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Dyspraxia Following Division of the Cerebral Commissures

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THE BASIC picture of the cerebral deconnection or split-brain syndrome[1] has been extended and elaborated in recent years through the study of some patients in whom cerebral commissurotomy had been carried out by P. J. Vogel at the White Memorial Medical Center, Los Angeles, in an effort to curb severe epileptic seizures not controlled by medication.[2,3] Earlier descriptions of these cases dealing with visual, tactual, and language functions primarily indicate that the two separated hemispheres function quite independently with respect to most mental or gnostic activities.[4-8] In brief, speech, writing, and calculation, plus visual gnosis for the right half visual field and stereognosis of the right hand, were found to be lateralized in the dominant left hemisphere, while stereognosis of the left hand and visual gnosis of the left half visual field were found restricted to the right minor hemisphere. Other functions including some aspects of language comprehension and the perception and construction of spatial relationships were found bilaterally but unequally represented in the two hemispheres.

The present report is focused on the motor symptoms in this same series of patients. With the main motor cortical controls for the right arm and leg located in the left hemisphere and those for the left limbs in the right hemisphere, section of the commissural cross-connections poses obvious problems for motor control and coordination particularly where a performance triggered and directed from one hemisphere involves skilled movement in the distal extremities of the limb or limbs represented in the opposite hemisphere. Other problems in motor control arise in relation to cerebral dominance, the mediation of attention and volition and bimanual activities that involve mutually dependent interactions between right and left limbs. The extent to which praxic disturbance is actually observed following cerebral disconnection, however, has been a matter of considerable disagreement in both the experimental and clinical studies. At one extreme observations like those of Liepmann,[9] Downer,[10] Gazzaniga and associates,[4] and Geschwind[11] have emphasized the severity of the motor dyspraxia produced by callosal lesions, whereas others have stressed the mildness or absence of the same motor deficits.[6,12-21]

Passing reference to many of the motor symptoms described below has been made in earlier reports in connection with other aspects of functional impairment. The following is an attempt to bring together in a more unified account these and further observations on motor control.

Case Material and Acute Neurologic Changes

A total of nine patients were available for study, all of whom had undergone essentially the same extensive disconnection of the cerebral hemispheres in a single operation that included complete section of the corpus callosum and anterior commissure. The hippocampal commissure is presumed to have been sectioned along with the callosum in all patients. In three patients the massa intermedia was also sectioned and in three others it was judged to be absent. All nine were right handed.

Two patients in particular were selected for special study on the basis of their smooth rapid recovery from the surgery and because complications including extra-commissural brain damage appeared to be at a minimum. With the

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aim of determining the chronic symptoms produced by pure lesions of the commissures, we have based most of the following description of the long-term deconnection symptoms on these two patients, using the others only for general comparisons and indications of the variations in symptoms that may occur with coexistent brain damage. On the other hand, it should be pointed out that the seizures in both of these individuals apparently stemmed from birth injuries. Accordingly, it is possible that these two individuals represent a higher than normal degree of bilateralization of cerebral function with the severity of their commissurotomy symptoms correspondingly reduced.

Accurate determination of the nature of praxic function during the first week following surgery was difficult due to much variation between and within individuals. All patients except one who was operated on from the left side showed good control of movement of the right arm and leg within a few hours after surgery. At the same time all patients showed in some degree left-sided apraxia to verbal commands. For example, spoken commands such as "Raise your left arm," "Move your left foot," "Make a fist with your left hand," could not be carried out. In one patient, control for this latter type of response was recovered by the end of the first postoperative day while in most of the others it had returned by the end of the first week. In patients where the extra-callosal brain damage was considered to be greater these deficits were more pronounced and in the first patient they still remain severe five years following surgery. During the time when the left-sided apraxia to verbal command was present, patients could usually carry out the same act if the requested movement was demonstrated by the examiner.

It does not necessarily follow that this apparent early asymmetry in praxis reflects a true asymmetry in the basic physiology of the commissures related to cerebral dominance. Movements of the right hand governed by the right hemisphere were just as severely affected. For example, the ability to draw with the right hand an object seen in the left half visual field or held in the left hand out of sight was also presumably impaired at this stage since this impairment was evident later. In brief, it appeared to be the manual responses governed by the homolateral hemisphere that were most affected, with the impairment present on both sides.

Hypotonia was found to be somewhat more pronounced in the left arm than in the right and lasted for at least several hours after return of consciousness, persisting for nearly a week in some patients. On the right side hypotonia was evident only briefly, if at all, and forced grasping, when present, lasted only a few days at most. The plantar reflex in all patients was initially extensor on both sides reverting to normal at a variable rate, and usually sooner on the right side than on the left. Early neurologic asymmetries could be ascribed, in part at least, to the unilateral surgical exposure and retraction. The acute phase of recovery was further complicated by variables associated with diaschisis, age differences, and differences in extent and duration of extracerebral damage. A general trend was nevertheless evident that resembled somewhat that seen in recovery from hemiplegia.[22] Thus an initial hypotonicity in the left limbs was succeeded by a paresis with extensor plantar reflex in the foot and tonic grasping in the hand followed by a gradual return to normality. This included a phase of idiokinetic apraxia of variable duration from which, as mentioned above, some patients have not completely recovered. Also as voluntary control of the left limbs returned, proximal control typically appeared before distal control was possible. Thus responses of the left arm and thigh to a verbal command returned before left toe movement which in turn reappeared before left wrist and finger movement. Movements of the entire left hand, such as opening and closing a fist, were present before there was control of individual finger movement.

The foregoing picture of dyspraxia and the general recovery trend was evident mainly in the left, not the right, extremities. This may be attributed in part to the constant prevalence of dominant activity in the left hemisphere. The above motor symptoms appear almost entirely under conditions where the limb in question is being governed from its homolateral and not its contralateral hemisphere. Since the right hand was almost constantly engaged in activity of some sort going on in the major hemisphere, this direct contralateral action tended to obscure any deficits in ipsilateral control of the right hand by the right hemisphere. When these symptoms were seen they had to be elicited by specific testing conditions. Even then, however, they were occluded much of the time by incidental processes going on in the major hemisphere.

Observations: Chronic Motor Symptoms

Left Hemisphere Controlling Dominant Hand.—All patients were able to respond in normal fashion with the right arm, hand, leg, and foot to stimuli presented to the left hemisphere, ie, through sensory stimulation of the right hand or right half visual field. The same was true for auditory or general visual input that had to be processed in the major hemisphere like complex linguistic or mathematical instructions.

The lateralization of motor control to the left hemisphere in these tests could be achieved most directly by confining the sensory input to the right half visual field. When a spot of light was flashed to any point in the right visual field, it could easily

be pointed to accurately with the right hand. Similarly, simple geometric shapes flashed to the right field could easily be outlined or drawn correctly with the right hand. Fine control of individual finger movements was evident in tests involving blind manipulation of objects by the right hand, localization of stimulated points on the fingers, and the mimicking of hand, thumb, and finger postures from sketches presented to the right half visual field.

Pictorial material and words presented to the right visual half field could be named or described in writing with the right hand with normal facility. Written commands tachistoscopically presented to the right visual field for movement of the right hand such as "point," "tap," "rub," "grip," etc, were easily and correctly performed. In other tests the examiner would set the patient by instructing him to point to whatever part of his head or body was named in flash presentations to the right visual half field. Again the patients had no trouble in pointing correctly to eyes, nose, neck, mouth, ears, cheeks, etc. In short, no motor impairment was observed in performances that combined movement of the right hand with control from the major hemisphere. It may be noted, however, that these tests were designed mainly to detect differences between the minor and major hemispheres and between contralateral and ipsilateral control systems. Like most of the tests we have applied to date these tasks did not serve to tax the upper limits of performance on the dominant side.

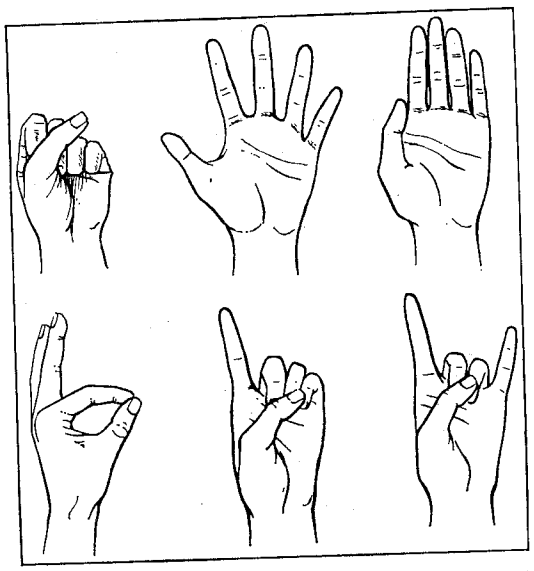
Selective dyspraxia of the right hand in copying geometric figures and in working block design tests was pronounced in an earlier patient,[4,23] and also appeared to varying degree and duration in the other patients, affirming the superiority of the minor hemisphere for spatial constructional tasks. The condition probably persists chronically in all patients to some degree, especially with respect to the control of finger movement, but its manifestation tends to be obscured by the reinstatement of ipsilateral control from the right hemisphere.

Written commands to turn the head "left," "right," "up," or "down" gave no trouble when presented to the left hemisphere, and printed commands for facial movements like "smile," "frown," "hum," "laugh," "chew," "blow," etc, also were carried out correctly. That is, movement of the proximal and axial structures, like that of the right limbs, remained unimpaired when control was through the major hemisphere.

Left Hemisphere-Subordinate Hand.—Performance with the subordinate hand was also tested in similar tasks that involved sensory input and control from the major hemisphere. In general the performance with this ipsilateral system, left hemisphere to left arm, went well as long as the response could be carried off without specific control over the distal musculature. Thus the patients could readily point to an object in the left visual field and could trace or draw its outlines, either in the original position in which it was seen or on a piece of paper. When single printed words were flashed tachistoscopically to the left hemisphere they could generally be written out with the left hand and the same was true for word or number answers to verbal or arithmetic problems presented orally. The writing of the left hand was more hesitant, gross, and crude than that of the right hand, and it tended to break down easily and to fail as free shoulder, elbow, and body movements were restricted.

This ipsilateral control from the dominant hemisphere appeared at its worst in tasks in which the left hemisphere was required to direct the individual fingers of the homolateral hand. For example, when points were stimulated on the fingers and palm of the right hand all patients were extremely poor at indicating the matching points on the left side by movements of thumb and fingers of the left hand. The left hand performed these same movements easily, of course, when stimulation was on the same side. The foregoing impairment persists for years even when the same patients demonstrate good ipsilateral left hand control at the shoulder and elbow.

Similarly, when outlines of the hand and fingers held in a variety of postures are flashed to the major hemisphere the patients readily mimic the posture with the contralateral right hand but usually fail with the left hand (Figure). Correct responses were obtained with the left hand only in mimicking the most simple postures like making a fist or extending all digits at once. The same postures and movements required in the above tests could be performed easily by the left hand when the cortical control was shifted to the right hemisphere by presenting the sensory stimulus through the left half visual field or the left hand.



Sample drawings of different hand postures that were flashed to left and right visual half fields to test capacity of each hemisphere to mimic given posture with ipsilateral and with contralateral hand.

Right Hemisphere-Subordinate Hand.—As already indicated, good performance is the rule in nonverbal tests in which the sensory information is projected to the right hemisphere for readout with the left hand. Fine individuated finger movements and good differential mimicking of hand, thumb, and finger postures are readily demonstrated under these conditions. The left hand also can draw geometric outlines that have been identified by the left hand or through the left half visual field. Objects like cigarettes, keys, glasses, eating utensils, etc, including small pins and thumbtacks and the like, are manipulated correctly and with highly refined delicate movements of fingers and thumb. Movements of the left leg and foot similarly show a normal order of facility in various nonverbal tests involving control from the minor hemisphere. The same is also true for movements of the head and trunk.

Right Hemisphere-Dominant Hand.—The greatest impairment detected with nonverbal testing was seen in tasks in which the minor right hemisphere was called upon to control movement of the right hand. Fairly good performance was obtained in tests that involved a simple direct response like pointing to an object or tracing the outline of something flashed to the left visual field. Responses of this kind involve shoulder movement mainly. At times the patients could also draw correctly with the right hand various simple geometric shapes prsented to the left half visual field or to the left hand out of sight. The results were erratic, however, and failures were more common. To what extent the poor performance in these latter tests reflected an inadequate control system from the right hemisphere to the motor centers for the digits is not certain. Oftentimes one gained the impression that the difficulty lay in the competition for right hand control that came constantly from the major hemisphere. The effect of such interference was tested by deliberately presenting a second stimulus simultaneously to the major hemisphere. Under these conditions the ipsilateral manual control seemed to be easily overpowered at any time by the contralateral system whenever the opposite hemisphere decided at the same moment to make a different movement in the given hand. In other words, the right hemisphere could direct the right hand toward a particular object only if the left hemisphere did not at the same time have contradictory information as to what it thought the right hand ought to be doing. Similarly, a triangle flashed to the right hemisphere could be drawn by the right hand provided some other figure was not also flashed to the left hemisphere at the same time. In the latter case the right hand consistently drew the figure seen through the left hemisphere.

Minor Hemisphere Performance With Verbal Input.—It has been pointed out elsewhere[4-8,19,20] that visual material presented to the left half visual field or objects placed in the left hand cannot be described by any of these patients either in speech or in writing. This condition has persisted through the years in all patients with little or no change. These and related results support the conclusion that the organization of speech and writing is confined almost entirely to the major hemisphere. Whenever a written or spoken response is required for stimuli presented exclusively to the minor hemisphere the performance, therefore, fails as a rule. The possibility that the minor hemisphere can trigger a few simple words and phrases under special conditions, however, is by no means excluded, in the evidence to date. This latter question has not been tested specifically.

In other tests that involved presentation of linguistic and arithmetic material to the minor hemisphere for simple manual readout with either left or right hand, striking

impairments were also evident. The severe apraxias and dyspraxias observed under these conditions require special treatment, because the basic defect is presumably attributable, not to any direct impairment in motor control as such, but to the low capacity of the minor hemisphere to comprehend and process the linguistic and mathematical symbols involved.

It was difficult to determine the extent to which a voluntary action can be carried out in response to verbal material presented exclusively to the minor hemisphere. Previous studies showed that the right hemisphere can read, comprehend, and remember the names of familiar objects.[6-8,19,20] Words flashed to the left half visual field could not be spoken or written by the patient, but an object that best matched the test stimulus could be retrieved with the left hand from among a series of unrelated items. The volitional act of searching with the left hand in such tests, however, might conceivably have been prompted from the major hemisphere and also stopped from the major hemisphere in response to reflexive movements that occurred when a correct match was found.

In further tests more specifically aimed at this question of whether volitional actions can be triggered by verbal commands presented exclusively to the right hemisphere, simple verbs and action nouns of various kinds were tachistoscopically presented in the left visual field. One series required the patient to make appropriate facial responses to words like "smile," "laugh," "nod," "frown," "chew," etc which involve a motor system that has bilateral representation in each hemisphere. In other series the patient was required to move the left or right hand appropriately to commands like "tap," "squeeze," "point," "knock," etc. In all such tests the patients displayed almost complete inability to make appropriate responses to these simple commands.

Further tests indicated that the difficulty was not in making the required movement, but rather in comprehension of the words. If, instead of presenting the word "knock," a picture of the same gesture was flashed to the right hemisphere, there was no problem in using the left hand to make the given movement. Further when the test required that the left hand be used merely to point to a picture card among a series portraying the flashed word, such as "knock," the performance level was poor. Inability to perform this type of task, which was readily carried out with object nouns, suggests that this category of language is represented very poorly if at all in the right hemisphere. Reactions that could not be carried out by the left hand nor through head nodding after verbal presentation to the minor hemisphere, could not be performed with the right hand either, nor with the left foot or any other means of expression.

Bimanual Control.—The present patients were fairly good at coordinate use of the two hands in activities like juggling, or catching thrown objects. One patient described by Akelaitis et al[12] could play the piano and type by touch after complete section of the callosum. It would appear that much of the coordinate control involved under such conditions must come from the single dominant hemisphere, attending to a single unified activity. Impairment in the ability to do two different things concurrently with the hands, as in writing with the right hand while sorting cards with the left, was stated to be the most consistent symptom in the Akelaitis series.[12] A few tests were run on the present patients in which each hand was required to respond to a different stimulus presented separately to the contralateral hemisphere thru the corresponding visual half field. Two visuotactile tasks that could easily be carried out singly broke down when the two were presented together, one to each hemisphere. One or the other often succeeded but usually not both indicating interference. However, in double reaction time tests it was found that the two hemispheres could work together. While one performed a color discrimination, the other made a brightness discrimination and each then simultaneously made a selective response to the proper key with the corresponding hand. Unlike normal subjects the commissurotomy patients performed the double discrimination task as rapidly as the single task.[24] In related studies carried out on the monkey (M. S. Gazzaniga and E. D. Young, unpublished data), it has been found that the split brain monkey can process and respond to more perceptual information involving bimanual motor sequencing than can commissure-intact controls. The poor performance of the human subjects on simultaneous double tasks may be attributable, perhaps, to the overriding dominance of the left hemisphere and the consequent interference with the ongoing activities of the less assertive hemisphere on the right.

Comment

In the foregoing observations along with related data from animal experiments,[15-17] one can see possible explanations for some of the contradictions in preceding accounts of the motor symptoms of hemispheric deconnection. The discrepancy between the present observations that correspond closely with those of Akelaitis[12,13] and our earlier findings in one patient that correspond with the descriptions of Liepmann[9] and Geschwind[11] as well as similar differences in the animal literature may be largely resolved along the following lines. After pure lesions of the commissures in which each hemisphere is preserved in good functional condition, the capacity of the two hemispheres to direct ipsilateral as well as contralateral movement makes for a minimum of praxic disturbance. Even writing may be carried out with the subordinate hand guided from the major hemisphere. However, these ipsilateral control mechanisms are less proficient and particularly they are more delicate and more easily disrupted than are the contralateral systems. Hence, complications in the form of preoperative lesions or other extracommissural damage resulting from surgical trauma may impair or eliminate the delicate ipsilateral control mechanisms while sparing function in the more robust contralateral system.

Between the extreme in which minimal extra cerebral damage is present and that at the other end of the spectrum in which only the more stable elements of contralateral control are preserved, lie many intermediates in the motor syndrome. The picture is further complicated by the functional plasticity of the neocortical commissures and the consequent individual variations in functional pattern that develop in the commissures as a result of differences in training and maturation and particularly in response to asymmetric cerebral damage.

The ipsilateral control appears to be strongest for movement of axial structures in head, neck, and trunk and weakest over the thumb and fingers especially of the right hand. Considerable individual variation is to be expected again in the ipsilateral control of the digits correlated in part with training but also probably with inherent differences in the distribution of uncrossed components in the corticospinal and related motor systems.

It seems clear that ipsilateral control is more proficient with the corpus callosum intact. This could mean that one hemisphere normally sends detailed instructions for muscle contraction into the motor cortex of the opposite side, but there are alternative possibilities. It appears best at this stage to recognize that the exact nature of what is transmitted by the callosum in different kinds of activities is still not understood.

Related problems remain in connection with the initiation of voluntary responses and the extent to which volition is centered in the major hemisphere. The presence of speech, writing, calculation, the bulk of language comprehension, and all the ideation dependent on these would strongly favor the use of this major hemisphere for the decisive triggering and directive guidance of motor activity. Except in those special testing situations in which considerable care was taken to evoke leading voluntary action from the minor hemisphere and in particular tasks like constructing block designs one got the impression that the separated major hemisphere was in command most of the time. The inability of the minor hemisphere to respond to even simple verbal input for select actions compared to its ability to comprehend moderately sophisticated names of objects suggests a correlation with the lateralization of conscious volition. Only the outlines of these and related problems are discernible at present.

Summary

Praxic disturbances observed in a series of nine patients with complete section of the neocortical commissures ranged considerably in nature and severity depending apparently on factors such as age at operation, reeducative activity and degree, and distribution and duration of associated cerebral damage. Two of the nine patients having smooth, rapid recovery from the surgery and an apparent minimum of associated symptoms were selected for special study as being most representative of pure lesions of the commissures.

The overall picture of praxic disturbance in these selected cases was mild and resembled that described by Akelaitis and coworkers in the early 1940's in contrast to the more severe symptoms outlined by Liepmann and others and observed by us in an earlier case.

Except for fine differential movements of thumb and fingers, each hemisphere ap-

peared to exert volitional control over the movements of the homolateral as well as contralateral limbs.

The most pronounced deficiencies were evident with lateralized visual input in tasks where the right hand had to be directed from the right hemisphere.

It would appear that many of the contradictions in earlier descriptions of dyspraxia following callosal lesions may be accounted for in terms of the varied extent to which the ipsilateral motor control mechanisms were disrupted by extracommissural cerebral damage, diaschisis, and related effects.

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LIBERAL INSTITUTIONS

Liberal institutions immediately cease to be liberal, as soon as they are attained; afterwards, there are no more mischievous or more radical enemies of freedom than liberal institutions.

The same institutions produce quite other results as long as they are fought for; they then, in fact, further freedom in a powerful manner.—Nietzsche