer to regard conscious experience as a kind of "inner aspect" of the physiological action. In this interpretation, consciousness represents the inside, subjective, owner's view of the one single brain process. Either way, it is generally agreed that the introspective conscious qualities do not interact as causal agents in brain physiology and hence can be safely ignored in any objective scientific explanation or model. "Consciousness is passive" we are told. "It doesn't *do* anything." Hence we can forget it; or, in the stance of electrophysiology, "Who needs it!"

This kind of thinking is directly contradicted in our present view in which the reverse contention is advanced, namely, that consciousness does do things and that it is highly functional as an important component of the causal sequence in higher level reactions. This is a view that puts consciousness to work. It gives the phenomena of consciousness a use and a reason for being and for having been evolved.

In the present interpretation the subjective phenomena of conscious experience are conceived to be direct emergent properties of brain excitation, inseparable from the brain process and its structural constraints, but nevertheless different from and more than the sum of the electrophysicochemical and physiological activities. The mental as opposed to the elementary analytic properties of the cerebral process are conceived to be more molar. They are holistic, configurational, gestalt, encompassing and entitive in nature. Because they also are dynamic, not static, properties of the cerebral circuitry in action, the term mental *forces* would seem reasonable and appropriate. The term fits the phenomena of subjective experience but does not imply here any disembodied supernatural forces independent of the brain mechanism. The mental forces as here conceived are inescapably tied to the cerebral structure and its functional organization.

Like other properties of brain excitation such as the electrical, chemical and physical, the conscious properties are conceived to be embedded within the brain process as an essential constituent of the action. In their position at the upper levels of the organizational hierarchy, the conscious forces encompass and transcend the details of nerve impulse action in the same sense that the properties of organism transcend those of the cell—the cell those of the molecule—the molecule, the atom, and so on. It is in these terms that the conscious phenomena can be seen to influence and in considerable degree to direct and govern the flow pattern of nerve impulse traffic.

Unlike the more elementary properties of brain tissue we have as yet no means for recording nor for describing the emergent dynamic pattern properties of the different kinds and species of conscious cerebral processes. Nor do we know enough as yet about cerebral organization to even imagine the nature of the qualities and the critical variables that might be required to produce different conscious effects.

It follows from this interpretation that cerebral organization in perception and other gnostic activity must be such that the brain is sensitive to and responds directly to the pattern properties of its own excitation. The different kinds and patterns of excitation process involved in perception are presumed to operate as entities in cerebral function having their own special properties and qualities. These latter *are* the conscious qualities of subjective experience, that is, the sensations, the perceptual images and so forth. As you look about the room it is the images you see that the brain process is responding to directly, rather than to the nerve impulse components and other subelements of which these same conscious images are built. The latter point is critical, namely, that the brain responds to the overall encompassing effect or functional gestalt of an excitation pattern as an entity, rather than to the individual impulse elements of which the excitation process is composed. Considerable indirect evidence can be found in support of this. It follows further that a full explanation of a conscious sequence of neural events at the cerebral level would not be possible in terms of the biochemical and electrophysiological events alone. An additional explanatory description is needed that takes into account the dynamic conscious properties and qualities at the upper levels of the neural hierarchy.

ACKNOWLEDGMENT

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