1972 (161)

CLAREMONT READING CONFERENCE

Sponsored by The Claremont Graduate School

THIRTY-SIXTH YEARBOOK

Edited by
MALCOLM P. DOUGLASS

1972

Permanent Conference Theme:
Reading is the process of making discriminative responses.

Special Theme for the 39th Annual Claremont Reading Conference:

THE PERSON IN A MASS SOCIETY

Hemispheric Specialization of Mental Faculties in the Brain of Man*

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The following deals with aspects of brain organization that help to shape some of the basic features of that complex referred to in the conference theme as "the person." Among other things the observations bare on questions concerning problems of cerebral dominance and handedness, the relation of conscious awareness to brain mechanisms, the inherent individuality of the person, differences between verbal and spatial modes of thinking, and between the male and the female mind and related questions.

The material that I'll be drawing on comes from collaborative studies with a long line of colleagues on a group of brain-operated patients. These are mostly patients of Drs. Philip Vogel and Joseph Bogen, neurosurgeons at the White Memorial Medical Center in Los Angeles, and most of them have undergone essentially the same rather special type of brain operation for control of epileptic convulsions. Put crudely, this operation consists of having the brain divided down the middle into its right and left halves. More precisely, the surgery involves a selective section of the bands of nerve fibers that cross-connect the left and right hemispheres. This is a kind of surgery that is undertaken only in extreme cases as a last resort measure in an effort to control epileptic seizures that are not contained by medication. It represents a last-ditch stand against advancing, life-threatening epilepsy.

Skipping over details, the surgery in effect eliminates all direct cross-talk between the hemispheres. Because the brain is bisymmetric in all its parts, each of the disconnected hemispheres retains a full complement, or complete set of brain centers and their interconnections, for all the different kinds of cerebral functions, excepting only those that require left-right crossconnection between the hemispheres. From the standpoint of brain anatomy, the surgery creates a number of obvious problems for brain function. Recall that the optic

* This article is based on a lecture presented in the 1971 Beckman Evening Lecture Series of the California Institute of Technology. Work of the author and his laboratory is supported by grant #MH 03372 of the National Institute of Mental Health of the U.S. Public Health Service and by the F. P. Hixon Fund of the California Institute of Technology.

image of the outside world on its way into the brain gets split down the middle, with the left half of the visual field being projected into the right hemisphere, and vice versa. Normally these two cortical half-fields are cross-connected by fibers that run through the callosum and they therefore are left unconnected after the surgery. The same applies to the sensory representation of the hands and the legs, and also for the primary motor control of the limbs, the left side of the body being represented in the right hemisphere, and the right side in the left hemisphere. Language is centered in the left hemisphere of the typical right-handed individual, and is thus cut off after the surgery from information relating to the left half of the visual field, the left side of the body, the right nostril, and from everything else that goes on in the opposite right hemisphere.

In view of these extensive anatomical disconnections and the fact that the corpus callosum is the largest fiber system of the brain by far, it is fair to say that one of the most remarkable effects of this kind of surgery is the apparent lack of effect, insofar as ordinary daily behavior goes. A person two years recovered from such an operation could easily go through a complete routine medical examination without revealing that anything was particularly wrong to someone not acquainted with his medical history. This is what prompted our studies on the callosum in the beginning. The remarkable lack of symptoms after surgical section, and also with congenital absence of the corpus callosum, had become one of the more challenging puzzles in brain research back in the 1940's and '50's, and was being cited to support radical, almost mystical theories of how brains operate at their upper levels without depending on specific fiber connections.

Despite the deceptive normality of these people under ordinary conditions and in contradiction to earlier neurological doctrine, we can now demonstrate with appropriate testing procedures a whole multitude of distinct impairments in cerebral cross-integration. These are most simply summarized by saying that the surgically disconnected left and right hemispheres function independently with respect to most mental activities. Each hemisphere, in other words, has its own private sensations, perceptions, thoughts, ideas and feelings, all cut off from the corresponding experiences in the opposite hemisphere. Each left and right hemisphere has its own private chain of memories and learning experiences that are inaccessible to recall by the other hemisphere. In other words, each of the disconnected hemispheres can be said to possess a separate mind of its own.

This condition is manifested in many ways in different kinds of test situations(1). For example, following the surgery these people are unable to recognize or remember a visual stimulus item that they have just looked at if it is presented across the vertical midline in the opposite half of the visual field. The usual perceptual transfer that one normally expects to find between the left and right halves of vision is lacking. Similarly, things identified by touch with one hand cannot be found or recognized with the other hand. Odors identified through one nostril are not recognized through the other. Further, these people are unable to name or to talk or to write about things seen in the left half field of vision, things felt with the left hand or foot, odors smelled through the right nostril, or things heard by the right hemisphere.

Most of these deficits are easily compensated or concealed under ordinary conditions, as by eye movements, shifting of the hands, etc., and they require controlled lateralized testing procedures for their demonstration. We test the function of each hemisphere separately by confining the sensory input, central processing, or/and the motor readout to a single hemisphere. The visual material is flashed to left or right half field at 1/10 of a second, too fast for eye movements to get the material into the wrong half of the visual field. Under these conditions the subjects regularly report that they do not see stimuli projected to the left of center, as if they were blind in the left half field.

However, with a change of testing procedure, the subjects proceed to correctly point to a matching object or to retrieve with the left hand a corresponding object, showing that they are quite capable of recognizing and identifying among a choice array the very same stimulus that they have just told us they did not see. The hemisphere that talks to us did not in fact see the left field stimulus; this was seen only by the opposite, right hemisphere, which, lacking speech, is able to express itself only by manual responses. The subjects appear thus to possess two distinct inner visual worlds, cut off from each other, and each oblivious of the existence of the other. Many similar performances of this kind, reviewed and presented elsewhere, support the conclusion that each hemisphere has its own separate domain of conscious awareness.

The conflict and disruption of behavior that might be expected to result from having two separate control systems competing to run the one body tends to be counteracted by a large variety of unifying factors. Whereas the main wiring of the brain is lateralized and crossed, there exist also some weaker uncrossed sensory and motor systems, which though relatively crude, do help greatly to keep the behavior unified. Just the unity of eyeball optics, for example, assures that whenever one hemisphere moves the eyes to fix on a target, the other hemisphere also is conjugately locked on the exact same target at all times. Effective use of the various unifying mechanisms of this kind can apparently be enhanced to a considerable extent through training, learning, and re-education, particularly in the younger patients. The youngest of the present group, operated at age 13, performs cross-integrations today with increasing facility that he was quite unable to perform during the first year or two after surgery.

The extreme to which this kind of functional compensation can go is illustrated in the occasional rare individual born without a corpus callosum, but in whom the remainder of the brain remains essentially normal. Only about 17 such cases have been recorded in medical history, most of whom were discovered at autopsy in post-mortem examinations because during life the condition is asymptomatic and hence does not attract medical attention.

A few years ago Dr. Saul and I had an opportunity to examine and study such a person(2). This was a 19-year-old college Sophomore making an average scholastic record, and presumed normal until hospitalized for a series of headaches. X-rays revealed a congenital total absence of the corpus callosum. Her total I.Q. was slightly above average at 104. To make a long story short, she performed all the tests that we had devised for the surgical patients with no difficulty, responding essentially like a normal control subject. Apparently she had greatly enriched by practice and use the function of the uncrossed fiber systems of the brain as well as those of the anterior commissure which remained intact. Also, there was evidence from lateral amytal tests, that she had developed language in both hemispheres. All this speaks for the functional plasticity of the developing, still growing brain as compared to the adult brain.

However, there is another side to the story. The necessary crowding of both the language plus the non-language functions together into each hemisphere instead of the more usual left-right division of labor, apparently was not achieved without paying a price. Further testing on more complex mental tasks showed her performance to be sub-normal in working spatial puzzles, making block designs, in drawing, in object assembly, and in a variety of perceptual motor tasks, like stringing beads, putting pegs in holes, and buttoning clothes, all performed for speed. Whereas she was above normal in verbal reasoning, she was very low in non-verbal reasoning. In school she was poor in mathematics, particularly in geometry, and had exceptional trouble in map tests and in geography. This array of deficits in non-verbal performances contrasted with her above normal score of 112 on the verbal portion of the WAIS. In general, these difficulties appear to reflect weakness in the mental specialties of the non-verbal hemisphere. With both the language and the non-language functions obliged to share the same hemisphere on each side, the verbal faculties had apparently developed at the expense of the non-verbal.

What we're getting into here is the general problem of cerebral dominance and lateral specialization of function. In sub-human mammals the hemispheres are essentially symmetric in their basic functional potential, but in man we have to deal with right-left specialization. In these commissurotomy patients we have an exceptional opportunity to make direct comparison between the performances of the left and right hemispheres working independently on the exact same task in the same individual. The results of such studies generally strengthen and extend the evidence for hemispheric specialization.

We have already seen that practically all speech and writing and calculation were found to be centered in the disconnected left hemisphere. This verbal hemisphere is also the more aggressive, executive, leading hemisphere and seems to carry the main load of behavior postoperatively. It is the dominant and highly developed capacities of the left hemisphere that apparently are responsible in large part for the earlier impressions that the cerebral functions continue unimpaired in the absence of the corpus callosum. The minor, right hemisphere lacking language, and like the animal brain, unable therefore to communicate what it is thinking or experiencing, is much less accessible to investigation. The nature and the quality of the inner mental life of the silent right hemisphere has accordingly remained relatively obscure.

Some authorities have been reluctant to credit the minor hemisphere even with being conscious, contending that it must exist in a kind of reflex, trancelike, or automaton state, the reasoning being that the conscious self by nature has to be single and unified. Actually the evidence as we see it favors the view that the minor is very much conscious, and further that both of the disconnected left and right hemispheres may be conscious simultaneously in different and even in conflicting mental experiences that run along in parallel. From its non-verbal responses we infer that the minor hemisphere senses, perceives, and has ideas and feelings all at a characteristically human level, and that it learns and remembers and is even superior to the major hemisphere in certain types of tasks.

The exceptional activities at which the disconnected minor hemisphere has been found to excel are firstly, of course, all non-verbal performances. The disconnected minor hemisphere is found to be superior in the construction of block designs, in copying and drawing various test figures, and in the construction of spatial representations generally (3, 4), in cross-modal spatial transformations (5), in the spatial parts of the Raven's Progressive Matrices Test(6), in identifying and recalling nondescript *shapes* or *forms* made of bent wire perceived and identified by touch alone(7), in the perception of part-whole relationships (8), and in discriminating the unification of fragmented figures(8). In addition to being all non-verbal activities, all those various tasks at which the right hemisphere is found to be superior, seem to a large extent to involve a direct apprehension and cognitive processing of spatial form and spatial relations as such.

Scanning movements of the eyes from the right to the left edge of an object being examined in free vision would result in the projection of two complete perceptual images in the divided brain, one in each hemisphere(9). The well-known constancy of the visual image in the presence of eye movement must be taken into account. This right-left reduplication of perceptual images is something that would seem logically to occur also in the normal brain, and we have long wondered what good may be served by such a redundant doubling in the cerebral operations. However, if as we now suspect, each hemisphere processes its sensory information in distinctly different ways, then such a doubling begins to make sense.

In the normal intact brain the right and left contributions in any given perceptual experience become fused, making it difficult or impossible to determine which hemisphere is doing what. In a series of studies still in progress headed by Trevarthen and Levy (10), we have been deliberately arranging it so that different, mutually conflicting sensory images are seen on right and left sides simultaneously. The aim is to set up rival, competing processes that also will evoke distinctly different right and left responses, from which we can then infer more about dominance and what each hemisphere contributes to any given perceptual experience. The procedure involves the use of composite left-right visual stimuli flashed at 1/10 of a second, with the subject's gaze centered in the midline. Each hemisphere completes the missing half of its own ½ stimulus according to a general perceptual rule applied to brain lesions. This means that the two hemispheres think they see different things at the same point in space at the same time, something that the normal brain of course does not do.

Since each hemisphere has its own inner visual world, neither knowing what the other is experiencing, the subject's remain blandly unaware that there's anything particularly strange in the chimeric stimuli, even in the face of leading questions. The same principle has been used further by Trevarthen and Levy to test for the perception of geometric and nondescript figures, the perception of movement, of words, of serial patterns, colors, and various combinations of these. The question is, which side will dominate under different test conditions, that is, with different categories of test material, with different mental and motor sets, with different forms of readout, central processing, and so on.

In general, the results conform with the earlier findings in that if linguistic processing of any kind is involved, the subject's response is dominated by the left hemisphere, that is, they select in favor of the right half of the composite stimulus.For the perception of faces, however, and for any direct visual-to-visual matching of shape or pattern, the right hemisphere dominates and the subject selects the left half of the composite stimulus. Nondescript shapes difficult to discriminate verbally were found to be exceedingly difficult for the left hemisphere, even when they were presented exclusively to the one hemisphere with no competing stimulus on the opposite side. It is interesting that the right hemisphere was found to dominate the verbal hemisphere even in the case of words presented in cursive script provided that no interpretation of the word meaning was involved.

Under these testing conditions the subjects show signs of confusion and conflict as secondary effects when one hemisphere sees or hears the other giving what the first hemisphere considers to be an incorrect response. This is something we have to deal with all along in working with these people. When this happens the correctly informed hemisphere may give a disgusted, negative shake of the head; or if it is the verbal hemisphere it may make remarks like, "Now why did I do that? What made me do that?" We purposely don't dwell on these confusions and pass on to the next trial.

However, this kind of annoyance in the second hemisphere with what is a correct response for the first hemisphere, along with the occasional double correct responses in which first one and then the other hemisphere gives a different and correct response, gives further support to the conclusion that each hemisphere is indeed having its own separate and different perceptual experience, with both being conscious simultaneously in parallel.

The chimeric findings reaffirm the earlier impression that the left and right hemispheres perceive and apprehend things in different ways. In dealing with faces, for example, the right hemisphere seems to respond to the whole face directly as a perceptual unit, whereas the left hemisphere seems to see separate salient features, like a mustache, eyebrows, hair, etc., to which verbal labels are easily attached.

Another thing to come out of these latter studies is the demonstration that the minor hemisphere is quite capable of capturing and controlling the motor system of the body under conditions in which it is in equal and free competition with the major hemisphere, that is, the sensory input is equated and the subject is quite free to use either the left or the right hand. We have not seen this so convincingly before. It suggests that in the normal, intact brain, the control of voluntary, willed movement is not routed entirely through the major dominant hemisphere, but comes partly in some activities directly from the minor hemisphere.

Looking back over the evidence one sees an implication that strong, cerebral dominance and specialization is good, whereas cerebral ambivalence is not so good. If it be true that a hemisphere committed to language is thereby handicapped in spatial, perceptual, nonverbal functions like geometry, drawing, sculpture, mechanical ingenuity, then this should show up statistically in a population of left-handers in an analysis of their I.Q. subtest profile. Left-handers are more bilaterialized for language, that is, they are more apt to have some language represented also in the minor hemisphere as is shown in the way they recover from cerebral injuries. Comparing a group of 10 left-handers with 15 right-handers, all graduate science students, Levy (5) found that left-handers showed three times a greater discrepancy between the performance and the verbal scales on the Wechsler Adult Intelligence Scale, with the performance score, which reflects predominantly right hemisphere functions, always lower, as predicted.

A similar discrepancy was reported by Lansdell (11) for persons who had developed right hemisphere speech as a result of cerebral trauma suffered early in life. Further, Nebes (8) using his part-whole circle-arc test, found left-handers as a group scored very significantly below right-handers with hardly any overlap. Silverman (12) has reported that left-handers are inferior to right-handers on basic perceptual alignment tests.

All of this fits the idea that verbal and the non-verbal perceptual faculties don't do so well when they develop for one reason or another within the same hemisphere, and that the more common tendency when this occurs is for the non-verbal performance functions to be handicapped in favor of the verbal functions. Left-handed individuals who can align themselves with Leonardo da Vinci, Raphael, Michaelangelo and many other greats in history, should remember that all of these findings are very statistical. The individual left-hander brain comes in all degrees and kinds of right-left asymmetry. A complete mirror-switch for example should leave no effect on cerebral performance save for those little problems of getting along in a right-hander world.

In any case, it may be seen that differential loadings of these right and left hemispheric faculties in different individuals could make for quite a spectrum of individual variations in the structure of human intellect, from the mechanical or artistic geniuses on the one extreme, who can hardly express themselves verbally or in writing, to the highly articulate individuals at the other extreme who think almost entirely in verbal terms. Individual variations of this kind are thought to be hereditary or at least innate to a considerable degree. Left-handedness for example tends to be a familial trait, and the anatomical asymmetrics in the brain that are correlated with cerebral dominance have been reported recently by Wada to be demonstrable already at birth in the brains of stillborn infants. Reading and language disabilities are agreed to be congenital, and often show a clear family history with a somewhat higher incidence among left-handers. One of the commissurotomy patients is a left-hander and shows a lateral cerebral reversal for speech into the right hemisphere but like left-handers statistically, there is not a corresponding switch in spatial perceptual faculty, so that both of these then have to develop in the right hemisphere.

The dichotomy we've drawn between verbal vs. nonverbal mental capacities may suggest to some the possibility of looking for correlated male-female differences. We have not pursued this ourselves as yet but note that it is reported that males are found to be six times more frequently afflicted than females with congenital language disabilities. On the Porteus Maze Test applied widely to children in many cultures, the girls were found to be significantly inferior to the boys. Smith(13) concludes that females show a selective spatial disability (the other side of the coin being that they presumably show a verbal superiority?). Patients with Turner's syndrome, that is females lacking one of the usual pair of the female X chromosomes are found to do pretty well on the verbal portion of the Wechsler I.Q. scale, but are selectively and profoundly deficient in the non-verbal perceptual functions(14). It is also reported by Money(15) that genetic females masculinized in utero by excessive male hormone through accidents of treatment or pathology show an exceptionally high incidence of very high I.Q.'s. These mental differences between the sexes have generally been considered in the past to be socially or culturally induced, but the possibility remains that something more basic is involved(16), like a lesser degree of hemispheric differentiation and dominance in the female.

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