Short-term memory and brain-bisected man¹

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Hemisphere disconnection in man yields two systems, each of which can perform most human activities independently and separately and without help from the other. The present study examines whether both hemispheres working in parallel can process more information than can one working alone. The results affirm this view and suggest that the informational cross-talk ongoing via the callosum in the normal brain limits the short-term memory capacity of each hemisphere and, therefore, of the brain as a whole.

Studies on the separated hemispheres in monkey (Sperry, 1961) and man (Gazzaniga et al, 1965, 1967; Gazzaniga, 1967) have revealed that each half-brain can behave independently and outside the realm of awareness of the other hemisphere. Discriminations learned by one half-brain cannot be performed correctly by the other if the interhemispheric cerebral commissure systems are sectioned prior to training. These studies on the double brain phenomenon have raised new questions regarding the nature, overall capacity, and distribution of information processing systems in the primate brain. In brief, from an information processing point of view the question becomes, can the two hemispheres working separately, but simultaneously, perform at a higher level than the joined hemispheres of commissure intact controls?

Experiments on this question to date have been carried out in the monkey (Gazzaniga & Young, 1967). Normal monkeys when required to push the lit button of a pair, can handle up to six pairs—three in each visual field after the cue lights have been left on for 600 msec. If the stimuli are presented for less time, their performance deteriorates. Split-brain monkeys, however, quickly

exceed this limit and are able to respond correctly to eight pairs of lights left on for only 200 msec. Thus, the upper limit of a normal animal was surpassed following brain bisection. The following reports similar effects in a related test carried out in commissure sectioned man.

PROCEDURE

The two experimental Ss had undergone brain bisection, which included midline section of the corpus callosum and anterior and hippocampal commissure, at least three years prior to this testing, in an effort to limit the interhemisphere spread of seizures. Medical (Bogen et al, 1966) and psychological (Gazzaniga, 1967) descriptions of the patients appear elsewhere. The controls were three experienced Ss completely familiar with the present tests. All Ss were seated in front of a Dodge tachistoscope and asked to fixate a point in the center of the visual field (Fig. 1). An array of alphabetic letters was flashed either to the left or right of fixation, or both, depending on the test condition. After presentation of the stimulus the S was shown a list of 20 consonants and was required to point with his left hand to as many of the test letters as could be remembered.

Prior to the test, two practice trials were run; one trial presented four vowels to the left field and one presented four vowels to the right field. On the following 10 trials, the test stimuli were four black letters printed on a white background and were presented tachistoscopically for 100 msec. On half of the trials the four letters fell to the left of fixation and were therefore projected to the right hemisphere. On the other trials the four letters fell to the right of fixation and were therefore projected to the left hemisphere. The letters were selected from 20 consonants and each consonant appeared twice, once in the left visual field and once in the right. On each of the next 10 trials, eight consonants were flashed, four in each half field. In this series each consonant was used four times, twice on the left and twice on the

Fig. 1. Top schematic view of S positioned in front of tachistoscope. Letters falling to the left of fixation (relative to the S) are presented to the right hemisphere and those falling to the right of fixation are presented to the left hemisphere.

Table 1
Average Correct Responses on Each Trial

Normals	Single Field	Double Field	Ratio
1	3.8	3.9	1.03
2	3.5	3.8	1.09
3	3.3	3.6	1.09
Splits			
NG 1	1.2	1.8	1.50
2	1.0	2.0	2.00
LB 1	1.5	1.9	1.27
2	1.6	2.1	1.31

right. Since the total number of responses was not limited, the error rate and rational guessing probabilities were used to correct the scores for guessing (2). The two patients went through the task twice, once in the sequence described above and once in reverse order.

The motor response used posed no special problem for the controls. In the brain-bisected patients tested, using the left arm has little disruptive effect on behavior since each disconnected hemisphere can easily control either arm to a high degree (Gazzaniga, 1967).

RESULTS

As can be seen from Table 1, normals were able to recall an average of 3.5 letters when a total of 4 was presented to one visual field or the other. Under conditions of double field stimulation their average rose very little, with the net result that the ratio of double field score to the single field score was never higher than 1.09. This clearly suggests that in the normal intact brain, separate, direct stimulation of one hemisphere allows performance at a level that cannot be transcended when parallel and similar stimulation is performed on the other hemisphere.

In split-brain patients, stimulation of one hemisphere produces a base rate of performance that was stable for each S but considerably lower than the overall performance of the normals. With double field stimulation, however, the brain bisected patients score nearly doubled in one case and significantly increased in the other. In the split-brain cases, therefore, both hemispheres working in parallel processed more information than did a single disconnected hemisphere. Why the split-brained Ss performed at an overall lower level than the practiced normals is not clear. A likely explanation would be that each patient has been for a number of years on anti-convulsant medication. Additionally, they were both epileptic and suffered from a certain degree of brain damage.

Inspection of individual responses made relative to the separate hemispheres, revealed that Case LB reported twice as many letters projected to the left hemisphere as to the right, whereas Case NG reported equally well from each hemisphere. Also, during double field stimulation, LB always produced the left hemisphere information before the right as well as reporting more from the left. Case NG, however, using the left hand in response, always reported the right hemisphere information first, but each hemisphere performed equally well. These data on NG are consistent with experiment studies on the monkey which show that discrimination learning is better in the hemisphere contralateral to the responding arm (Trevarthen, 1962). This type of explanation may also hold for LB. For weeks prior to this test, his school teacher had required him to write with his right hand hundreds of short sentences. In effect, this may have created a

strong left hemisphere set which would explain his superior scores on the left side at the expense of those on the right.

DISCUSSION

The foregoing suggests the callosum inhibits the short-term memory mechanism of each hemisphere. One possible explanation for this would be the following: In the normal intact brain, the left speech hemisphere is aware of and can describe all aspects of the left visual field, in addition to the right field. This may not be, because a duplicate pattern of the visual world is sent across via the callosum, as recent electrophysiology work would suggest (Gazzaniga et al, 1967; Berlucchi et al, 1968), but rather because the callosum relayed abstracted and descriptive information about that part of the visual world. It is the right hemisphere that is conscious of the left visual field and the left hemisphere is aware of the left field only as a result of the running description given to it by the right hemisphere. It is as if two people were looking at two different aspects of a similar visual scene. One could be aware of the other only indirectly by listening to a description of it, not by actually seeing it.

If this kind of informational exchange is incessantly taking place in the callosal intact brain, the informational load placed on one hemisphere would instantly be communicated and processed in the other, leaving little channel space for more incoming information. If the hemispheres were disconnected, however, each system would be free of the job of keeping the other up-to-date, as well as listening to the other, and thereby be free to work to full capacity and in parallel with the opposite half-brain.

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NOTES

1. Aided by USPHS Grant No. MH 13289. I would like to thank J. Shea for assisting in collection of the data.
2. The scores were counted in the following way:

$$Q = \frac{N_R W - N_E A}{W - N_E}$$

where N_R = number of responses, N_E = number of errors, A = (number of consonants), W = $A \cdot$ (number of consonants on stimulus card). I would like to thank Dr. A. Sandusky for suggesting the approximate statistical correction for guessing.