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# INTERHEMISPHERIC RIVALRY DURING SIMULTANEOUS BILATERAL TASK PRESENTATION IN COMMISSUROTOMIZED PATIENTS[1]

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The majority of studies on commissurotomized patients have been designed to test the performance of one hemisphere at a time, usually by lateralizing stimulus input or response readout. Results with this alternate left or right testing procedure have highlighted the functional specializations of the two hemispheres, as well as numerous cross integration deficits (for review, see e.g. Bogen, 1969a, 1969b; Gazzaniga, 1967, 1970; Sperry, 1970, 1973; Sperry, Gazzaniga and Bogen, 1969). A smaller number of studies have utilized simultaneous bilateral testing to examine bimanual coordination (Preilowski, 1972), and the extent to which performance efficiency of one hemisphere is affected by simultaneous task activities in the other. Results with the latter have varied according to task requirements and control conditions, demonstrating improved parallel performance by the two hemispheres after commissurotomy (Gazzaniga and Sperry, 1966; Gazzaniga, 1968; Gazzaniga and Hillyard, 1973), less interference between the hemispheres than within a hemisphere (Kreuter, Kinsbourne and Trevarthen, 1972), and interhemispheric competition (Levy, Trevarthen and Sperry, 1972; Teng and Sperry, 1973).

The nature, level and extent of the left-right interference and the implications regarding attentional and other unifying control factors in cerebral function remain largely unknown. The present study was designed to further examine interhemispheric interference in the following two aspects: 1) In what ways is performance deterioration during bilateral testing related to the performance levels of the two hemispheres during unilateral testing? For instance, is performance deterioration during bilateral testing observable only if performance during unilateral testing is below a certain level, or mainly in the inferior hemisphere? 2) When performance deterioration occurs

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during bilateral testing, is it caused by continuous interference throughout all stages of the input-output chain, or is it localized mainly to some specific all-or-none gating mechanism at one of the stages?

## Material and Method

### *Experimental design*

A dot-counting task permitting simultaneous out-of-sight manual responses from the two hands was used to optimize parallel performance by the two hemispheres. From 1 to 5 dots were flashed, either in left or right visual field alone, or in each of the two fields simultaneously. The patients were asked to indicate the number of dots seen in each field by extending the same number of fingers with the ipsilateral hand. The hemispheric variable (left or right) and the unilateral versus bilateral testing variable were combined in a factorial design to permit close comparison of the performance of each hemisphere under unilateral and bilateral testing conditions. A duplicate set of comparison trials were presented in which a single numeral was flashed instead of a corresponding number of dots to eliminate counting, but the same manual responses were required. Thus, performance on dot-counting could be partitioned into counting versus noncounting stages to examine whether deterioration, when observed, occurs in both or only one of them.

### *Subjects*

Six commissurotomized patients (code names AA, CC, LB, NG, NW and RY) were included. Their medical histories have been summarized recently by Milner and Taylor (1972). All are right-handed, but show large individual differences with respect to general intelligence level, presurgical brain damage (in the left hemisphere for AA and CC, in the right hemisphere for NW and RY, and in both for NG), age at operation (from 13 to 43), age at testing (from 20 to 49), period since operation (from 5 to 8 years), sex, etc.

### *Material*

The stimulus material consisted of 25 dot slides and 25 numeral slides. For the dot slides, there were from 1 to 5 dots in the left and the right field of the slide. Each number of dots in one field was paired with all five possible numbers of dots in the other field, resulting in one slide each for the $5 \times 5$ possible left-right dot combinations. For the numeral slides, the number of dots in each field of the slide was simply replaced by a corresponding number. All stimuli were made transparent on opaque background. When back-projected onto the screen, each dot subtended a visual angle of 0.5°. Dots in each field of the slide were randomly positioned except that they were at least 2° from the vertical midline and at most 6° from the fixation point, with the added restriction that rim-to-rim distance between any two dots was at least 0.8°. Each number form (taken from Letraset Futura Medium papers) was about 1° wide by 1.5° high,



centered 3° laterally from the fixation point on the horizontal midline. Thus the two types of stimuli were presented in comparable areas of visual field, and the numerals were intentionally made large for easy tachistoscopic perception.

### *Procedure*

Each patient was individually tested in two sessions given one month apart. In the first session, 75 trials with the dots were presented, followed by 75 trials with the numerals. The order of stimulus material was reversed in the second session. The 75 trials were generated by presenting each of the 25 dot or numeral slides three times, once each for left field (LF), right field (RF), or bilateral presentation, well mixed in pseudo-random order. When stimulus in only one field was shown, stimulus in the other field was occluded by a piece of opaque film identical to the background of the slide. Exposure time was 50 msec. Monocular viewing with the right eye was adopted in all cases.

The patient was seated at the end of a table facing 55 cm away a back-projection screen with a 0.2° fixation spot in the center. He was asked to rest both his forearms on the table, with hands shielded from his view, and to hold both hands in loose fists during the rest condition. The nature of visual stimuli and the requirements for finger responses from the hand ipsilateral to the stimulus field were explained, followed by preliminary practice trials. For formal testing, a 25-trial run of about 5 minutes was followed by a rest period of at least 5 minutes, and a longer rest was given after 75 trials before the change of stimulus material.

### *Data analysis*

Preliminary comparison of results from the two sessions showed no noticeable differences, thus they were combined in subsequent data analysis. Each patient received 50 each of LF-only, RF-only, and Bilateral trials with the dots as well as with the numerals. A bilateral trial involved stimulus presentation in both visual fields. Thus for each type of stimuli there were 50 trials under each of the $2 \times 2$ conditions of LF versus RF input, and Unilateral versus Bilateral testing. The patient's responses were classified among five categories of Correct, Over-count, Under-count, Omission (lack of response in the presence of stimulus), and Commission (presence of response in the absence of stimulus), the last of which was of course only observable during unilateral stimulation. Since the left-field, left-hand combination is primarily related to the right hemisphere, and the right-field, right-hand combination to the left hemisphere, the corresponding hemispheric designation will be used for convenience in the following presentation.

All statistical tests involved two-tailed t tests for correlated means with 5 degrees of freedom. For instance, in comparing unilateral with bilateral input, the numbers of responses from both hemispheres during unilateral input were summed for each patient and subtracted from the sum score during bilateral input. Then whether or not the mean difference score from the six patients was significantly different from zero was tested. Difference between the two hemispheres was tested by analogous procedures. To test for Hemisphere by Input interaction, the difference between the two hemispheres during unilateral input was subtracted from their difference during bilateral input for each patient, and then the significance of the mean "difference of differences" score from the six patients was determined.

## Results

Response frequencies to the numeral stimuli under the four input conditions are represented in Table I. Taking the group as a whole, performance in terms of number of correct responses is generally better during unilateral than bilateral input (Mean = 25.33, t = 2.95, $p < .05$), but the two hemispheres do not differ significantly (Mean = 3.00, t = .15, $p > .10$), and there was no significant Hemisphere by Input interaction (Mean = 11.67, t = 1.36, $p > .10$).

TABLE I

*Response Frequencies to the Numerals*

| | Patient | Left hemisphere Cr | Ov | Ud | Ex | Cm | Right hemisphere Cr | Ov | Ud | Ex | Cm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Unilateral | AA | 33 | 1 | 15 | 1 | | 49 | | | 1 | 1 |
| | CC | 50 | | | | | 49 | | 1 | | |
| | LB | 49 | 1 | | | 2 | 50 | | | | |
| | NG | 50 | | | | 1 | 49 | | | 1 | |
| | NW | 43 | | 3 | 4 | | 4 | 7 | 1 | 38 | 1 |
| | RY | 50 | | | | | 48 | 1 | 1 | | |
| | Mean | 45.8 | 0.3 | 0.3 | 0.8 | 0.5 | 41.5 | 1.3 | 0.5 | 6.7 | 0.5 |
| Bilateral | AA | 4 | | | 46 | | 49 | | | 1 | |
| | CC | 4 | | 2 | 44 | | 42 | 2 | 2 | 4 | |
| | LB | 49 | | | 1 | | 49 | | | 1 | |
| | NG | 17 | | | 33 | | 36 | | | 14 | |
| | NW | 40 | 1 | 4 | 5 | | | | | 50 | |
| | RY | 50 | | | | | 32 | 3 | 3 | 12 | |
| | Mean | 27.3 | 0.2 | 1.0 | 21.5 | | 34.7 | 0.8 | 0.8 | 13.7 | |

Legend. Cr: correct; Ov: Over-count; Ud: under-count; Ex: extinction; Cm: commission errors.

Inspection of individual data in Table I shows that performance during unilateral input in either the left or the right field was generally nearly perfect. The only big exception was during left field stimulation for NW, who had a ventriculo-jugular shunt on the right side, and usually had poor voluntary control of her left hand. Performance deterioration during bilateral input was almost exclusively due to response omission, or extinction.

Although the averaged group data might suggest that extinction was equally shared between the two hemispheres, this is not true at all for the individual patients who typically showed predominantly one-sided extinc-



tion. Furthermore, the frequency and laterality of extinction during bilateral input does not bear any clear relationship with the performance level during unilateral input. For instance, perfect performance by each of the hemispheres during unilateral input may be accompanied by considerable extinction on either the left (RY) or the right (CC) side, or neither (LB). The lack of response extinction found in LB is atypical among the patients, but this youngest and brightest patient generally performs better than the others, and shows the least of the commissurotomy syndrome in other studies as well.

Response frequencies to the dot stimuli are presented in Table II. Comparisons between the two tables show that patterns and frequencies of response extinction to the dots are similar to those to the numerals, and the inferior performance to the dot stimuli is mainly due to increased counting errors. These results support the assumption that the main significant task difference between the response to the dots and that to the numerals is the additional counting stage involved in the former case.

TABLE II

*Response Frequencies to the Dots*

| | Patient | Left hemisphere Cr | Ov | Ud | Ex | Cm | Right hemisphere Cr | Ov | Ud | Ex | Cm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Unilateral | AA | 18 | 1 | 31 | | | 44 | | 5 | 1 | |
| | CC | 32 | 1 | 17 | | 1 | 48 | 2 | | | |
| | LB | 45 | 1 | 4 | | 6 | 48 | | 2 | | |
| | NG | 37 | | 12 | 1 | 11 | 36 | 13 | 1 | | 9 |
| | NW | 29 | 5 | 14 | 2 | 1 | 16 | 7 | 1 | 26 | 1 |
| | RY | 29 | 1 | 18 | 2 | 2 | 43 | 1 | 5 | 1 | |
| | Mean | 31.7 | 1.5 | 16.0 | 0.8 | 3.5 | 39.2 | 3.8 | 2.3 | 4.7 | 1.7 |
| Bilateral | AA | 4 | | | 46 | | 44 | 2 | 4 | | |
| | CC | 7 | 2 | 10 | 31 | | 34 | 9 | | 7 | |
| | LB | 42 | 2 | 5 | 1 | | 50 | | | | |
| | NG | 13 | | 8 | 29 | | 33 | 16 | | 1 | |
| | NW | 25 | 16 | 8 | 1 | | 1 | 15 | 6 | 22 | |
| | RY | 27 | 4 | 19 | | | 26 | 6 | 3 | 15 | |
| | Mean | 19.7 | 4.0 | 8.3 | 18.0 | | 32.2 | 8.0 | 2.2 | 7.5 | |

Legend. See Table I.

In order to compare "net, cognitive" dot counting ability independent from overt motor responses, for every patient a number of net counting errors is derived for each hemisphere under each input condition.

This is done by subtracting the sum of overcount and undercount response to the numeral stimuli from that to the dot stimuli. On the average, the numbers of net counting errors for the right hemisphere were 4.33 during unilateral input and 8.50 during bilateral input, and those for the left hemisphere were 14.17 during unilateral input and 11.17 during bilateral input. The difference between the hemispheres approaches statistical significance (Mean — 12.51, $t = 2.00$, p about .10). On the other hand, the difference between unilateral and bilateral presentations is not significant (Mean = 1.17, $t = 0.22$, $p > .10$), nor is there significant Hemisphere by Input interaction (Mean = 7.17, $t = 1.67$, $p > .10$). The right hemisphere superiority and the absence of bilateral input effect becomes more obvious when we express the mean number of correct responses to the dot stimuli in proportion to that to the numeral stimuli. The proportion scores for the right hemisphere were .94 during unilateral input and .93 during bilateral input. Those for the left hemisphere were .69 during unilateral input and .72 during bilateral input. These proportions indicate that, considering performance in the counting stage alone, the right hemisphere was correct over 90 per cent of the time, whereas the left hemisphere was correct about 70 per cent of the time, with no performance deterioration in either hemisphere during simultaneous bilateral task presentations.

To examine whether or not the two hemispheres also differ qualitatively in dot counting ability, their respective frequencies of over-count and under-count errors were compared. Net counting errors to the dot stimuli were derived for each patient by subtracting the few over-count and under-count errors to the numerals from the respective errors to the dots. The average numbers of net over- and under-counts by each hemisphere during each input condition are presented in Table III.

TABLE III

*Mean Numbers of Net Over-count (Ov) and Under-count (Ud) Errors to the Dots (N = 6)*

| Input | Left hemisphere | | | Right hemisphere | | |
|---|---|---|---|---|---|---|
| | Ud | Ov | Ud — Ov | Ud | Ov | Ud — Ov |
| Unilateral | 13.00 | 1.17 | 11.83 | 1.83 | 2.50 | —0.67 |
| Bilateral | 7.33 | 3.83 | 3.50 | 1.33 | 7.17 | —5.84 |

During unilateral input the large number of errors made by the left hemisphere were overwhelmingly under-counts, whereas the small number of errors made by the right hemisphere showed no difference between the two error categories. During bilateral input, both hemispheres showed a decrease in their under-counts and an increase in their over-counts. The



difference in differential error pattern in terms of the number of under-counts in excess to that of over-counts is significant between the hemispheres (Mean = 21.83, $t = 2.91$, $p < .05$) and between unilateral and bilateral presentations (Mean = 13.50, $t = 3.94$, $p < .05$), with no significant Hemisphere by Input interaction (Mean = 3.17, $t = 1.18$, $p > .10$).

The patients' responses have also been analyzed as a function of the stimulus value. To save space no detailed analysis will be presented except to mention the following statistically tested results. Responses to the numerals did not differ whether the numeral was "large" (4 or 5) or "small" (1 or 2). On the other hand, for either hemisphere more incorrect responses were made to the dot stimuli when the number of dots was large. This was especially true for the left hemisphere, due to a large number of almost exclusively under-count errors when there were three or more dots.

Finally, it can be noted from Table I and II that more commission errors occurred with dots than with numerals. Responses of the inappropriate hand seem unrelated to either the stimulus value, or the responses of the appropriate hand. However, the sum of the extended fingers from the two hands almost always exceeded the number of dots shown, thus ruling out fixation shift as a possible explanation.

## Discussion

The present results showed frequent unilateral extinction during bilateral testing, but its laterality and frequency bore no clear relationship with either the absolute or the relative performance levels of the two hemispheres for unilateral input: Perfect or nearly perfect performance by both hemispheres during unilateral input could be accompanied by frequent response extinctions that occur predominantly either in the left or in the right. On the other hand, mediocre performance by a hemisphere during unilateral testing was not necessarily followed by further performance deterioration during bilateral testing. While the frequency of response extinction was unpredictable, its laterality seems most probably related to the presence of some extracallosal brain damage.

The absence of increased counting errors during bilateral input suggests that interhemispheric interference is not equally present in all stages of the input-output chain, but takes the form of competition in some gating mechanism. Thus during bilateral input one hemisphere either fails to perform at all, or performs nearly as well as during unilateral input. Together with other related experiments (Gazzaniga and Sperry, 1966; Teng and Sperry, 1973; Levy, Trevarthen and Sperry, 1972), the pattern of results suggests that interhemispheric competition in the commissurotomized patients manifests itself mainly in response extinction rather than response degradation such as increased reaction time or errors. When task demand favors one hemisphere over the other, extinction occurs in the weaker hemisphere. However, even when both hemispheres seem equally proficient during unilateral input, extinction still may occur during bilateral testing.

Remarkably similar patterns of extinction and obscuration have long been noted in neurological patients and, to a lesser degree, also in healthy individuals. Although there has been no proven or commonly accepted explanation, extinction and obscuration are generally considered to be sensory phenomena (Bender, 1952, 1972; Benton and Levin, 1972). On the other hand, motor interference has sometimes been implicated in the case of commissurotomized patients (Gazzaniga and Hillyard, 1973; Levy, Trevarthen and Sperry, 1972). If motor rivalry is chiefly responsible, the hemisphere that has earlier readiness to respond might be expected to dominate over the other. In the context of dot counting the dominant hemisphere could be the right one because of its faster (Diamond and Beaumont, 1972) and presumed Gestalt-like parallel mode (Levy-Agresti and Sperry, 1968; Cohen, 1973) of perception, or one that received a smaller number of dots. Neither expectation derived from the motor rivalry hypothesis was confirmed by the present results.

The slightly better dot counting ability of the right hemisphere over the left observed in the present study is consistent with earlier findings with normals (Kimura, 1966) and patients with unilateral cortical damage (Kimura, 1963; Warrington and James, 1967). Error analysis of the current data further revealed that, for all six patients, the inferior performance of the left hemisphere was due to a disproportionately large number of under-count errors, especially when the number of dots was large. A possible explanation is that the brief exposure time of 50 msec. is too short for the left hemisphere to complete its sequential counting, but long enough for right-hemisphere Gestalt-like apprehension (Levy-Agresti and Sperry, 1968; Cohen, 1973).

The present results have also shown for both hemispheres significantly more over-counts and less under-counts during bilateral than during unilateral dot presentations. The lack of similar findings with the numeral stimuli argues against bilateral motor control as a possible explanation. In addition, finger responses from both hands were sometimes observed during unilateral input that add up to more than the number of dots in the stimulus set. These two related observations are in accord with the suggestion of a possible presence of some relatively weak ipsilateral projection of visual information (Trevarthen, 1970; Trevarthen and Sperry, 1973; Sperry, 1973). When the stimulus is as simple as the flashed dots this ipsilateral projection is nevertheless effective enough for behavioral responses.




## Summary

Six commissurotomized patients were tested and the performances of their left and right hemisphere on a dot counting task were compared during unilateral and bilateral input to study aspects of interhemispheric interference. From 1 to 5 dots were flashed, either in the left or the right visual field alone, or in each of the two fields simultaneously, and the patients were asked to indicate the number of dots seen in each field by extending the same number of fingers with the ipsilateral hand. Comparison trials were also presented where the number of dots were replaced by a corresponding numeral to eliminate counting. Comparable incidences of responses extinction to the dots and to the numerals were frequently observed during bilateral input. Their occurrence bore no clear relationship to the performance levels during unilateral input. Rather, the predominant side of extinction varied among the patients and seems to be related to the presence of some contralateral brain damage. Despite frequent response extinctions, no concurrent increase in counting errors was observed during bilateral input, indicating that interhemispheric interference in the present case is not equally present in all stages of the input-output chain, but takes the form of an all-or-none rivalry in some gating mechanism. Ancillary findings support different modes of information processing by the two hemispheres, and a possible presence of weak ipsilateral projection of visual information.


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