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DIFFERENTIAL-HANDED RESPONSE TO VERBAL AND VISUAL SPATIAL STIMULI: EVIDENCE OF SPECIALIZED HEMISPHERIC PROCESSING FOLLOWING CALLOSOTOMY

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Abstract—Left- and right-hand responses were studied in a patient who had undergone complete corpus callosotomy to examine selective hemispheric processing employing free-field stimuli. Tests of verbal and visual spatial processing were presented, and multiple choice performances were obtained using both left and right hands. A double dissociation emerged, with superior left-handed performance on visual spatial tasks, and better right-handed performance on verbal tasks. In addition, the patient displayed hemispatial dyscalculia in which he solved written arithmetic problems disregarding free-field numerical information presented toward his left. Evidence of multimodality left-sided extinction was also present. Further, despite unilateral callosal apraxia, the left hand displayed superiority during a continuous performance task. These results demonstrate that specialized functions of the cerebral hemispheres may be observed for response output in the absence of restricted hemispheric input, and that components of the neglect syndrome may be seen following corpus callosotomy.

INTRODUCTION

THE STUDY of patients who have undergone corpus callosotomy or commissurotomy to control seizure frequency and intensity has greatly contributed to our understanding of the specialized cognitive functions of each cerebral hemisphere. The left hemisphere is dominant for linguistic tasks whereas the right hemisphere is superior for visual spatial processing. Split-brain studies have traditionally utilized tachistoscopic presentation of verbal and non-verbal stimuli to ensure that the material to be studied has been presented solely to a single hemisphere. Similarly, restriction of hemispheric input has been performed using somesthetic presentation with objects presented out of sight to a single hand [37].

In contrast to the multiple reports of left/right brain asymmetries based on controlled hemispheric input, relatively less information has been presented concerning cognitive asymmetry based on control of hemispheric output. BOGEN [7] described left-handed dysgraphia, in which the patients were unable to write with their left hands, and right-handed dyscopia, in which patients could not copy geometric designs with their right hands, to varying degrees in eight patients following commissurotomy. GAZZANIGA [14] reported superiority of the left hand in arranging blocks to match a sequence, and in copying a necker cube and three-dimensional house drawing.

The right cerebral hemisphere is specialized for visual spatial tasks, speech prosody, and

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attention directed toward external space [21, 29, 34]. Lesions to the right hemisphere may produce neglect syndrome, which may include hemi-inattention, extinction to double simultaneous stimuli, hemiakinesia, allesthesia, and/or anosodiaphoria. The neural substrate of neglect syndrome has been hypothesized to reflect impaired attentional-arousal systems secondary to neuronal networks that form the basis of corticolimbic-reticular interaction [20, 28, 41].

Neglect syndrome has not been reported to occur reliably in split brain patients. In BOGEN's early report [7], he noted a tendency for the left side of Greek cross copy to be defective when copied by the right hand. Similarly, neglect of the left-sided numbers when drawing a clock has been reported [23]. However, PLOURDE and SPERRY [30] observed no hemispatial neglect by callosotomy patients using the rod bisection task. Because of the frequency of anosognosia following right hemisphere lesions, the left hemisphere's capacity to identify and localize the left side of the body for "self" and for confronting person was also assessed. These tasks were satisfactorily performed; consequently, PLOURDE and SPERRY [30] argued that damage to the right cerebral hemisphere alone is insufficient to account for neglect syndrome.

Interhemispheric independence between verbal cognition and motor response was demonstrated by KREUTER *et al.* [25]. A split-brain patient was unable to maintain right-handed finger tapping while performing a complex verbal task, but was able to maintain finger tapping with the left hand while performing this task. When visual input is restricted to a single hemisphere in monkeys with both optic chiasm and corpus callosum sectioned, the hand contralateral to the hemisphere receiving input was used to perform visually guided movements [12]. Thus, the hemisphere actively processing the stimuli determined the hand of response. By extension, evidence of lateralized specialization should be observed in humans if output is initiated by only the right or left hemisphere during performance of cognitive tasks thought to maximally engage a hemisphere. In the present report, a variety of commonly employed neuropsychological tests were administered without controlling visual hemifield input (i.e. free-field) to a patient who had undergone complete section of the corpus callosum for seizure control.

CASE REPORT

Subject

J.M. was a 33-year-old, right-handed man who underwent a two-stage sectioning of the corpus callosum, sparing the anterior commissure [44]. A high school graduate with average performance, he attempted 1 yr of college but was forced to quit due to increasing seizure frequency that contributed, in part, to failing performance (grade point average = 0.9/4.0). His seizures began at age 14 after normal growth and development. The seizures were generalized tonic-clonic in type, refractory to all major anticonvulsants, and of unknown etiology. A positive family history of seizures was present, with his maternal grandmother's sister and paternal uncle suffering seizure disorders. CT scan performed 2 yr prior to initial surgery was normal, and EEG at that time revealed epileptiform spikes in the right mid-temporal region with paroxysmal background slowing. EEG performed 1 yr prior to his initial surgery contained multiple bilateral independent spike and wave discharges. J.M. was left hemisphere language dominant by intracarotid sodium amytal testing. Preoperative neuropsychological testing was not conducted by the psychologist previously assigned to the case.

The anterior 2/3 of the corpus callosum was sectioned on 2/24/84. After no significant seizure relief was obtained, the posterior 1/3 of the corpus callosum was sectioned on 10/22/85. MR scan revealed division of the corpus callosum without additional lesions (Fig. 1). The patient was tested 6 months following the second operation, and again 12 months later. Seizure frequency was brought under better control following his second operation. Although the seizures tend not to be as severe, he still experiences weekly seizures.

Neurobehavioral screening. J.M. was examined for evidence of standard disconnection signs. The session was videotaped for subsequent review. Line drawings of common objects were presented to either hemifield for approx. 1 sec with J.M. instructed to maintain his vision at midline. Since we were unable to employ tachistoscopic

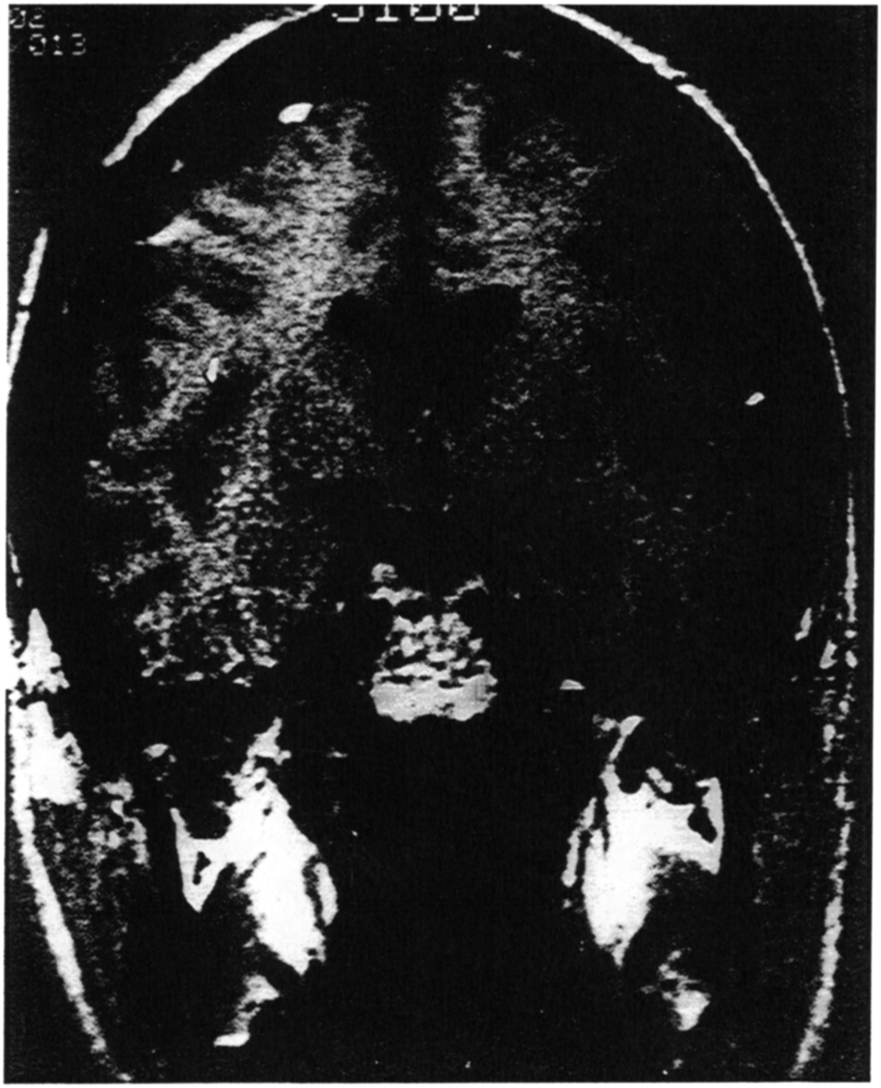

FIG. 1. Coronal MR scan following initial surgery. Note that fibers of the corpus callosum are completely severed.

presentation, we continued to present pictures randomly until four stimuli were presented to each hemifield without J.M. deviating his gaze.

Tactile naming was assessed by using the Neurosensory Center Comprehensive Examination of Aphasia (NCCEA) subtest [38]. Common objects were presented out of sight to each hand, and J.M. was requested to name the presented object. Tactile-visual matching, also from the NCCEA, was tested by presenting objects out of view to a single hand, and then having J.M. point to the identical object from an array with his other hand. An eight item visual naming control was administered later to ensure that any performance deficits were not due to object naming difficulty.

Cross-replication of hand posture and finger localization were obtained. For hand posture replication, J.M.'s hand was placed in position behind a screen, and he was instructed to put his contralateral hand in the same posture. Similarly, for finger localization, a single digit was touched and J.M. was asked to indicate on his other hand the corresponding finger stimulated.

Neuropsychological evaluation The battery of neuropsychological tests included a combination of tests in widespread clinical use, and specialized tests to systematically investigate differential response output. Wherever possible, responses were obtained using a single hand. The tests were then readministered with J.M. responding with his other hand. Hand of initial response was alternated.

General cognition. The Wechsler Adult Intelligence Scale—Revised, Wide Range Achievement Test (Level-2)—Revised (WRAT-R), and Peabody Picture Vocabulary Test-Form L (PPVT) were administered. The WAIS-R contains 11 subtests assessing verbal and non-verbal reasoning, attention/concentration, and speed of response. Due to extreme response slowness by the patient, the WAIS-R Performance subtests were scored without strict adherence to standard time constraints. The WRAT-R [22] is a test of academic achievement, and contains subtests assessing written spelling, oral reading, and written arithmetic. The PPVT [13] is a receptive sight vocabulary test in which the patient is read a word, and then selects one of four pictures that best illustrates the word.

Visual spatial tasks

Complex figure. Two forms of the complex figure were employed [33, 40]. The subject is requested to copy the figure which consists of 18 scorable elements. Due to the significant amount of time required for left-handed drawing, immediate and delayed recall was performed only with the right hand.

Judgement of line orientation. This task requires the patient to identify the spatial orientation of lines by indicating which lines from the response card are in the same orientation as the standard [4]. This task has been shown to be a relatively pure, non-complex measure of right hemisphere functioning [5].

Visual discrimination test. This test of visual perception and discrimination presents 20 items to the patient [42]. The item in the center of the page is the target, and the subject is to indicate which of the peripheral four figures (one in each quadrant) is identical to the target.

Greek cross copy. The task from the Reitan-Indiana Aphasia Screening Test [32] is to copy a cross.

Facial recognition. This test assesses the capacity to discriminate photographs of unfamiliar faces [4]. It consists of matching identical front-view photographs, matching front-view with three-quarter view photographs, and matching front-view photographs with pictures obtained under different illumination.

Colored progressive matrices. This test contains 36 geometric patterns with a portion of the pattern omitted [31]. A combination of strictly visual-perceptual (incomplete figures) and spatial patterning/analogy designs is presented. The subject is to select the correct answer from a series of 6 to 8 choices that correctly completes the pattern.

Line bisection. This task requires the patient to place a mark in the center of lines of differing length that are distributed in various orientations on a single page.

Rey memory screening. This is a screening test originally devised by REY [33] to detect malingering. The test stimulus consists of five rows, each containing three elements. The test card is presented to the patient for 10 sec, and it is emphasized that the card contains 15 elements. However, each row contains items that are conceptually related, making it a task that all but the more seriously impaired patients can perform adequately [15].

Cancellation tests. We administered a verbal letter cancellation task in which the subject is instructed to cross out each occurrence of the letter "A" presented in a regular array of letters [29].

Continuous performance test. This is a test of sustained visual attention [35]. Letters of the alphabet are randomly generated on a microcomputer for a 5 min period at the rate of one/sec. The subject rests his hand on the space-bar, and is instructed to depress it following each presentation of the letter "X". Number of false positive responses is obtained in addition to number of correct responses.

Verbal tasks

Token test. This task from the Multilingual Aphasia Examination [3] is a modification of the test developed by DE RENZI and VIGNOLO [11]. Twenty-two commands are presented involving pointing and manipulation of 20 small and large circles and squares in 5 different colors. Two points are awarded if the subject executes the correct response on the first trial, and one point is given for success on the second trial.

Serial digit learning. This is a digit supraspan learning task [4]. A sequence of eight numbers is read to the patient, and the patient is instructed to learn the number sequence over repeated trials. However, unlike the standard administration, we constructed a response card containing the digits 1 9 in order that J.M. could indicate numeric sequence with either hand without an oral response. He was able to point to individual numbers with each hand satisfactorily.

Word recognition memory. We developed a verbal recognition memory test with visual input. We presented 10 words in a free-field format and instructed J.M. to read each word aloud. Multiple choice recognition was then obtained for four lists of 10 words following 20 min delay. For each trial, responses were obtained using each hand separately, and the order of response was counterbalanced.

Dichotic word listening. This task presents two different words to each ear simultaneously, and the subject is requested to identify which word he hears [10].

Sensory/motor tasks

Stereognosis. This task, from the Halstead-Reitan Neuropsychological Battery, requires the patient to match plastic geometric shapes presented out of view to a single hand.

Tactile form perception. This test consists of two sets of cards that contain geometric shapes cut out of sandpaper. The subject's task is to explore the figure, concealed from sight, with a single hand and to identify the shape from a multiple choice card [4]. In contrast to the standard assessment, J.M. was allowed to indicate his response using the hand that explored the figure. This is a test of tactile discrimination and recognition, but is of greater difficulty than the Halstead-Reitan stereognosis tokens.

Tests of extinction. To test tactile extinction, unilateral hand stimulation was performed randomly interspersed with double simultaneous hand stimulation. J.M. was instructed to verbally respond "left", "right", or "both" depending on the side of stimulation. In the visual modality, two conditions were administered, one in which he would respond verbally,and one in which he was instructed to point to the side(s) of stimulation. To test for auditory extinction, he was only required to point to the side of stimulation.

Finger tapping. This is a standard measure of fine motor speed. Five trials of 10 sec duration not deviating more than 10% were obtained with each hand.

Apraxia screening test. This is a supplementary non-language test from the Boston Diagnostic Aphasia Examination [16]. It contains a series of buccofacial, intransitive limb, transitive limb, and whole body commands that the patient is requested to perform with left and right hands individually. Imitation is requested if the patient fails to perform the task to command, and, if applicable, a real object is provided to the patient.

Ancillary tests

Selective reminding procedure. This is a serial word learning task in which the patient is prompted on each trial only of those words not spontaneously recalled on the preceding trial [8]. A word has operationally entered long-term storage (LTS) if it has been recalled on two consecutive trials, demonstrating the ability to recall without prompting. LTS score reported is the sum across trials. Continuous long-term retrieval (CLTR) is the number of words recalled from operationally defined long-term storage, summed across trials, in which the patient no longer requires subsequent reminding to elicit recall for the remaining trials of the test. We used Form 4 from HANNAY and LEVIN [18], and examined only his oral response.

Wisconsin card sorting test. This test requires the patient to sort cards into one of three different categories [19]. Ease of establishing response sets, and difficulty maintaining mental set once changed, are assessed. No differential hand of response was requested, and he was allowed to sort with either hand.

Prosody. We presented the sentence "The fish jumped out of the sea" with varying inflection (e.g. happy, sad, don't care), and the subject was instructed to point to a face expressing different emotions with a single hand. Five trials of each emotion were administered with the examiner standing behind the patient [34] and responses with right and left hands were obtained.

RESULTS

Traditional disconnection signs

J.M. was able to name easily all line-drawings presented to his right hemifield (4/4), but able to name 1/4 pictures presented to his left visual hemifield. J.M. displayed left unilateral tactile anomia, that is, the inability to name objects palpated with his left hand. He was unable to name any object in his left hand while correctly naming 4/8 of the right-handed objects. Performance on tactile-visual matching was intact for the right hand (7/8) but impaired for the patient's left hand (1/8). Visual naming of these same eight items was intact. He was unable to cross-replicate hand postures with either hand. Cross-replication of finger localization was poor, with J.M. able to cross-localize bilaterally the thumb and fifth fingers only. His ability to raise the hand contralateral to the one stimulated was grossly intact.

Although he could respond quickly following left hand stimulation (right hand raise), he had relative difficulty when the right hand was stimulated. In the latter condition, his left arm was lifted more slowly, picked up with his right hand, or not moved at all.

Cognitive performance

On the WAIS-R, J.M. obtained a Full Scale IQ of 71, which places his general level of cognitive functioning in the borderline range. A significant split between the verbal and performance subtests was present, with a verbal IQ of 79 and a performance IQ of 63. Age corrected scaled scores were as follows: information = 8, digit span = 6 (6F, 2R), vocabulary = 6, arithmetic = 7, comprehension = 5, similarities = 7, picture completion = 5, picture arrangement = 3, block design = 5, object assembly = 2, digit symbol = 1. Performance on the WRAT-R reading (Level 2) resulted in a standard score of 99; Performance on the spelling subtest resulted in a standard score of 98. The arithmetic subtest was not scored due to hemispatial dyscalculia, which we will discuss below. He obtained standard score on the PPVT of 75.

His FSIQ is incompatible with an average high school graduate, and we do not feel that this test fully measures his general level of intellectual function. Because he was right-handed, he would initially attempt solutions with his dominant hand from the performance subtests, and had difficulty coordinating his hands for bimanual task solution. He also displayed word finding problems, and had extremely long response latencies for which the examiner could not always wait for a response. Finally, our patient received the WAIS-R and not its predecessor as the majority of previously reported patients have; in consequence, his FSIQ is approximately 8 points lower than that which would be expected using the earlier test version [43]. The suggestion of higher previous function is present on the WRAT scores on reading (47th centile) and spelling (45th centile).

Visual spatial tasks

Consistently better performance was observed for the left hand on visual spatial tasks (see Table 1). Copy performances of the complex figures (CF) are displayed in Figs 2 and 3 and presented in Table 1. Although copy completion took slightly under 5 min for his right hand, he required slightly over $\frac{1}{2}$ hr to complete the copy with his apraxic left hand. Due to time constraints, immediate and delayed recall were obtained only for the right hand (Fig. 4).

Greek cross copy was adequate with his left hand when considering the apraxia. Right hand copy of the cross was performed initially without the left portion of the figure, and this was added after J.M. re-examined the standard and his reproduction (see Fig. 5). Other evidence of inattention to left space was obtained during performance of Rey's Malingering Memory test. The left row was omitted during right hand recall (see Fig. 6). This task was presented in a free-field format, with instructions to study 15 different items and then reproduce them following a 10 sec exposure. Additional examples of left inattention are evident in his right-handed performance on the WRAT-R arithmetic subtest. On six problems, incorrect responses were present which, if ignoring the information on the left side of the problem, would be correct (see Fig. 7). However, other components of neglect syndrome were absent. For example, performance on cancellation and line bisection tasks were within normal limits.

Continuous performance test accuracy was asymmetrical. Initial performance with his right hand was 65.2% correct (15/23) with five false positive responses. Performance with his left hand was strikingly better, 92.3% correct (24/26), with three false positive responses. To

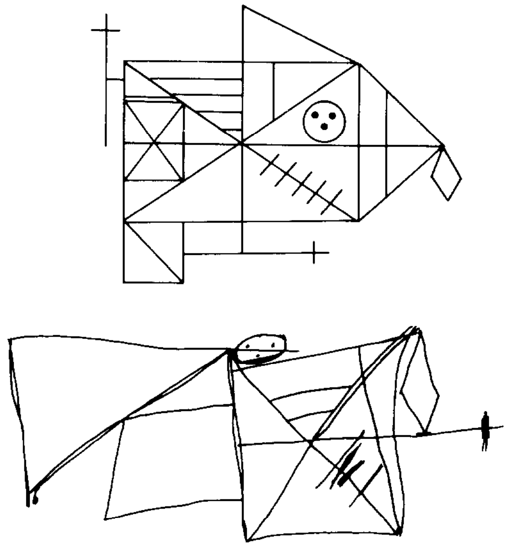

FIG. 2. Right hand copy of the Rey–Osterrieth complex figure. Note the poor organization of elements within the figure, and gross misplacement of individual elements.

ensure that this was not an artifact of stimulus familiarity, we repeated the test with his right hand, and obtained results comparable to trial 1 (62.5% correct {15/24}, with nine false positive errors).

Verbal performance.

Token test identification varied as a function of response hand (Left correct = 7/44, Right correct = 34/44). All words reported by J.M. on dichotic word listening were presented to his right ear (24/34). No words dichotically presented were reported from left ear stimulation. On multiple choice word recognition, he identified 17.5% more words with his right hand (see Table 1).

On serial digit learning, J.M. achieved the discontinue criterion of two consecutive trials on Form 1 using his right hand following trial 3, resulting in a performance level of 23/24. He never achieved the criterion to discontinue the test using his left hand, and his performance was 3/24. He was able to point to individual numbers with each hand satisfactorily.

Sensory/motor tests

Significant callosal apraxia was present in J.M.'s non-dominant left hand. Both transitive and intransitive limb items were performed easily by the right hand, with "sawing" the only correct response with his left hand. Further, left responses tended to have a perseverative quality from previous responses, and performance improved only mildly to imitation. Bucco-facial items were performed without error. Whole body items were grossly normal. However, he displayed great difficulty co-ordinating his hands to fold a piece of paper, place it in the envelope, seal the letter, and place a stamp in the corner of the envelope.

Stereognosis was intact bilaterally to matching. However, naming of shapes placed in the

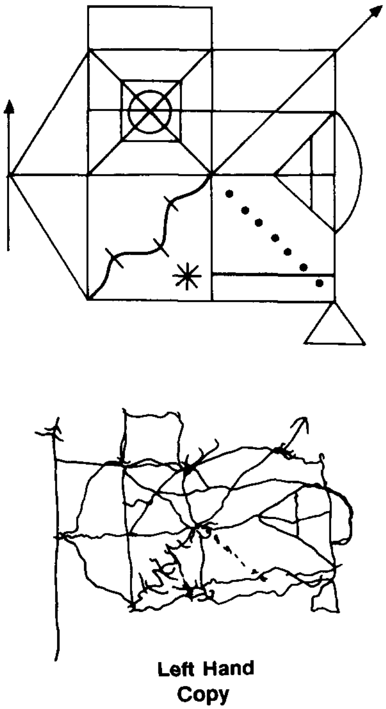

FIG. 3. Left hand copy of the Taylor complex figure. Despite the significant amount of callosal apraxia, the copy preserves the overall shape and configuration of the figure.

TABLE 1. Performance by each hand on clinical and specialized neuropsychological tests

	Left hand	Right hand
Visual tests		
Visual discrimination*	19/20	12/20
Line orientation*	25/30	10/30
Facial recognition*	40/54	37/54
Complex figure*	27.5/36	13.5/36
Colored progressive matrices†	14/36	8/36
Verbal tests		
Token test†	7/44	34/44
Serial digit learning†	3/24	23/24
Word recognition*	27/40	34/40
Other tests		
Tactile form perception*	5/10	1/10
Finger tapping*	35.2	36.4
Continuous performance†	92.3%	65.2%
Speech prosody†	12/12	12/12

*Assessed 6 months post-surgery.
†Assessed 18 months post-surgery.

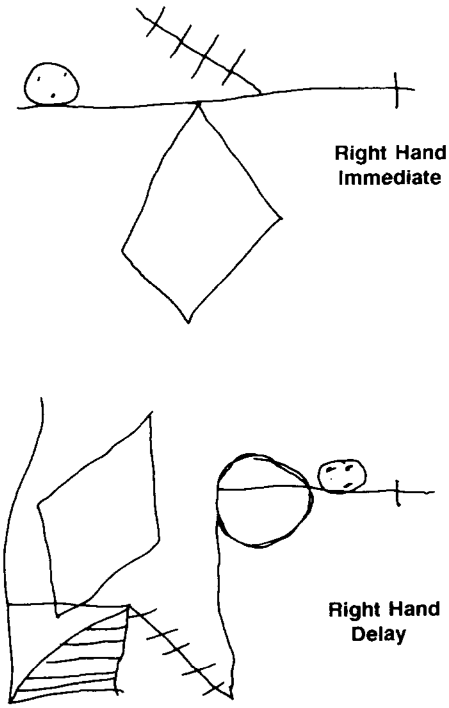

FIG. 4. Immediate and delayed memory reproduction of the Rey–Osterrieth complex figure. Despite the same basic elements reproduced, a different organization of elements is present.

patient's left hand was impaired. Tactile form perception was impaired bilaterally, although a response asymmetry was observed with superior left hand performance (see Table 1). No motor asymmetry was present on finger tapping.

Extinction

On the examination of tactile extinction in which a verbal response was requested, J.M. responded "right" to all double simultaneous hand stimulations, and correctly identified all left and right unilateral simulations. A second trial was attempted, but he then established a response set of answering "both" to any stimulation. For visual presentation, there was a suggestion of left-sided neglect when an oral response was required, although less pronounced. J.M. correctly identified 6/8 left and 7/8 right unilateral visual movements. For seven of the eight double simultaneous movements, he responded "right". When allowed to point to the visual field containing the movement, performance improved with only two "right" responses to bilateral stimualtion. In the auditory modality, no consistent evidence of left extinction was observed.

Ancillary tests

Selective reminding learning was in the normal range. We compared his levels to the data obtained on college students at a southern university in the U.S.A. [18]. Long-term storage was 131/144 with a continuous long-term retrieval score of 105/144. Normative comparison values for LTS and CLTR are 128 (SD = 14) and 112 (SD = 30) respectively. He performed

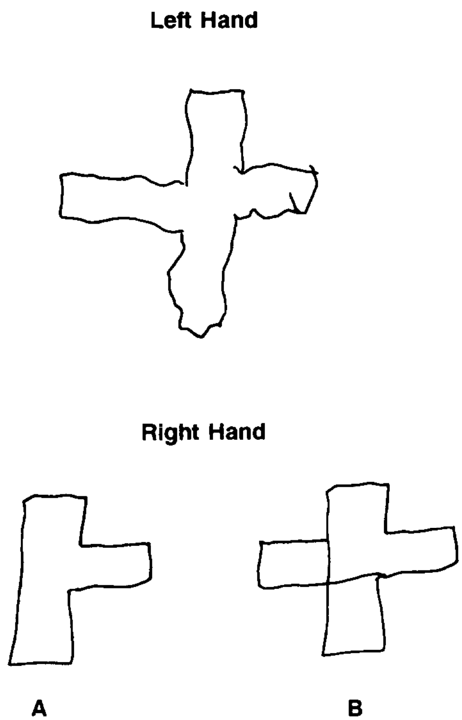

FIG. 5. Left and right hand copy of the Greek cross. The copy of the left hand is characterized again by dyspraxia but the shape is generally well preserved. Copy by the right hand is presented below. The initial copy of the design (A) is performed without drawing the left arm of the cross. After studying the copy a few seconds, the left arm was then added (B).

quite slowly, requiring 35 min to complete 12 trials. Wisconsin card sorting performance was impaired, with J.M. able to sort only three categories. His error rate was 50%, and his rate of perseverative responses was 59%. We failed to detect an asymmetry of response to prosody (see Table 1).

DISCUSSION

The present report confirms that the specialized cognitive functions of the cerebral hemispheres can be differentiated following corpus callosotomy by relying solely on selective response output. A double dissociation was observed, with right hand (left brain) superiority for tasks with a strong linguistic component, and left hand (right brain) superiority for visual-spatial tasks (see Table 1). We also observed components of neglect syndrome including multi-modality extinction and hemispatial dyscalculia. Similarly, right brain dominance for attention directed at external space was observed with a left-/right-hand performance dissociation on the continuous performance test.

Visual-spatial performance

In addition to the quantitative differences demonstrated using standard scoring criteria, striking qualitative differences are also present (Figs 2 and 3). Even though the left hand copy is confounded by significant callosal apraxia, which is reflected in shaky, lightly drawn lines,

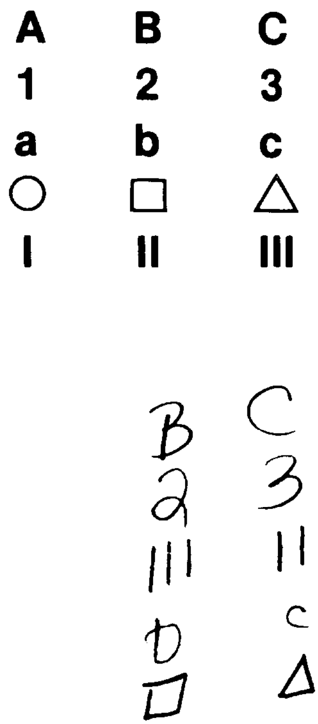

FIG. 6. Performance on Rey's "memory" test to screen for malingering. The top portion of the figure was presented for ten seconds in a free-field format. The bottom portion is J.M.'s free recall drawing.

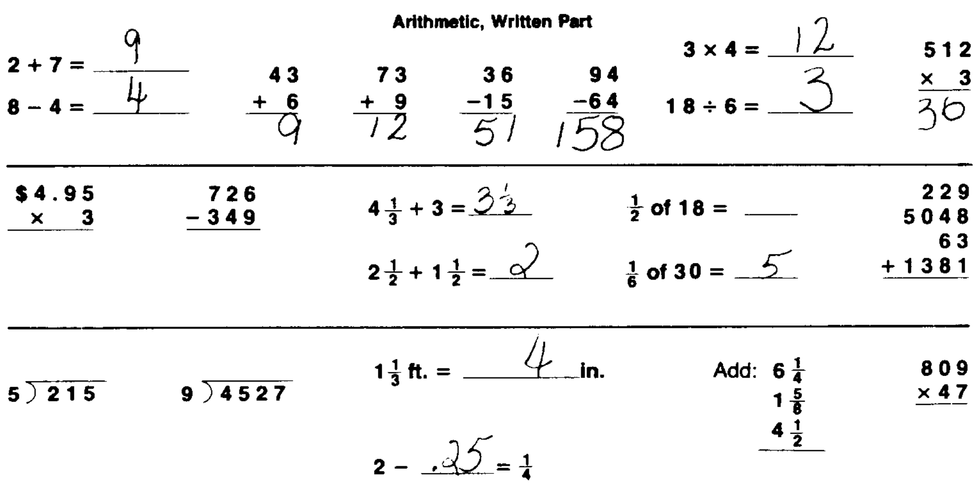

FIG. 7. A portion of J.M.'s performance on the WRAT-R arithmetic subtest. Note the hemispatial dyscalculia for many of the problems. The test was presented in a free-field format. (Test form reproduced by permission of Jastak Associates, Inc.)

the ability to maintain the overall configuration is present with no gross distortion or misplacement of individual details. Time to completion was in excess of 30 min. Copy by the right hand took slightly under 5 min, and was drawn with sharp firm lines. The right-handed copy contains many of the CF elements, but their placements within the figure are poor without maintaining the overall figure configuration. Distortion is also seen with the immediate and delayed memory conditions with the right hand (Fig. 4). It is interesting to observe that, although the same individual shapes tend to be present in both immediate and delayed recall conditions, the elements are placed in different positions within the figure.

Despite the consistent left hand superiority on most visual tasks, the response asymmetry was less pronounced for discrimination of unfamiliar faces. This test has been reported to be more sensitive to right hemisphere lesions [17]; however, a left hemisphere component is also suggested by performance failure of comprehension impaired aphasics. Further, prosopagnosia can be seen with right posterior/inferior lesions, but is most commonly associated with bilateral cerebral dysfunction [2]. Thus, the facial recognition task may not lateralize as strongly as the more spatially oriented visual tasks. For example, the largest asymmetry was present for line orientation, and a substantial asymmetry was also present for visual form discrimination. These variations in test asymmetries cannot be explained by different assessment times (6 vs 18 months) since these visual spatial tests were obtained during the initial assessment.

Language

On the token test, the right hemisphere displayed relatively poorer syntactic ability, which is consistent with reports of right hemisphere language [45]. J.M.'s verbal asymmetry, as demonstrated by manual output, not only invoked commands of relatively complex syntactic structure, but also recent memory functioning. Although he was able to point easily to individual numbers upon command with either hand, a marked asymmetry in serial digit learning was observed.

Neglect syndrome

Neglect syndrome has not been described routinely in patients following commissurotomy [24, 30, 37]. Previous studies reporting no neglect in callosotomy patients have relied on line bisection tasks to demonstrate absence of neglect syndrome, a finding that we corroborate. Similarly, our patient displayed no preference to respond to multiple choice visual spatial items in his right visual field. However, other components of neglect syndrome were present, including hemispatial dyscalculia, hemispatial memory recall, and multimodality extinction.

Although not discussed in terms of neglect syndrome, CAMPBELL *et al.* [9] reported that in ten patients with complete commissurotomy including the anterior commissure, somatosensory deficits were present in half the sample. One patient with normal face/hand identification prior to surgery displayed left-sided deficits to single and double simultaneous stimulation following surgery. This task required the patient to point to the site of stimulation. Four additional patients who received only post surgical testing displayed bilateral identification difficulty; however, three of these patients revealed greater left-sided impairment.

One possible explanation for J.M.'s presentation of neglect is greater pre-existing right hemisphere damage prior to surgery. With hemispheric disconnection, the rudimentary visual spatial systems of the left hemisphere are unable to compensate for the dysfunction. CAMPBELL *et al.* [9] described persistent impairment in visual spatial function, in conjunction with relatively normal verbal skills, in four patients with pre-operative evidence of right hemisphere lesions. However, they also reported impairment for block design performance, a task that J.M. performed relatively well, and J.M.'s performance on line orientation was estimated to be at the 56th centile. Nevertheless, J.M. exhibited evidence of pre-existing right-hemisphere dysfunction based upon preoperative EEGs. In addition, the patient reported by JOSEPH [23], displaying left neglect when drawing a clock, reportedly had EEG seizure onset recorded with depth electrodes beginning in the right hemisphere with rapid generalization.

Support for an interaction between callosotomy and pre-existing unilateral hemisphere damage is suggested by TENG and SPERRY [39]. They presented dots to unilateral hemifields or to both fields simultaneously, and patients were instructed to indicate the number of dots presented by extending the same number of fingers with their ipsilateral hand. Response extinctions, in which subjects would indicate respond with only a single hand following bilateral stimulation, tended to be consistent within subjects, but the predominant side of extinction varied across patients. Thus, the authors speculated that their extinction effect was related to the presence of contralateral brain dysfunction. Since the anterior commissure was spared in J.M., and subcortical hemispheric information exchange exists in this population [36], it is possible that pre-existing right hemispheric damage and hemispheric disconnection are contributing to the hemispatial paralexia during some verbal tasks, and the presence of left unilateral tactile extinction. However, it could also be argued that the early pre-existing right cerebral damage would produce functional reorganization in which the left hemisphere would assume a greater role in visual spatial processing. In such a case, the pre-existing damage to the right hemisphere would be expected to decrease the likelihood of left hemispatial neglect by the right hand.

Neglect syndrome has been postulated to occur more frequently in right brain disease due to specialization of the right hemisphere for attentional/intentional mechanisms directed at external space [21]. In the present report, the asymmetry on the continuous performance test (CPT), a test of sustained visual attention, is in the direction predicted by this theory of hemispheric specialization despite the presence of left hand apraxia. The CPT asymmetry cannot be explained by simple motor speed differences because finger tapping rate was bilaterally symmetrical. Further, the CPT asymmetry cannot be explained by the pre-existing right hemisphere damage. Thus, CPT results are consistent with the findings of neglect syndrome during left brain initiated response.

Intermanual competition

Although the alien hand syndrome has been amply documented following corpus callosotomy [1], the expression of the specialized functions of each hemisphere through the intermanual conflict is noteworthy. Immediately following surgery, J.M. exhibited intermanual conflict with difficulty coordinating bimanual activity. However, during the initial neuropsychological assessment (6 months), no direct response competition was observed (e.g. buttoning a shirt with one hand and unbuttoning with the other) other than that seen during cognitive performance. Over the 1 yr interval between assessments, the severity of the alien hand competition diminished. However, even during the latter assessment, he continued to display response competition that was cognitively appropriate. This was true for left hand response during language tasks (i.e. right hand correction) and for right hand response with visual tasks (i.e. left hand correction). Consequently, the reports of left alien hand following commissurotomy [6, 44] may be related, in part, to task demands.

When executing visual tasks with the right hand, and performing verbal tasks with his left hand, J.M.'s contralateral hand would occasionally indicate the correct choice. This was at times perplexing to the patient. For example, during the picture vocabulary test, he was responding with his right hand. However, when presented with "feline", his left hand responded initially and pointed to a sheep. He then shook his head "no", and correctly pointed with his right hand to the cat. When asked which response was correct, he kept pointing to both responses with each hand and became frustrated with his inability to provide a single answer. When asked to name the correct picture, he said, "I can't tell you, but it ain't no sheep".

Even more striking was the competition between hands when performing the visual spatial tasks. If he responded incorrectly with his right hand, his left hand would frequently, although not always, come up and point to the correct solution. However, if verbally questioned which response was correct, he would again point with his right hand to the same incorrect answer that he had previously indicated with his right hand and state, "this one". He would then shake his head "no", and again correct his response with his left hand. This cycle of incorrect right hand and correct left hand response could be repeated, despite observing the correct solution of his left hand.

That J.M. did not benefit from the feedback provided by the correct choice of his other hand was surprising given the description reports of the sometimes elaborate strategies that split-brain patients have been reported to employ [14]. The intermanual competition observed in J.M. was cognitively motivated toward problem solution. The failure to benefit from correct solution during visual spatial tasks may be an inability of the left cerebral hemisphere to appreciate the correctness of the left hand's response. That is, the correct response indicated by the patient's left hand may have been perceived as merely a distraction, much in the same way that the left hand would behave inexplicably as part of the alien hand syndrome. Whenever the left hand appeared to behave independently from verbally mediated conscious volition, the patient would refer to it as having a "mind of its own". Consequently, when the left hand would correctly point to the correct solution, no change in the initial right-handed response would be warranted since the hand appeared to behave without conscious intent. On the Halstead-Reitan stereognosis test, when verbally responding to the shapes presented to his left hand/right brain, he would guess incorrectly. However, when allowed to match the shape by pointing with his left hand, he performed without error. When subsequently asked which shape was the one that he felt was correct, he would verbally respond with the same incorrect shape he originally named. He would then point correctly with his left hand; if again asked to name the shape, he would again name incorrectly.

Several previous reports employing unilateral response in split-brain patients are consistent with our patient. LEVY *et al.* [27] employed chimeric figures in which simultaneous, but discrepant, stimulus input was provided to each hemisphere, and required their patients to point unilaterally to the "single" presented stimulus. Other trials were administered in which the patients were instructed to name the stimulus. In general, a right hemisphere superiority was present for non-verbal tests. However, when a verbal description was requested, the left hemisphere performed at a higher level. When told prior to a trial to visually match a face by manual response, but prior to responding, requested to verbally name the stimuli, responses were obtained in which a visual match for the left stimulus half was given, and the verbal response describing the right stimulus half. This pattern was also present when instructed to name, and then interrupted with the instruction to visually match instead. The conflict between verbal and manual responses was also confusing to the patients. However, both when the manual response preceded the verbal, and when the verbal response preceded the manual, the incorrect hand changed to the other response on only 1/4 occasions. In a separate study, similar dissociations to chimeric stimuli were present, with left-hemispheric control when instructions for verbal functional analyses were requested, and right-hemisphere control when visual matches were requested [26].

The double dissociation of response in J.M. indicates that selective output can reveal the specialized cognitive functions of each cerebral hemisphere following callosotomy. Further, certain aspects of the neglect syndrome may be observed following callosotomy. Similar examination of other patients with hemispheric disconnection will be necessary to demonstrate the robustness of our findings. Thus, in conjunction with the studies employing chimeric figures, our patient demonstrates that control systems exist that tend to activate the appropriate hemisphere for relevant task solution.

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