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Effects of Commissurotomy on the Processing of Increasing Visual Information

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Summary. Two normal and two split-brain monkeys were trained to respond to increasing amounts of flashed visual information distributed equally in each half visual field. It was found that the brainbisected animals were able to perceive and respond correctly to more information in a given period of time than were the normal controls.

Key Words: Callosum — Information capacity.

Introduction

Split-brain research over the past decade has repeatedly shown that each hemisphere in cat [*5*], monkey [*6*], [*7*], and man [*1*], [*2*] can separately and independently learn discriminations of all kinds, and that most problems trained to one hemisphere do not transfer to the other. Studies of this kind suggest that a state of mental duplicity exists following brain bisection and raise the question of whether or not the callosum- sectioned animal can in fact handle more bits of information in a given period of time than can a commissure-intact control. The following experiment directly examines this question by comparing the ability of brain-bisected and normal monkeys to handle a complex spatial problem involving the simultaneous presentation of up to eight light-dark discriminations. The task was presented in such a fashion that it could be made increasingly more difficult as was warranted by the individual animal's performance.

Methods

Four monkeys (*macaca nemestrina*) were used throughout all training procedures. Two of the animals underwent brain bisection which included midline section of the corpus callosum, anterior and hippocampal commissures and optic chiasm. Following the experiments the animals were killed and examined. The optic chiasm was separately studied and found to be completely sectioned in both animals, while the commissures proved to be completely sectioned in only BMG. In WFB the splenium was left intact.

The animals were kept in combination living and working cages described in detail elsewhere [*3*]. Attached to the rear of each cage were sheet metal panels, upon which were mounted 16 pushbuttons as shown in Fig. 1A. These pushbuttons offered eight pairs of light-dark discriminations. Exclusive projection of four of the eight pairs to each eye was accomplished by color-coding the stimulus lights. The eight pushbuttons to the left of the midline were covered with blue filters, while those pushbuttons to the right of the midline were covered with red filters. In the training apparatus, the left eyehole was covered with a red filter and the right eyehole with a blue filter. As a result the eight pushbuttons on the left were worked with the left hand and were seen only by the right eye, and the eight pushbuttons to the right of the midline were worked with the right hand and were seen only with the left eye.

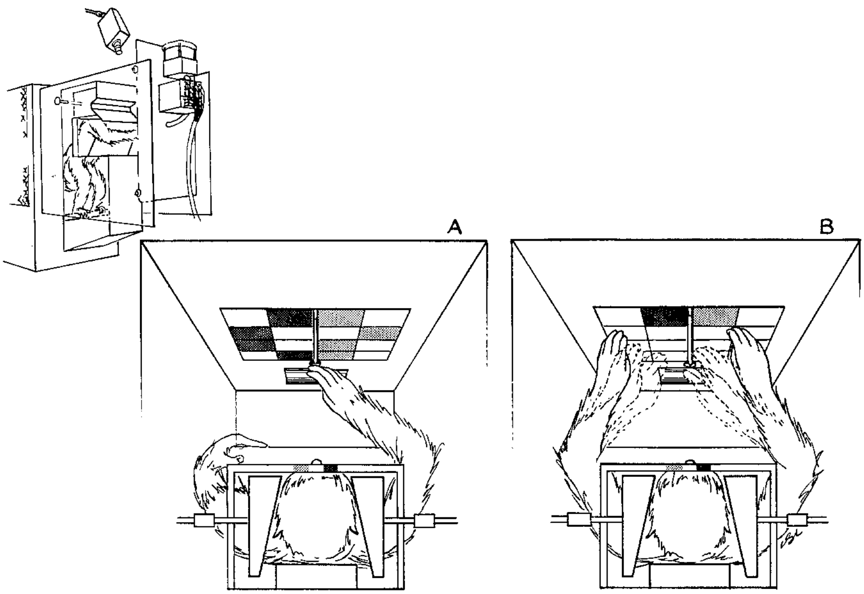

Fig. 1. *Shows both general and overhead views of training apparatus.* a) Animal pulls lever at bottom of response panels to activate problem and tachistoscopic flash of stimuli. b) Animal then proceeds to push the appropriate buttons at each level, eventually working up to Level IV and if entirely correct, a food reward is delivered below the activating lever

The ultimate task which took up to 6 months to learn, involved presentation of all eight discriminations at once (four to each hemisphere) by simultaneously lighting one pushbutton of each discrimination pair for a short time (Fig. 1A.). For a correct response the animal had to push all illuminated buttons to the left of the midline with the left hand and all of those to the right with the right hand.

Training of the task began by only presenting to the animal one of the eight discrimination pairs on the lower level of lights (Level I). After learning to push the illuminated buttons of the pair, the complexity of the problem was increased by adding a second pair of lights at the same level which was presented simultaneously with the first pair. Now the animal had to push both the illuminated button to the left of the midline and also the illuminated button to the right, either in quick succession (and in any order) or simultaneously. When this had been learned, the discrimination task was no longer automatically and continuously presented. Instead the animal was required to initiate each trial by first pulling a lever placed immediately below the matrix of buttons. The lever activated timing circuits which presented the stimuli for variable periods of time starting at 1.2 sec and gradually worked down to 0.2 sec. The animal had to perform at criterion before the duration of the stimulus was stepped down. Also, as an animal responded to each discrimination pair its light turned off, unless, of course, the light had already gone off due to a short flash interval. When the lights were flashed for only 0.2 sec, for example, they were usually off by the time the animal had reached Level I. As a result, therefore, at short time durations the animal responded in the absence of the stimulus and therefore had to remember which of the buttons were illuminated.

After criterion was finally reached on the first level at 0.2 sec, the stimulus duration was increased back up to 1.2 sec, or occasionally even longer, and two more pairs of lights were added to the overall discrimination sequence. Now, upon activation of the lever, four lights would flash on in a random fashion on any of the eight lower buttons. The schedule required the animal to start at the lowest level and first press the bottom two lights before preceding to Level II. Again, after criterion had been reached at 1.2 sec, the duration of the flash was reduced in 0.2 sec intervals. Subsequently, and in similar fashion, Level III and Level IV were added to the sequence. Fig. 1B shows an animal moving to Level IV after having successfully completed Levels I, II, and III. Again, as mentioned above, at short stimulus durations, the entire matrix of lights had gone off before the animal commenced the response sequence. Consequently, in the final stage of the problem, the animal had to remember the relative position of eight lights randomly distributed over 16 pushbuttons. If all eight responses were correct the animal received a reward. If the animal made a mistake at any point in the sequence, the trial was terminated and an incorrect response was recorded.

The animals had up to 10 sec, to make a response on each of the self initiated trials. In general the response required less than 2 sec. As mentioned above, an animal was maintained on a particular level and time duration until he correctly completed the problem more than 51% of the time in two consecutive sets of 20 trials. The score that could have been effected by chance varied according to the level examined, and ranged from 25% on Level I to 0.39% on Level IV. Raising the criterion did not significantly alter the relationship between the normal and the experimental animals.

It should be pointed out that if the normal animal did not fixate on the midline for the duration of the flash, the visual information presented to each eye was available to both hemispheres because of the intact optic chiasm. It could be argued, therefore, that the effects observed in chiasm-commissure sectioned animals were due to the section of the chiasm and not to the commissures. However, although eye movements were not observed, it seems most likely that the animals learned to fixate the midline (thereby in effect creating a chiasm-split) since fixation elsewhere or continuously scanning eye movements would, with short stimulus durations, greatly impair perception of the stimulus display and thus greatly reduce the score. In chiasm-commissure section animals, of course, each hemisphere initially received only visual information flashed in the contralateral visual field. Likewise, because the split-brain animals performed so well, it is assumed that they learned to fixate the midline between the two sets of buttons so as to allow the complete projection of each task-situation to the contralateral hemisphere.

Results

From the findings summarized in Fig. 2, it can be seen that the brain-bisected animals were clearly able to perform at a higher level than the normal controls. Both normals stalled at an early stage in Level III, yet both were continuously over-trained (LSE 8,600 trials; RFK 12,000). On the other hand, the split-brain monkeys advanced past these critical points with no greater effort than at any

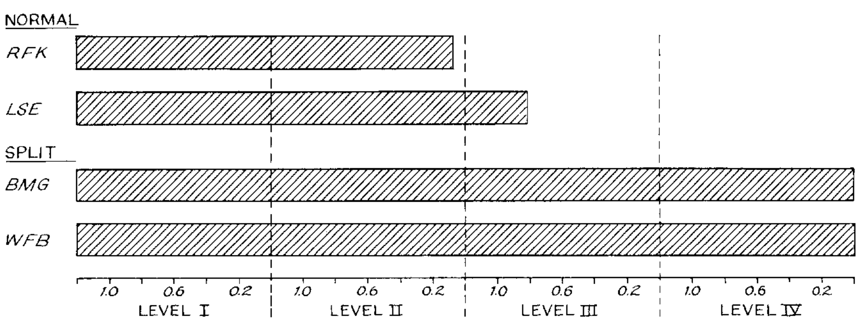

Fig. 2. *Highest attainment of criterion for each animal.* Times refer to duration of stimulus presentation at a particular level

previous level. Also, prior to Level III, scores of the normals and splits were more or less similar with trials to criterion for each level ranging from 0—2800 but with the mean being 200. Usually, once a particular level was reached, the trials to criterion from one time stage down to the next were zero. Occasionally, however, a disportionate number of trials would be needed. The reasons for this are unclear, but may reflect nothing more than distracting events occurring during the working schedule. Also, the split-brain animals started slowing in their proficiency at Level IV, 0.6 sec; thereby suggesting the upper limit of their bihemispheric attention span was being approached. The maximum capacity was not determined.

It is interesting to note that both the split-brain and normal animals tended to use the two hands alternately rather than in unison. First the left hand would respond then the right and then upon moving up to the next level either the left or right, following no discernible pattern, would again trigger the alternating sequence of responses.

Discussion

These results indicate that animals with commissure section can process more visual information in a given period of time than can commissure intact controls. Presence of the neocortical commissures appears to inhibit duplicate mechanisms present separately in each hemisphere. Moreover, the results for WFB show that the anterior region of the commissures is critical, even though it is the splenium that transmits visual information from one hemisphere to the other.

The question remains in what sense the information capacity of the brain has been increased. If the two hemispheres are considered as equipotential entities capable of acting separately, then the results affirm the truism that interaction between information processing systems reduces the summed information capacity of the two separate systems. [*4*] On the other hand, had the experimental task required the matching of information presented separately to each hemisphere, then sectioning the commissure would have reduced the overall capacity of the system by disallowing the essential integration. Therefore, it can be concluded that splitting the brain increases the information capacity only for tasks not requiring integration of the two hemispheres.

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References

[*1*] Gazzaniga, M.S., J.E. Bogen and R.W. Sperry: Observations on visual perception after disconnexion of the cerebral hemispheres in man. Brain **88**, 221—236 (1965).
[*2*] —, and R.W. Sperry: Language and speech after brain bisection in man. Brain (in press).
[*3*] — Interhemispheric communication of visual learning. Neuropsychologia **4**, 183—189 (1966).
[*4*] —, and R.W. Sperry: Simultaneous double discrimination response following brain-bisection. Psychonom. Sci. **4**, 261—262 (1966).
[*5*] Myers R.E.: In: Brain mechanisms and learning, pp. 481—505. Ed. by J.F. Delafresnaye Oxford: Blackwell 1960.
[*6*] Sperry, R.W.: Cerebral organization and behavior. Science **133**, 1749—1757 (1961).
[*7*] Trevarthen, C.B.: Double visual learning in split-brain monkeys. Science **136**, 258—259 (1962).

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