INTERMANUAL INFORMATION TRANSFER IN PATIENTS WITH LESIONS IN THE TRUNK OF THE CORPUS CALLOSUM

SHLOMO BENIN* and AVRAHAM SAHAR†

Aranne Laboratory of Human Psychophysiology and Department of Neurosurgery, Hadassah University Hospital, Jerusalem

and

MORRIS MOSCOVITCH

Erindal College, University of Toronto, Mississauga, Ontario, Canada L5L 1C6

(Accepted 19 April 1984)

Abstract—Interhemispheric transfer of haptic information was examined in six partially callosotomized patients and three control subjects. Three different portions of the trunk were severed in different subjects. The most anterior 10 mm of the trunk, anterior to the foramen of Monro, was sectioned in one patient. Three other patients had lesions restricted to the anterior part of the trunk posterior to the foramen of Monro. The posterior third of the trunk was damaged in two patients. The splenium, genu and rostrum of the corpus callosum were intact in all six patients, as were the anterior and hippocampal commissures. Poor transfer of haptic information was found only in the three patients with the lesion located in the anterior part of the trunk posterior to the foramen of Monro. The functional anatomy of this region is discussed. It is assumed to house fibers responsible for interhemispheric transfer of complex tactile information.

INTRODUCTION

The transcallosal route for removal of tumors within the third ventricle has been advocated as a better alternative to the conservative frontal, transcortical operation. It was suggested that the transcallosal approach minimizes the likelihood of postoperative epilepsy [15, 20]. This surgical procedure had also enabled the investigation of functions of the neocortical commissures, in particular the trunk of the corpus callosum, in patients with almost no other brain damage.

The dramatic “split brain” syndrome described by SPERRY and his colleagues [5] following complete interhemispheric disconnection was not found in patients with partial commissurotomy that left the splenium intact. More recent studies, however, reported behavioral deficits caused by disruption of the callosum limited to the trunk. DIMOND et al. [1] described changes in hand preference, memory deficits and decreased capacity to transfer visuo-spatial information following section of the whole middle third of the corpus callosum. Deficits in the interhemispheric transfer of tactile, but not of visual information, occur with incisions that include the whole anterior part of the trunk [4, 7]. To localize more precisely the callosal

*Reprint requests should be sent to S. Bentin, Neuropsychology Laboratory, 116B1, VA Medical Center, West Haven, CT 06516, U.S.A.
†Department of Neurosurgery, The Chaim Sheba Medical Center, Tel Hashomer, Israel 52621.
fibers that are necessary for transferring complex haptic information between the hemispheres, it is necessary to study patients with smaller lesions. The present study reports six cases with smaller lesions in the anterior or posterior parts of the callosal trunk. In four patients, intraventricular colloidal cysts were approached through the anterior part of the trunk (three posterior and one anterior to the foramen of Monro). Tumors in the pineal regions, required posterior callosal incisions in two patients.

CASE REPORTS

Case 1. A 23-year-old right-handed woman was first admitted in 1976 for investigation of right fronto-temporal headaches followed by vomiting and memory disturbances. Ventriculography showed marked dilatation of both lateral ventricles, but no tumor could be identified. A right ventriculo-peritoneal shunt was implanted. Two months later, a pneumo-encephalogram showed a small tumor at the roof of the third ventricle. Several months later, a left ventriculo-peritoneal shunt had to be added, since the tumor blocked the left foramen of Monro. CT-scan demonstrated that the tumor rose from the roof of the third ventricle, blocking both foramina of Monro, bulging slightly more to the right. The patient received radiotherapy.

In 1978, an operation was performed to remove the tumor. At operation (A.S.), a 15 mm incision was made in the midline of the corpus callosum, immediately posterior to the foramen of Monro. The tumor was seen beneath the corpus callosum and easily removed from both foramina of Monro, and from the anterior part and body of the third ventricle. However, a small fragment of tumor tissue, which was adherent to the vein of Galen had to be left. The patient made an uneventful recovery. The histological diagnosis was oligodendroglioma. The patient has resumed her work and other duties. CT-scan showed no further growth of the residual tumor.

Case 2. A 12-year-old right-handed girl was admitted in 1978 with fever of 38°C and stupor for 24 hr prior to admission. No localizing signs or signs of intracranial pressure were found. On CT-scan, mild dilatation of the lateral ventricles could be observed. Right lateral ventriculostomy was performed as an emergency procedure. A repeated CT-scan demonstrated an isodense nonehancing lesion. Left ventriculostomy was added, following which the child gradually regained consciousness. Ventriculography was consistent with the diagnosis of colloid cyst.

The tumor was approached transcortically as in Case 1. There was however, difficulty in identifying the midline. The incision was 20 mm long. The colloid cyst was adherent to the choroid plexus, and the septal vein on the left, which was coagulated and divided. The girl quickly recovered. She was able to walk and eat unaided within a week. She rejoined her former elementary school within several months and finished it at an average level of success.

Case 3. A 38-year-old right-handed woman had been examined several times for recurrent headaches. In 1976 she was admitted in stupor, following an attack of severe headache. Angiography revealed dilatation of both lateral ventricles and depression of the internal cerebral vein. Ventriculography failed to demonstrate the anterior part of the third ventricle. A ventriculoperitoneal shunt was installed. Two weeks later, a PEG demonstrated a round mass at the roof of the third ventricle, immediately posterior to the foramen of Monro.

By utilizing a 20 mm midline incision in the anterior part of the trunk of the corpus callosum posterior to the foramen of Monro, the colloid cyst which was situated beneath the left fornix was easily removed. The patient made a quick and uneventful recovery.

Case 4. A 35-year-old right-handed woman suffered from recurrent headaches for a period of six months. A CT-scan revealed an isodense lesion in the third ventricle with obstructive hydrocephalus. A right carotid artery angiography was consistent with diagnosis of a colloid cyst.

At operation, a 10 mm incision was performed in the anterior part of the trunk, anterior to the foramen of Monro. The section was enlarged using automatic retraction. The CSF was removed, and a green/gray mass was observed blocking both foramina. The cyst was divided from the fornix and transferred to the right lateral ventricle, from where it was completely removed.

The recovery was rapid, with no significant events. The patient resumed all her previous activities.

Case 5. A 20-year-old right-handed male college student was admitted in 1979 for investigation of progressive polydipsia and polyuria, increasing weakness and loss of body and facial hair, over a period of 18 months. The patient was fully conscious, but slow cerebration was apparent and Parinaud sign was elicited. Endocrinological examination showed evidence of severe panhypopituitarism, including diabetes insipidus. The CT-scan showed marked dilation of the lateral and third ventricles, and a large, round, well-delineated mass in the pineal region, enhancing with contrast material. Angiography confirmed the finding.

At operation, a 16 mm incision was made through the corpus callosum at the posterior part of the trunk, immediately anterior to the splenium. The tumor, which proved to be a germinoma was removed except for a small part of the capsule, adherent to the right internal cerebral vein.

Recovery was uneventful. The Parinaud sign disappeared within 2 weeks. Hormonal levels were examined a month after surgery and found normal. There was no diabetes insipidus. The patient resumed his studies 2 months after the operation.
Case 6. A 14-year-old right-handed male patient had been followed since infancy when he was operated for hydrocephalus. The boy's physical development was normal. Mentally, he was below average and attended a low-level vocational school. On routine survey of previously operated patients, the CT-scan revealed a normal ventricular system and an apparently cystic lesion, 5 cm in diameter, in the pineal region.

The patient was operated upon in October 1979. At operation, a thick-walled cyst was observed, which depressed and actually made a deep groove in the posterior part of the trunk of the corpus callosum, just above the splenium. Recovery was uneventful. The patient resumed his studies a month after surgery.

BEHAVIORAL TESTING AND SEQUELAE

Preoperative testing was possible only with patient 4. Postoperatively, all patients were tested following full physical recovery. Cases 1 and 3 were tested 2 years after the operation whereas the other 4 patients were tested within the first 6 months. Three female control subjects matched for age and formal education with patients 1-4 were also tested. The test battery included the standard Wechsler Adult Intelligence Scale (WAIS) and the Wechsler Memory Scale (Forms 1 and 2 were used respectively for the pre- and postoperative testing of patient 4) (Table 1).

<table>
<thead>
<tr>
<th>Patients*</th>
<th>Verbal</th>
<th>IQ Performance</th>
<th>Tests Total</th>
<th>MQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>93</td>
<td>81</td>
<td>87</td>
<td>62</td>
</tr>
<tr>
<td>2</td>
<td>87</td>
<td>92</td>
<td>89</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>112</td>
<td>108</td>
<td>112</td>
<td>117</td>
</tr>
<tr>
<td>4 Preop.</td>
<td>116</td>
<td>110</td>
<td>114</td>
<td>118</td>
</tr>
<tr>
<td>5 Postop.</td>
<td>116</td>
<td>114</td>
<td>115</td>
<td>116</td>
</tr>
<tr>
<td>5</td>
<td>118</td>
<td>109</td>
<td>115</td>
<td>92</td>
</tr>
<tr>
<td>6</td>
<td>90</td>
<td>97</td>
<td>94</td>
<td>89</td>
</tr>
</tbody>
</table>

*Patients 1, 3 had lesions in the anterior third of the trunk, posterior to the foramen of Monro. Patient 4 had a lesion in the anterior part of the trunk, anterior to the foramen of Monro. Patients 5 and 6 had lesions in the posterior part of the trunk.

Inspection of Table 1 reveals that with the possible exception of the performance IQ of patient 1, all the intelligence scores were within the normal range. Comparison of the MQ and the IQ scores suggest a specific memory disorder in patients 1, 2 and 5.

In addition, the interhemispheric transfer of tactile information was tested by three tests designed specifically for this study.

1. Tactual recognition

We reasoned that if the severed parts of the corpus callosum were critical for interhemispheric transfer of haptic information, stimuli presented to one hand should be recognized well using the same hand, but poorly using the opposite hand. The patient, blindfolded, sat facing a table on which two stimulus boards were present. The stimuli were six different shapes each made of five ball pinheads (1.3 mm radius) inserted into a masonite board. On the 40 × 30 cm test board, 36 stimuli were arranged in a 6 × 6 matrix (Fig. 1). Each shape was represented once in each row, in random order. Three of the six shapes were
chosen as possible targets (Fig. 1). The separation between any two pin heads in a pattern was 1 cm. The distance between two extreme pin heads within one pattern was 2.5 cm and the distance between the centers of two adjacent patterns was 6 cm. Subjects were not instructed to use specific fingers and, in fact, all used their index and middle fingers to palpate the patterns.

Using one hand only, the patient had to palpate the stimulus that was designated as the target for that trial, and presented on a separate board. The patient then searched for it systematically (row by row) by touching each shape on the test board and reporting after each stimulus if the target was or was not encountered (see exact instructions and mode of administration in the Appendix). The patient searched either with the same hand that he used to learn the target (nontransfer mode) or with the contralateral hand (transfer mode). All possible hand combinations (left–left, left–right, right–left, right–right) were tested. In the “simultaneous” condition, the patient could palpate the targets with the “learning hand” throughout the search either by continuously leaving the hand on the target if searching involved the contralateral hand, or by constant rechecking if searching involved the same hand. In the “successive” memory condition the target was not available to the subject once the search process began.

All three target stimuli were presented in each memory condition. Each was presented for learning once to the left and once to the right hand. Summing over the memory conditions there were 12 trials in the transfer and 12 trials in the nontransfer mode. To avoid overfamiliarization with the test board, only the upper three rows were used in the “simultaneous” memory condition while the bottom three rows were used in the “successive” memory condition. This procedure allowed for a maximum of 36 misses and 180 false alarms in each mode.

Table 2. Number of errors made by each patient in the transfer and nontransfer modes in the simultaneous and successive conditions of the “tactual recognition test”

<table>
<thead>
<tr>
<th>Patient*</th>
<th>Simultaneous Transfer</th>
<th>Successive Transfer</th>
<th>Total Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td>25</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>4 (Preop.)</td>
<td>8</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stat. sig.</th>
<th>N.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>P &lt; 0.005</td>
<td></td>
</tr>
<tr>
<td>P &lt; 0.004</td>
<td></td>
</tr>
</tbody>
</table>

*Patients 1–3 had lesions in the anterior third of the trunk, posterior to the foramen of Monro. Patient 4 had a lesion in the anterior part of the trunk, anterior to the foramen of Monro. Patients 5 and 6 had lesions in the posterior part of the trunk.

The total number of errors (misses and false alarms) made by each callosal damaged patient in each mode and in each memory condition are given in Table 2. The number of errors averaged according to the location of the lesion is presented and compared with the control group in Fig. 2.

Significantly more errors in the transfer than in the nontransfer mode were found only in
Fig. 1. Test boards used in the "tactual recognition".
the three patients with the lesion located in the anterior part of the trunk but posterior of the foramen of Monro (binomial test, \( P < 0.01 \)). Memory load enhanced the transfer effect in patients 1 and 3 as shown by the higher proportion of errors in the transfer relative to the nontransfer mode. The averaged results presented in Fig. 2 indicate that all patients made more errors than the control group, but only in patients 1–3 was the number of errors in the transfer mode significantly higher than in the nontransfer mode.

2. Finger sequence repetition

In this test of intermanual transfer of information, the patient had to replicate the sequence in which fingers were touched on one hand, by moving in sequence the appropriate fingers of the same or contralateral hand.

The patient sat blindfolded, his palms on the table. In one condition both palms were face down, forming mirror images of each other (mirror condition), whereas in the nonmirror condition, one palm was up. We used these two conditions because pilot studies on normal subjects indicated that intermanual transfer in this task might be more difficult in the mirror condition.

The experimenter touched three different fingers (except the thumb) in sequence, at a rate of 1/s, and the patient had to repeat the sequence, by raising the same fingers on the same or contralateral hands in an identical sequence. As with the “tactual recognition”, all possible hand combinations were used. There were four trials for each hand combination on each of the two conditions making a total of 32 trials. Only a sequence identically repeated was considered as a correct response on each trial.

The number of errors in the “mirror” and “nonmirror” conditions were not significantly different, therefore the results in those two conditions were pooled for further evaluation. All six patients and the three control subjects performed worse in the transfer than in the nontransfer mode, but this effect was significant only for the same three patients with lesions.
in the anterior part of the callosal trunk, but posterior to the foramen of Monro (binomial test, $P < 0.01$) (see Table 3 and Fig. 3).

<table>
<thead>
<tr>
<th>Patient*</th>
<th>LH Non-transfer</th>
<th>Transfer to RH</th>
<th>RH Non-transfer</th>
<th>Transfer to LH</th>
<th>Total Non-transfer</th>
<th>Transfer</th>
<th>Stat. sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>18</td>
<td>2</td>
<td>16</td>
<td>6</td>
<td>34</td>
<td>$P &lt; 0.001$</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>16</td>
<td>2</td>
<td>12</td>
<td>5</td>
<td>31</td>
<td>$P &lt; 0.001$</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>6</td>
<td>13</td>
<td>$P &lt; 0.07$</td>
</tr>
<tr>
<td>4{Preop.</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>N.S.</td>
</tr>
<tr>
<td>Postop.</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>N.S.</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>N.S.</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>13</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

*Patients 1–3 had lesions in the anterior third of the trunk, posterior to the foramen of Monro. Patient 4 had a lesion in the anterior part of the trunk, anterior to the foramen of Monro. Patients 5 and 6 had lesions in the posterior part of the trunk.

Fig. 3. Average number of errors made in the “finger sequence repetition test” by the control subjects and by the patients grouped by the site of lesion.

3. Naming familiar objects and letters by touch

All six patients when blindfolded, recognized and named perfectly after palpating with either hand a set of seven common objects and five plastic letters of the alphabet.
DISCUSSION

Intermanual transfer of nonsymbolic haptic information was disturbed in three patients with lesions limited to the anterior part of the trunk but posterior to the foramen of Monro. When the lesion was located anterior to the foramen of Monro or in the posterior third of the trunk, interhemispheric transfer was intact.

In contrast to patients with complete commissurotomies [2, 3, 16], all the patients in the present study, including those with lesions posterior to the foramen of Monro, were able to recognize and name common objects and letters placed in either hand. This suggests that the latter lesions affect only the transfer of complex, meaningless haptic patterns (pure touch information) and not of nameable objects that may be transferred via other pathways. Early investigations revealed that unilateral removal of the secondary somatosensory cortex (SII) in cats prevented interlimb transfer of tactual habits without affecting original acquisition [18]. More recent, anatomical studies have shown that the SI areas that represent the distal parts of the hands in the left and right cerebral hemispheres are not interconnected via the corpus callosum [8, 9, 10, 13], but that the SII areas might be [6, 14]. Complementing these evidences, our results support, to some extent Mishkin's hypothesis which assigns to SII a role in the interhemispheric transfer of complex tactual information similar to that attributed in vision to the inferior temporal cortex [11]. In contrast to Myers and Ebner [12], however, we suggest that the callosal region which is critical for that transfer is located in the anterior rather than the posterior part of the trunk.

The involvement of memory in this interhemispheric transfer deficit merits additional consideration. In the “tactile recognition test” the ratio of errors in the transfer over the nontransfer mode was higher in the successive than in the simultaneous condition in two out of the three patients with the lesion in the anterior part of the trunk, posterior to the foramen of Monro. The transfer deficit was enhanced by the additional memory demand. Similarly, a memory component is included in the “finger sequence repetition test” which shows impaired transfer, whereas single finger touch localization that is relatively memory free, typically shows normal transfer [1, 5, 7]. The impairment in tactile transfer with increased memory load seems to be related more to the additional processing demands that the memory load imposes rather than to a general memory loss that some subjects with callosal lesions suffer. Inspection of Fig. 1 reveals that the site of callosal damage correlates with the tactile transfer deficit better than does an overall memory deficit. Patient 5 who had evident memory loss following a lesion in the posterior part of the callosal trunk, had no deficit in tactile information transfer, whereas patient 3 whose memory was above average, nonetheless showed an enhanced deficit in the successive condition of the “tactile recognition test”.

In contrast to other studies [21, 1], memory was impaired in only three out of the six patients with lesions of the corpus callosum and the impairment seemed not to be related to the site of the callosal lesion. This is consistent with Geffen et al.'s [4] suggestion that callosal damage per se does not lead to memory deficits. That might be caused either by damage to the fornix [4], or by the intraventricular lesions [17, 19].

In conclusion, the present results suggest that damage to the area in the anterior part of the callosal trunk which is posterior to the foramen of Monro leads to deficits in intrahemispheric transfer of complex tactile information that cannot be easily named, especially if memory is involved.
REFERENCES


APPENDIX

The patient and the experimenter were both sitting at the same side of the table. The test materials (the test board and the three smaller target stimulus boards) were displayed face down on the table. The instructions were: “Our purpose is to see how well you can learn using only your sense of touch and how well you can transfer what you have learned with one hand, to the other hand. On each of the small boards in front of you there is a little shape that you will be able to feel with your fingers. On the big board there are many shapes, some of which are identical in form and orientation with those on the small boards. In a little while I shall cover your eyes and your task will be to learn how a shape feels like using only one hand. When you think that you have learned enough, I shall give you the big board and you'll have to search that board with your fingers and to tell me each time you will find that shape on it. Before each trial I shall tell you which hand you'll use for learning, and when learning is completed I shall tell you which hand you'll use for search.”

When the eyes were covered, all boards were turned face up. The small target stimulus board was placed at the right or the left of the big test board, in accordance with the hand used for learning. Each target stimulus was presented four times, once for each learning/testing hand combination. The order of trials was pseudorandomized so that the same stimulus did not appear in two consecutive trials. In each trial the experimenter named the hand to be used for learning and physically led the hand to the target stimulus. The patients were encouraged not to rush while learning and no time constraints were imposed on the search (however, the total search time was measured). When learning was completed, the experimenter named the hand to be used for searching and physically led that hand to the upper left or upper right corner of the search array for the left and right searching hands respectively.
In the transfer simultaneous condition the patient was told to leave the learning hand on the target board while the other hand was used for searching. In the nontransfer simultaneous condition the patient was encouraged frequently to refresh his/her memory by going back to the target board and in any case relearning was performed at the end of each row. In the successive condition the target board was taken away once the search started.

The simultaneous condition was always the first test in the battery. The successive condition was tested in a second testing session, usually 24 hr later. The patient was allowed to see the stimuli only after the successive condition test.