Neuropsychologia, 1969, Vol. 7, pp. 379 to 382. Pergamon Press. Printed in England

EYE POSITION AND VISUAL MOTOR COORDINATION*

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(*Received* 20 *May* 1969)

Abstract—We tested the ability of split-brain humans to locate accurately a point in space using an ipsilateral hemisphere–hand combination. Positive results were only obtained when the non-seeing hemisphere had target information in the form of knowledge of eye position. The results confirm the view that a main mechanism in the interhemispheric integration is cross-cued information.

INTRODUCTION

SEPARATION of the cerebral hemispheres in primates poses obvious problems for sensory-motor control systems requiring interhemispheric integration. In particular, understanding how control is realized for an arm ipsilateral, to a disconnected hemisphere receiving spatial information has been studied extensively in both monkey and man [1, 2]. Recent reports have emphasized the role cross cuing strategies play in interhemispheric management of sensory-motor responses [2, 3]. This view centers on the idea that the seeing hemisphere orients towards an object to be localized and that the concomitant head, neck, and eye adjustments are registered through proprioceptive mechanisms in the non-seeing hemisphere. Subsequently, the non-seeing hemisphere because it now possesses the target information is capable of directing the contralateral hand to the point in space.

The hypothesis would predict that restraining of head movement would impair ipsilateral eye–hand responses. This was recently confirmed in a study on monkeys where ipsilateral eye–hand responses in a monkey were impaired when the head was held [3]. It was seen, however, that with practice the monkeys became proficient in using ipsilateral eye–hand combinations even with the head held. This left open eye movements as the remaining cuing systems for the non-seeing hemisphere.

The experiment here reported was therefore undertaken with the aim of eliminating both head and eye movements and measuring the accuracy of visual motor responses under such conditions. The results support the hypothesis and underline the role of proprioceptive mechanisms in visual-motor response tasks. In addition, the data raise interesting questions with regard to the nature of central registration of eye position.

PROCEDURE

The experimental procedure was as follows: Two brain-bisected patients and one normal were studied. The test apparatus is shown in Fig. 1. All subjects were positioned in a head holder with a bite board, and were situated 24 in. from the display panel in a darkened room. The arm was positioned below and to the right of the panel and largely out of view. At the start of each trial, they were instructed to fixate a small light appearing on the vertical meridian. The position of their eyes was monitored using Beckman ocular electrodes. When fixation was observed to be true and steady, a 100-msec light flash was presented on one of 10 buttons, arranged on a horizontal scale and in the left half of the visual field.

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* Aided by USPHS Grant MH 13289. I would like to thank J. Shea for assistance in collecting the data.

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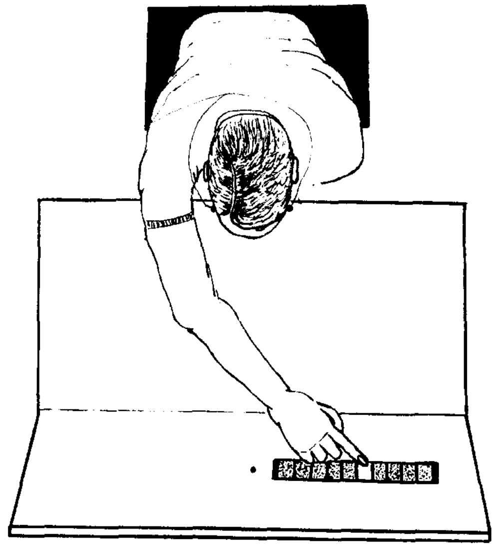

FIG. 1. Shows experimental arrangement. *S* with head fixed in head holder and bite board, fixates a light straight ahead. Any light flashed on response panel is projected to the right hemisphere and the main response requires motor mechanisms primarily centered in the left hemisphere.

Two experimental conditions were used. In Condition A, the subject, with the head fixed, was instructed to look towards the illuminated button and to touch it with the right hand. Because of the short duration duration of the stimulus, the light was off before the scan commenced. In Condition B, the test was identical except that the subject was instructed not to look at the illuminated button, but rather to maintain fixation before and during the manual response. In both conditions the light, of course, was exclusively flashed to the right hemisphere, but the manual response required the use of the motor system predominantly featured in the opposite hemisphere.

RESULTS

The results are shown in Fig. 2. The normal subject responded with ease and well under both conditions, thereby eliminating any possible complications due to procedural artifacts. The brain-bisected patients, however, were accurate in localizing the illuminated point only when eye movements were allowed. When the patients maintained fixation, performance with the right hand fell dramatically to a low level, and the actual hand movements made during these responses were extremely awkward. At the same time, of course, the right hemisphere had no difficulty in directing the left hand accurately under both conditions.

DISCUSSION

The foregoing results clearly indicate that sensory-motor responses requiring interhemispheric integration of information cannot be carried out accurately in the absence of cross-cued information. With the head held, but eye movement allowed, ipsilateral eye–hand control is realized. With eye movement eliminated, ipsilateral responses deteriorate. This finding confirms an earlier prediction that a primary mechanism for ipsilateral sensory-motor control does not lie in systems using cortical spinal mechanisms or sub-callosal interactions, but rather reflects a more straightforward case of the use of a behavioral strategy. Implications of this view for a theory of sensory-motor control mechanism have been outlined elsewhere [3].

In attempting to understand the exact nature of the cross-cued information, the present results allow for interesting speculations on the role and nature of eye-position information in eye–hand coordination. Consider the two test situations: In Condition A, the hemisphere not directly exposed to the visual stimulus but in major motor control of the hand would clearly not have spatial information available to it from retinal local sign [4]. The cross cued information, therefore, might possibly come from three sources: (1) Afferent information from the ocular motor system, which in some way registers final position of the eyes; (2) Corollary discharge information (efferent copy [5, 6]) from eye movements which somehow crossed over

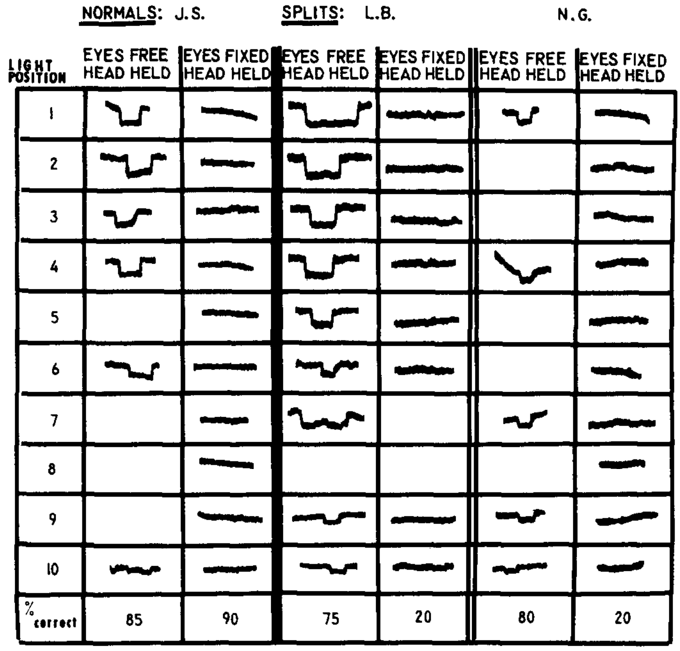

FIG. 2. Eye movement recording of both normal and brain-bisected patients are shown under each experimental condition. If the subjects were successful in touching the illuminated button a correct response was recorded. Non-correct trials consisted of responses to the left or right of the illuminated button. Per cent correct response reflects scores of at least 10 but usually 20 or more trials for each condition. Not all positions occurred in a test sequence due to the nature of the circuit generating the "pseudo-random" stimulus display.

from the seeing hemisphere. Similarly, another source of corollary discharge information might come from the hand movement which is presumably initiated by the seeing hemisphere. It is assumed that this would be useful corollary information since the hand movement itself is directed to a particular point in space; and/or (3) Efferent plan information as described by MACKAY [7] that somehow crossed over. In Condition B, since there is no eye movement and therefore no possibility of afferent information *per se*, the non-seeing hemisphere would have two possible sources of information as to the position of the stimulus. As in (2), listed above, it could be receiving corollary information from hand movement. Alternatively, efferent plan information, as in (3) above, might somehow transfer to the opposite hemisphere.

Clearly, because the patients were unable to localize points in Condition B, some ideas on the source of the cross cued information can be eliminated. Efferent plan information, for example, does not seem likely. This information is generated and present in the right hemisphere. It appears, however, as Condition B proves, to be limited to that half of the brain in brain-bisected patients.

It is conceivable that motor corollary information is also ruled out as a source of eye position information in this case. The argument would be as follows: Since the right hemisphere, with eyes fixed, can successfully direct the left hand in the present task, it is clear that local sign and motor corollary processes are functional and active. When the right hemisphere attempts to direct the right hand, all conditions are similar except that the pathway to the necessary neurological apparatus is absent, thereby causing an inadequate response. If corollary information were transferred to the left hemisphere which houses the necessary neurological machinery for the response, accurate movements could have been expected. It may be concluded, therefore, that corollary information does not transfer to the left, even though it remains active and accurate but isolated on the right.

The possibility remains that corollary information associated with eye movements is of a special class and kind. It could be argued, however, that this too, is not the critical information in Condition A. The eye movement is presumably initiated in the right hemisphere. In the split-brain case, this would mean that the left would know nothing about the perceptual information precipitating the movement, but merely note that the eyes had moved. In short, the right hemisphere is actively viewing the world while the left is in a passive state. In such cases, only active systems have corollary information; therefore, the left would have proprioceptive information only for knowledge of eye position.

In summary, a case can be made to show that the brain when registering eye position can use information derived from the ocular-motor system. One possible source for the bi-hemispheric registration of eye position would be the kind of mechanism active in the frontal eye fields as recently described by BIZZI [8].

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Résumé—On a examiné la capacité de sujets humains "split-brain" à localiser exactement un point de l'espace en utilisant une combinaison hémisphère-main ipsilatérale. Des résultats positifs n'étaient obtenus que lorsque l'hémisphère non-voyant obtenait des informations sur le but à atteindre sous la forme d'une connaissance de la position des yeux. Ces résultats confirment l'opinion qu'un mécanisme principal de l'intégration inter-hémisphérique est l'information au moyen de repères croisés.

Zusammenfassung—Wir untersuchten bei Menschen mit Balkendurchtrennung die Fähigkeit, einen Punkt im Raum genau zu lokalisieren unter Gebrauch von ipsilateraler Hand und Hemisphäre. Positive Ergebnisse wurden nur dann erzielt, wenn die nichtsehende Hemisphäre gezielte Information über die Augenstellung erhielt. Diese Ergebnisse bestätigen die Ansicht, daß der Hauptmechanismus bei der interhemisphärischen Integration auf kreuzweise vermittelten Informationen basiert.