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OBSERVATIONS ON VISUAL PERCEPTION AFTER DISCONNEXION OF THE CEREBRAL HEMISPHERES IN MAN[1]

BY

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INTRODUCTION

IN earlier reports we have outlined some of the functional effects produced in man by surgical disconnexion of the cerebral hemispheres as effected by a complete transection of the corpus callosum and the anterior and hippocampal commissures, with separation of the massa intermedia (Gazzaniga *et al.*, 1962, 1963). The observations were based on a case operated by Drs. Philip Vogel and Joseph Bogen at the White Memorial Medical Center in Los Angeles (Bogen and Vogel, 1962).

The present paper in the main is an account of some of the further findings obtained to date in the same person in tests directed principally at visual functions and also reports confirmatory findings on a second case similarly operated. The tests were aimed at determining the extent and kinds of interaction, if any, between the perceptual and mnemonic activities of the separated hemispheres, at detecting differences in performance capacity of the right and left visual half systems and at revealing the degree of lateralization in motor responses to right and left visual field stimuli. Tests concerned more specifically with language and with motor control will be reported separately.

TESTING METHODS

Projection of visual information confined to one or the other hemisphere was effected by presenting stimuli within the right or left half visual field while the subject was fixating a central point. All stimuli presented in the left half-field thus went to the right hemisphere and vice versa. Inadvertent projection of test information into the wrong hemisphere caused by eye movement away from the fixation point was controlled by tachistoscopic

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presentation of the stimuli at 1/10 to 1/100 sec. combined with close observation of the subject's gaze. Several variations of the general testing procedure were tried, including the use of goggles equipped with time shutters, ocular electrodes, and different tachistoscopic techniques.

The test conditions most extensively utilized were the following: The subject was seated at a table with his eyes approximately 6 ft. in front of a translucent white viewing screen 4 × 4 ft. with its centre at subject's eye-level. A small asterisk figure at the centre of the screen was used to facilitate fixation. The stimulus patterns, mounted in pairs or singly on 2 × 2 slides, were rear projected on to the screen from a distance of 10 ft. by an automatic projector equipped with a tachistoscopic shutter. A second projector, set on top of the first, maintained an even background illumination on the screen before and after each stimulus presentation. All patterned stimuli were black on a white background. They appeared 4 in. high on the screen and were placed no nearer the mid-line than 5 in. In later tests of the past eight months the single large screen was replaced by two commercial viewers placed side by side with the screens 4 in. apart as indicated in fig. 1. Each viewer had its own automatic slide projector

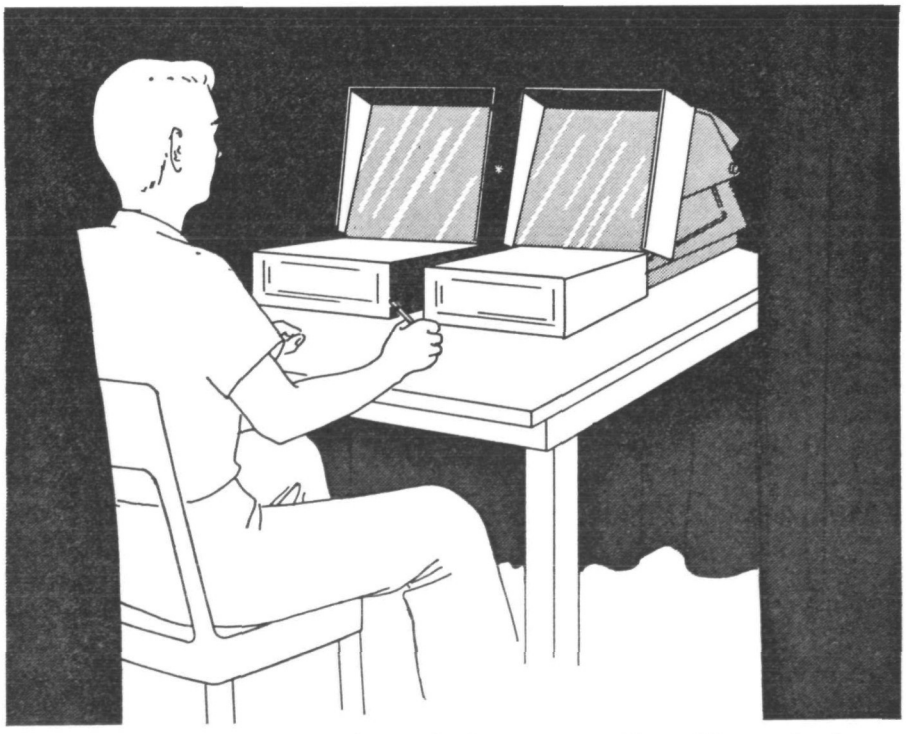

FIG. 1.—Two automated projector-viewing systems with tachistoscopic shutters were arranged so they could be used separately, in alternation, or in synchrony to present stimulus material in either half visual field from 2 × 2 transparent slides.

that could be controlled separately or flashed in synchrony with the other. For some of the tests a single unit was used with the subject fixating a point at the centre of the one screen. Each trial was preceded by explicit verbal instructions and/or overt demonstrations as to the nature of the test performance. One experimenter operated the projectors and watched the subject's gaze while another, sitting beside the table, recorded the results and checked the subject's general reactions. Because of the language handicap of the right hemisphere, all tests as a rule were run first with the right half-field and the right hand. It was easier for the patient to follow instructions for working on the left side after the test procedure had become familiar on the right side.

Case History

The patient, a male war veteran, had been suffering intractable generalized convulsions for more than ten years prior to surgery. He had always been right handed and preoperatively had no marked sensory or motor impairments save a mild hypæsthesia on the left side. He was a high school graduate with an above-average I.Q. and considerable self-education. He used to read a lot, including Greek history and his favourite author, Victor Hugo, until the seizures became severe after which he settled for television and the newspaper headlines.

Prior to surgery the patient had uncorrected visual acuity of 20/70+1 O.D. and 20/50 O.S. Extensive tests, including perimetry, showed no abnormality except some jerkiness of motion.[1] Tachistoscopic presentation of letters, numbers, geometric figures, and sentences, showed that all stimuli were easily recognized and interpreted correctly in either visual half-field and/or correctly recorded by manual response with either hand. He also wrote moderately well with the left hand as well as the right, and his reading in general was normal.

The corpus callosum, hippocampal and anterior commissures were all completely sectioned in a single operation (Bogen and Vogel, 1962) by exposure and retraction of right frontal and occipital lobes. Some atrophy of the right frontal lobe was observed and the massa intermedia was judged to be absent. No generalized convulsions have occurred in the thirty months since the operation (Bogen and Vogel, 1963). No significant change in either temperament or I.Q. was noted. Three months after the operation, uncorrected acuity was unchanged. Ishihara colour cards were read correctly. He had always been cheerful by nature with a quick sense of humour and the same general temperament was retained after surgery. Other results of pre- and early post-operative testing were outlined in an earlier report (Gazzaniga *et al.*, 1962, 1963).

Observations

Laterality in Visuomotor Integration

While the subject was seated before a table fixating on the central marker on a large upright screen, a bright spot of light $\frac{1}{2}$ in. in diameter was flashed in a prearranged pseudo-random schedule to different quadrants of the visual field. After each stimulus presentation, the subject responded immediately by pointing quickly to the spot where he had seen the light. When it was desired to test the use of a given hand, the subject's other hand was placed in his lap underneath the table.

[1]The optometric tests were performed by Dr. G. Kambara.

Under these conditions, early post-operative testing revealed that when the stimulus fell in the right visual field, it could be localized with only the right hand and/or verbally. Stimuli in the left field could be located only with the left hand and not verbally. When both hands were left free for response above the table, the subject always used the right hand to point to stimuli that fell in the right field and the left hand for those that appeared in the left field. While one hand responded, the other usually remained quite motionless. Reaction time to all stimuli was nearly three times slower than normal. Earlier indications that the left hand might respond at times to stimuli in the right field (Gazzaniga *et al.*, 1962) were not confirmed in the later testing. It is now believed that these earlier exceptions may have been due to failure to ensure adequate fixation on the centre of the screen. Tests similar to the foregoing, repeated at 24 months after surgery, show the patient now is able to use either hand to locate the visual target in either half-field, indicating an increased control of the secondary hand. Responses executed with the primary hand from each hemisphere remain markedly superior to those of the secondary in speed, accuracy and general coordination. Verbal recognition or description are still lacking, however, for the left field stimuli.

The results showed, in brief, that when visual stimuli entered one hemisphere, manual responses utilizing the arm governed primarily from the same hemisphere went off appropriately while responses with the other limb were absent in the early months and never became as good as those of the primary arm. Later testing revealed a definite improvement in motor control over the secondary arm. Throughout all these and other tests, it was only those stimuli that fell in the right visual half-field that were acknowledged and described verbally.

Retrieval Tests for Pattern Discrimination

A series of retrieval tests were designed whereby the subject was obliged to select from a group of five figures on 5×3 in. cards placed on a table in front of him, the one that corresponded to the pattern flashed tachistoscopically on the screen. Generally a new set of 5 cards was placed in front of the subject before each trial. Most sets contained the correct card and one blank card, plus three other incorrect cards. Geometric symbols, numbers, single words and short phrases were used; in some trials a simultaneous verbal description was requested while others involved only the manual response. The stimuli were flashed on the screen in either or both visual half-fields on a randomized schedule so that the subject could not anticipate where the next stimulus would appear. The subject then tried to pick out from the series of 5 cards in front of him the pattern, word or sentence most like the projected figure.

In this situation the right hand responded correctly with virtually 100 per cent accuracy to all stimuli presented in the right field, regardless of their

nature. The retrieval score with the right hand for the same set of stimuli flashed to the left field, however, failed to rise above chance. When stimuli were presented to the left field, the left hand was able to seek out the correct card at a level 2½ times better than chance. The left hand made no response or responded only at a pure guess level when the stimuli were presented to the right visual field. In cases where stimuli were presented in the left field only, the subject, when questioned, would commonly deny having seen anything and often seemed puzzled that he should be asked to pick up a card. When he was asked what figure he had chosen, just after a correct pattern had been retrieved with the left hand following left field stimulation, the usual reply was, "The blank one."

When stimuli were flashed simultaneously to both fields and each hand responded to its respective stimulus, the *per cent* of correct retrieval by either the left or right hand did not drop. Nor were there other indications of perceptual distraction, conflict or interference between the hemispheres under these conditions. Verbal recognition remained specific to right-field stimuli here as before.

During the first post-operative year the intermittent apraxia of the left hand often prevented appropriate responses by this hand to stimuli seen in the right visual half-field. During the second year there was increased ability of the patient to control his left arm so at the present date 2½ years after the operation the patient is able to respond with the left hand when discriminating stimuli are projected into the right visual field. There has been only slight, if any, improvement, however, in the ability of the right hand to respond correctly in discriminating stimuli in the left field.

Stimulus Preference Tests for Pattern Discrimination

When using the left hand to select one of 2 test objects or patterns, the subject frequently displayed persistent preferences for one over the other. This applied to tactile as well as to visual discriminations. Such left-hand preferences appeared also when no visual field restrictions were imposed and the subject was using the left hand to select objects with both eyes open. Presented with a choice of 2 objects or cards, the left hand picked one and consistently retrieved it, regardless of right-left position and other variables. This preference could be reversed by deliberately taking the subject's hand and placing it on the other stimulus and then rewarding this choice. As testing of this kind progressed, it became possible after some weeks to reinforce correct responses by reward signals instead of actual rewards, such as tapping a pencil on the table to indicate a correct choice. When an original preference had been reversed, there was a tendency for the subject to revert to the initial preference at the end of a short rest interval of 2 to 6 minutes; but a given preference did not carry over with any consistency from one week to the next.

These left-hand preferences were sufficiently consistent to make feasible

their use in finding out more about the visual discrimination capacity of the relatively inaccessible right hemisphere. Discrimination tests were run with procedures similar to those above but with a second, more portable system in which miniature projector units were positioned 3 feet in front of the patient's eyes on a 2×3 ft. black background supporting board (fig. 2). These units flashed $\frac{3}{4}$ in. geometric figures on a 1 in. ground

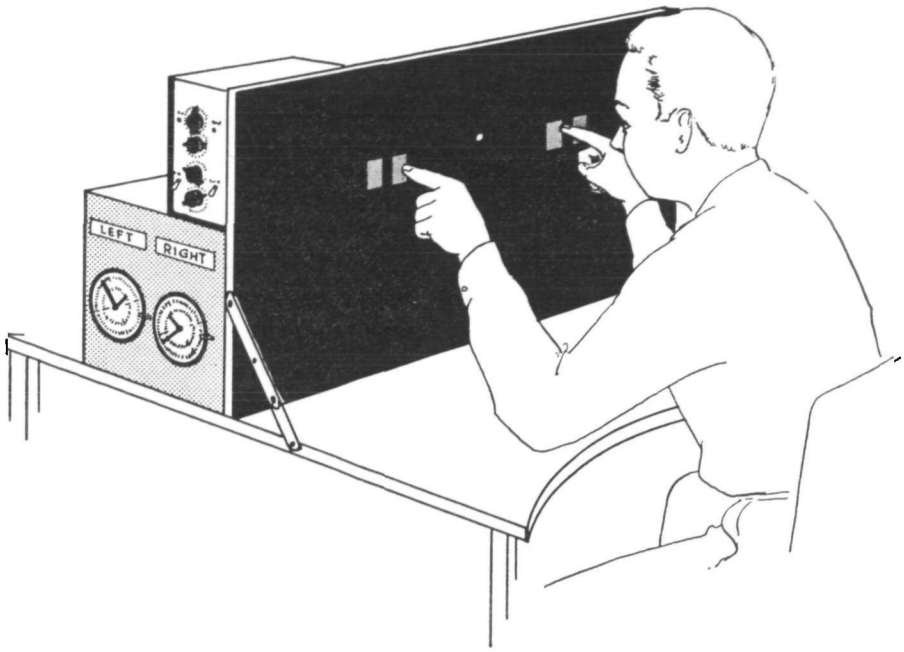

FIG. 2.—This apparatus was used for reaction time and was modified for other tests as described in the text. The stimuli were projected on the response panels in either or both visual fields.

glass screen at 0·1 sec. A pair of these screens was located in the left visual field and a single one in the right field positioned at points approximately 10 degrees lateral to and on a level with the fixation point. The subject again sat at a table in front of the units where he could easily point to the specific stimulus of his choice. A centre hole at the fixation point in the background board allowed the experimenter to observe the patient's eyes and to present stimuli only when the subject's gaze was firmly centred. The visual patterns consisted of a variety of simple geometric figures such as squares, triangles, circles and the like.

In each trial a pair of different geometric symbols was flashed to the left visual field, side by side (4 in. apart) in a horizontal plane. Simultaneously and at a corresponding point in the right field, either a cross or a circle was flashed. The right-left positioning of the 2 figures in the left field was

switched randomly in a standard discrimination procedure. The subject was instructed verbally and by demonstration to have the left hand point to the preferred stimulus in the left half-field. His left-hand responses were made immediately in a proficient, adept and somewhat automatic manner. Following his manual response to the left field, he was also asked which of the two stimuli had appeared in the right field.

The characteristic outcome was as follows: (*a*) Over a series of trials, the left hand would repeatedly point to one of the two left-field patterns, regardless of its right-left position; (*b*) the subject was able, on the same trial, to report accurately which of the two stimuli had been flashed simultaneously in the right visual field, and (*c*) when questioned, the subject consistently denied any knowledge of the stimulus flashed to the left field.

Tests for Lateral Specialization of Visual Function

The patient had always been right-handed and had never had occasion to write or draw with the left hand, so far as he or his family could recall. Following the commissurotomy, when he copied sample figures that suggested spatial perspective like the Necker cube, his performance with the left hand was consistently better than that with the right (fig. 3).

In order to get the left hand to perform, the subject was seated at a table and the performance was started with the use of the subject's right hand and verbal instructions. After the test procedure had become familiar, the hands were shifted with the aid of verbal instruction and "do this" demonstration. Subsequent changes were then made from one hand to the other and a three-minute period was allowed each hand for each drawing. Performance with the left hand was handicapped in that the hand would often tighten and go out of control before the three-minute period was up. Most commonly it would slowly swing upward from the paper to a raised position above the left shoulder.

When attempts were made in a recent session to assist the right hand in drawing a Necker cube, by demonstrating the strategy of first drawing two overlapping squares and then connecting the four corners, he was still unable to carry out the task with the right hand. However, immediately after the right-hand failure, his left hand drew the complete cube without copying from any example and without using the demonstrated strategy.

The subject was always able to reconstruct standard patterns in a block design test and to assemble complex object puzzles with the left hand. Those patterns that were correctly reconstructed with the right hand were always extremely simple and done so only after much practice. The inability of the right hand puzzled the patient and when it was apparent from his facial expression that he knew the right hand had performed incorrectly, the left hand folded behind him and sometimes restrained by the experimenter, would make spontaneously movements as if to reach out

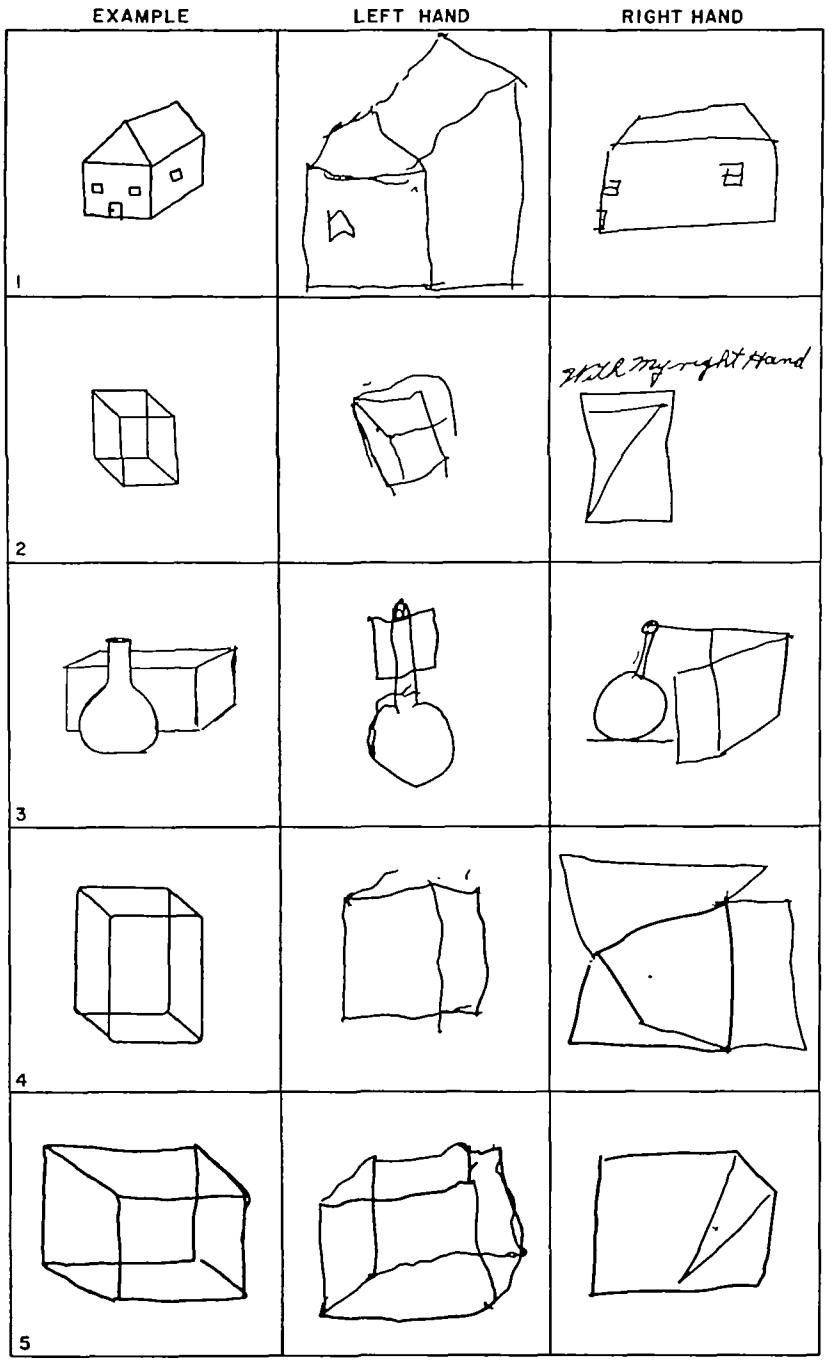

FIG. 3.—Samples of the performance of Case I with right and left hand in copying example figures, each trial being limited to three minutes.

and correct the error. When free use of both hands was permitted, the patient usually was unable to arrange the blocks and/or picture parts correctly, mainly because the right hand would always try to help and would consistently undo the superior accomplishments of the left.

Reading

There was no complaint by the patient of visual impairment during the first several months after surgery even though as evident from the above, he was unable to read or to describe objects, pictures or symbols presented in the left-half visual field. His reading in tachistoscopic tests after the operation, so far as the right half-field was concerned, seemed roughly normal in speed and comprehension. He continued to look at the evening newspaper and to watch television without comment.

Approximately 25 weeks after surgery, however, he began to complain of difficulty in sustained reading. As he described it, printed words tended to fade out until they became indistinguishable and he was obliged to stop and rest for some minutes after which he was able to continue for another short period. When asked to read aloud during a testing session, he did moderately well for about half a page, and then began to slow, to stumble, and had to stop. If the first word on a line was short, he would generally not include it in his verbal recitation. However, his answers to questioning regarding the content of what he had covered indicated good comprehension. With large print and simple material such as found in a book for 6-year-olds he was able to continue a little longer but the same problem persisted.

In March 1963 the uncorrected acuity was 20/70+1 O.D. and 20/50 O.S. Following correction, and if the head was turned to the left, acuity improved to 20/25 O.D. Perimetry with a variety of targets still showed a left homonymous hemianopia, for tests that required a verbal response. Normal tests, including the Lancaster red-green and orthoptic survey, showed normal stereopsis (as also found by Bridgman and Smith, 1945).

By about the 7th month, the subject had clearly abandoned efforts to read anything more than the newspaper headlines and the short phrases and words encountered in television. Tests of his reading ability run again at 18 and 30 months indicated little if any change from the condition at 6 months. In addition to this impairment, if short phrases or long compound words were printed out on a piece of paper, such as "ham and eggs," and presented to him briefly, with the last word or word segment being pointed to by the experimenter for a verbal response, the patient would verbalize the last word and claim that was all there was on the paper.

Intermodal Transfer

The patient was taught to distinguish with the left hand such objects as wooden ovals, pyramids or a door latch or electric plug, while wearing a

blindfold (fig. 4F). The patient was consistently unable to give a verbal description of an object that he was manipulating with the left hand.

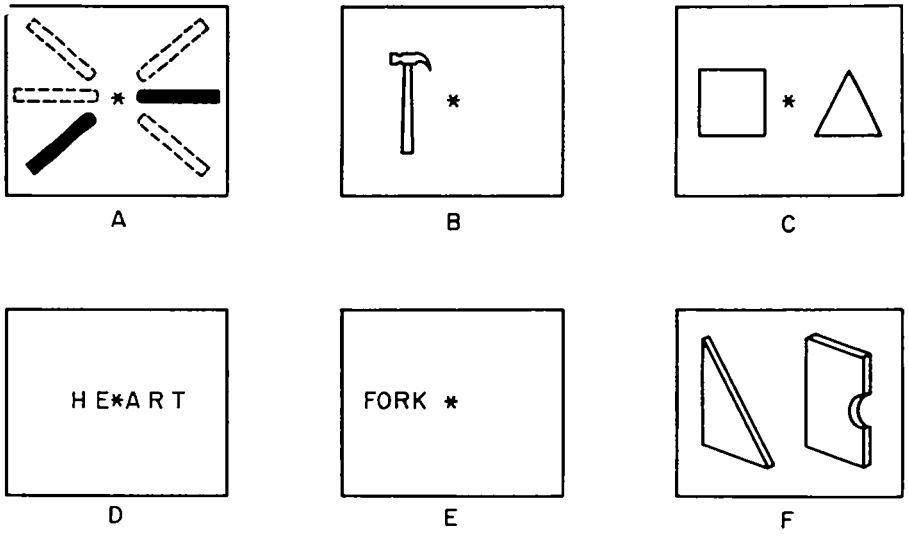

FIG. 4.—Each plate shows representative samples from a series of stimuli used in different visual tests as described. The point of fixation for samples A–E is identified by an asterisk. A, Split-bar test. Subject compares directional orientation of lines in right and left fields. One of 3 positions on left is paired with one of 3 on right in random order. Subject responds verbally, draws with right, left, or both hands, or points to matching samples. B, Object-retrieval test. Objects pictured in left or right fields are retrieved from among an assortment of other objects using different somatic-visual-cortical field combinations. C, Double field presentation of geometric figures, objects, scenes, numbers, colours, etc., is combined with verbal plus manual pointing, drawing and writing responses of one or both hands. D, Triple word test. Commissurotomy patients never identify the whole word, only right and left parts separately, and only the right vocally. E, Name-object retrieval test. Subject's visual and auditory comprehension of verbal material in minor hemisphere is shown by correct non-verbal responses (like pointing at correct one of a number of objects, signalling correct one of several definitions read by experimenter, etc.). Spoken or written answers even by left hand don't rise above pure guess level. F, Inter-modal finds the corresponding object by vision using left or/and right hands. Similar tests were run in a reverse order.

However, as soon as the object and the blindfold were removed, he had no trouble in pointing out, with his left hand, the correct object seen in a chance position among 6 other objects of similar size. After training and presentation to the left hand, responses carried out with the right hand were no better than chance and vice versa for objects not audibly named.

Other discriminations of the same sort of objects were made on the basis of unrestricted vision without tactile contact and with the left hand

responding by pointing at the chosen object. When the patient was then blindfolded, tactile recognition of the object palpated among a series of others was immediate with either hand.

In general, intermodal transfer of this sort occurred readily within one hemisphere but never between the hemispheres.

Confirmatory Findings on a Second Case

Many of the foregoing tests have now been applied to a second patient more recently recovered from the same kind of brain surgery done for the same reasons and with therapeutic results equally good to date. This is a woman 30 years old without history of prior brain injury. I.Q. tests before surgery gave scores in the 70–80 range, but were difficult to assess because of preceding seizures and heavy medication. The post-surgical recovery was excellent and more rapid than in the preceding patient, with no mutism or akinesis of the left arm after the 2nd day. The severe apraxia to verbal commands that has persisted in the preceding case was apparent here only in the early postoperative weeks. The patient's temperament, I.Q., swimming strokes and many other general features of behaviour appeared to have suffered little if any impairment. There were complaints, however, of reduction in vitality, initiative and memory that cannot be ascribed entirely to commissurotomy until possible involvement of the fornix is ruled out. Unlike Case I (Gazzaniga *et al.*, 1963), this person was able to localize verbally or by pointing with either hand, cutaneous stimulation across the mid-line on the torso and proximal extremities suggesting greater bilaterality in the cerebral representation of each cutaneous half-field. To what extent this is a reflection of natural individual variation rather than prior brain damage, remains a problem. The body map for cutaneous sensibility was much like that of Case I, however, when the tests involved more complex discriminations beyond that of mere localization of simple point stimuli. Postoperative testing through the 40th week included determinations of visual acuity and extent of visual fields, verbal and manual responses to tachistoscopically presented visual stimuli, retrieval, matching, transfer, preference block design and reading tests plus other tests of motor and somatosensory function. The testing sessions, carried out in the laboratory or in the patient's home, averaged about two hours every second or third week and totalled some hundred hours. The results in this second case are basically similar to those obtained in the first patient and can be most easily presented in terms of the differences that have appeared.

As in the first patient, all tests indicated a complete separation of the perceptual, cognitive and mnemonic activity of the left and right hemispheres in all the visual tests. Anything seen, comprehended or remembered as a result of lateralized input restricted to one hemisphere, could not be used to aid in any direct way responses that emanated from

the other hemisphere. In even so simple a performance as nodding the head "yes" or "no" to indicate whether red and green colours flashed to left and right fields were the same or not, there was no sign of cross integration. The same was true in attempts to tell whether broad lines or bars running from left to right field through the fixation point were straight or broken at the middle (fig. 4A). So far, we have found no evidence that what is perceived in the right half-field has any influence on the perception or comprehension of what is seen in the left half-field.

The most marked difference between the two cases was seen in the ability of the second case by the sixth postoperative month to use either hand in responding to unilateral cerebral input or to verbal instructions. When a perceptual or cognitive activity was centred or confined to one hemisphere, motor expression was usually better with the favoured or primary hand but fair to good response was also possible in many performances with the secondary hand ipsilateral to the working hemisphere. There was no difference between ipsilateral and contralateral combinations in reaction time to a simple flash of light in either half-field. This good control and use of the secondary hand in many activities tended to obscure the earlier evidence of hemispheric independence. For example, sketches of the Necker cube that in early months could be performed only with the left hand, indicating specialization of the right hemisphere, would be carried out with either hand by the seventh month after the operation.

Even so, when separate and different stimuli were projected to each hemisphere simultaneously, the patient tended to respond in a manner indicating that for each hemisphere, the contralateral hand was definitely favoured over the ipsilateral one. For example, when stimulus pairs (fig. 4C) were presented tachistoscopically and the patient was asked to pick out the "seen" stimulus from a series of sample cards, she characteristically picked only the "triangle" when she was working with the right hand. When responding with the left hand, she regularly ignored the figure in the right field and chose the one that appeared in the left half-field, in this case, the square.

The patient could write and execute printed commands only with the right hand during the early months after the operation. Subsequently, the control of the left hand by the left hemisphere improved, until the left hand could also be used for these purposes though generally not so well as the right. Hand use, *per se*, thus became much less valuable as a criterion of which hemisphere was active than it had been in the first case or during the first several months in the present case and it became necessary to rely more and more on speech for this purpose.

High to perfect scores were obtained for the discrimination and comprehension of patterned stimuli presented to the right hemisphere (fig. 4B, E) in a variety of retrieval and matching tests that included words and numbers with non-verbal responses. Her performance in this respect was

strikingly superior to that of Case I with known damage in the right hemisphere. Though able to comprehend written material in either field, Case II showed no ability at all to put together a longer word or a compound word that fell half in one field and half in the other (fig. 4D). With such a word as "heart" for example, with the fixation point falling between "he" and the "art," she would describe only the word "art." Other results involving symbolic capacities of the hemispheres will be reported elsewhere.

Discussion

It is evident in the foregoing that surgical disconnexion of the hemispheres, with the resultant separation of the cortical representation for right and left halves of the visual field and for right and left limbs, produced in both cases clear-cut functional disturbances that correlated directly with the anatomical separations effected by the surgery. Performances in which the visual inflow was restricted to one hemisphere and the response involved only the hand for which the primary cortical representation was in the same hemisphere, were little affected, whereas those performances requiring interaction or direct cooperation between the two hemispheres showed marked disruption. Activities that involved speech and writing were well preserved but only in so far as they could be governed from the left hemisphere. It was clear that visual information did not transfer from one hemisphere to the other. Nor was there evidence that the perceptual activities of one hemisphere influenced the other, for both cases failed to achieve even the simplest sort of integration between the two visual half-fields.

The impairment of ability to make certain responses with either hand to material seen across the mid-line of the visual field, especially pronounced in Case I, indicates that in the human brain the corpus callosum in the intact condition plays a major role in the mediation of those responses in which the sensory input is directed to one hemisphere and the primary motor control lies in the other. This conclusion is contrary to a prevailing impression that in man the corpus callosum plays little or no part in such activities (Paillard, 1960). The present findings in this regard are also quite different from those obtained in split-brain cats where the visual input into one hemisphere could be used during a learning situation to guide the ipsilateral forepaw as well as the contralateral forepaw (Schrier and Sperry, 1959). Results more in line with the present have been obtained in split-brain monkeys where significant deficits have been observed in activities that pair an eye with the ipsilateral hand (Downer, 1959; Trevarthen, 1962; Gazzaniga, 1964). These comparative observations, though still meagre, suggest that the cortical control in each hemisphere for the ipsilateral upper extremity becomes proportionately less proficient as one ascends the evolutionary scale, while the corpus callosum

becomes correspondingly more important in mediating such activity. This appears to be in part a matter of the relative importance of distal versus proximal movement in limb use, the latter being more subject to bilateral control by either hemisphere. At the same time, the severe apraxia seen in Case I and in some of the earlier reports where chronic lateralized cerebral damage was involved (Sweet, 1941; Bremer *et al.*, 1956; Geschwind, 1962) may have caused an unnatural dependence on the commissures and lead to some exaggerated conclusions regarding praxic functions of the corpus callosum.

The disconnected right hemisphere displayed subtle perceptual capacities as well as good comprehension for both the testing situation and at times the test stimulus itself. In this regard, results from Case 2 are especially clear in demonstrating that each of the separated cerebral hemispheres is capable of these higher mental functions. The upper limits of such function in the minor hemisphere, for the most part, remain to be determined.

The exact cause of the first patient's inability to read for a sustained period of time remains uncertain. A new set of eye-movement patterns and attention-forming mechanisms would be called for to compensate for the inability to comprehend the print on the entire left half-field. Excess scanning movements of the eyes stimulated by the need of more information from the left field might lead to a distracting fluctuation of attention between the two hemispheres. That a similar reading difficulty has not appeared in Case II suggests that pre-surgical brain damage may be a critical factor in the first case. In general, however, it remains a problem as to what extent the observed differences between the patients should be ascribed to pre-existent brain damage and how much to natural individual differences in brain organization. Cerebral dominance and lateral specialization including language functions along with the unsolved functions of the corpus callosum and other commissures would appear to be subject to a considerable range of individual variation.

One of the interesting questions regarding lateral specialization in the human cerebral cortex concerns the nature of the specialized functions allocated to the so-called minor or nondominant hemisphere. A number of studies based mainly on patients with unilateral cortical damage suggest that the perception of certain kinds of spatial relationships, the recognition of faces and certain non-verbal auditory functions like timbre and tonal memory, are among those that are more highly developed in the minor hemisphere (Hécaen *et al.*, 1951; McFie and Zangwill, 1960; Piercy *et al.*, 1960; Milner, 1962; Piercy and Smith, 1962). Commissurotomy cases, in which both hemispheres remain essentially intact but separated, offer obvious advantages for the testing of such lateral specialization. To a considerable degree, the properties of each hemisphere are reflected independently in the performance of the appropriate hand, especially in the

first patient and during the first months in the second case. The superior performance of the left hand over the right in the block design test, drawing and other simple tasks that incorporated spatial relationships observed in both patients offers striking support of the previous inferences that this aspect of visual activity is represented principally in the right hemisphere. Again it would seem that the corpus callosum in the normal brain must play a critical role in serving to integrate this component of visual function with others specific to the left hemisphere.

In regard to the foregoing, it is also of interest to note that while both patients were incapable of reconstructing Necker cubes, block designs and the like with the right hand, they were capable of matching the test stimulus by simply pointing with this hand or indicating the correct design among a sampling of five related patterns. This shows that the primary perceptual capacity of the left dominant hemisphere is capable of discriminating between correct and incorrect reconstructions. Since it is also true that both patients have no motor problems with the right hand, the difficulty in reconstruction in these visual tests must lie somewhere in between these two systems. The further tentative conclusion may thus be drawn from these cases that the lateral specialization lies more in the motor executive or expressive sphere than in the sensory-perceptual components of the performance.

These same problems and the analysis would appear to apply to the speech mechanism as well. Tests now in progress suggest that the disconnected right "non-speech" hemisphere may have a similar capacity to comprehend and to match written or spoken words at a rather high level but yet not be capable of expressing the comprehension through speech.

The total picture of the cerebral disconnexion syndrome as exhibited by Case 2 above, comes considerably closer to that depicted in the Akelaitis-Van Wagenen series (Akelaitis, 1941, 1943, 1944; Van Wagenen and Herren, 1940) than does that of our first case. This is attributable in the main to the greater motor control in each hemisphere for the ipsilateral side. Absence and impairments of right-left integration in gnostic functions, however, become strikingly apparent with application of critical tests. All the data are consistent with the earlier conclusion that surgical disconnexion of the hemispheres results in a splitting and doubling of most of the gnostic or psychic properties of the brain (Sperry, 1961*a*, 1961*b*). The normal unity of perceptual awareness in the primate brain may be inferred to be dependent to a large degree on the cerebral commissures, especially the corpus callosum. The functional separation of right and left mental spheres that is produced by cutting the commissures was strikingly evident in a number of the above testing situations, to the point as described where left and right hemispheres were attempting conflicting solutions to the same task.

SUMMARY

(1) This is a report of two cases of surgical disconnexion of the cerebral hemispheres in man effected by a complete transection of the corpus callosum and the anterior and hippocampal commissures, with separation of the massa intermedia.

(2) In this paper we discuss principally the responses of these patients to tests of visual functions.

(3) Performances in which the visual inflow was restricted to one hemisphere and the response involved only the hand for which the primary cortical representation was in the same hemisphere were little affected, whereas those performances requiring interaction or direct co-operation between the two hemispheres showed marked disruption.

(4) Activities that involved speech and writing were well preserved, but only insofar as they could be governed from the left hemisphere. It was clear that visual information did not transfer from one hemisphere to the other.

(5) The observations gave some support to previous views concerning lateral specialization of function in the human cerebral cortex as between the major and minor, or non-dominant, hemisphere.

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