BRAIN AND COGNITION 25, 128–137 (1994)

Letter Matching within and between the Disconnected Hemispheres

ZOHAR EVIATAR

University of Haifa, Israel

AND

ERAN ZAIDEL

University of California at Los Angeles

Three patients with complete cerebral commissurotomy from the California series were given two letter-matching tasks, one requiring physical identity and the other requiring nominal identity. The pairs of letters were presented unilaterally to each disconnected hemisphere or bilaterally, with each hemisphere receiving one of the letters to be compared. The disconnected hemispheres of all three patients showed good performance in the unilateral conditions, even when visual field and response hand were crossed. The crossed visual field–hand conditions resulted in both slower and less accurate responses. Only N.G. was able to cross-compare letters in the bilateral condition and only for physical identity. The results qualify previous reports that higher-level information can transfer subcallosally while visual information cannot.

An important issue in the study of the disconnection syndrome following complete cerebral commissurotomy is the extent of residual interhemispheric integration in the absence of the neocortical commissures. Many studies presented two different stimuli, one to each disconnected hemisphere, and asked the patients to compare them. The general finding is that the split-brain subject cannot compare the physical identity of stimuli across the visual fields, with the exception of crude information about rate of motion and relative displacement of objects and simple sensory features such as curved versus straight contours or sharp versus dull edges (Trevarthen & Sperry, 1973). However, persistent reports

The research reported in this paper was supported by an APA Dissertation Award and a UCLA Graduate Division Research Award to Zohar Eviatar, and by NIH Grant NS20187 and NIMH RSA MH00179 to Eran Zaidel. Reprint requests should be addressed to Zohar Eviatar, Institute of Information Processing and Decision Making, University of Haifa, Israel 31905.

0278-2626/94 $6.00

showed transfer of more abstract codes, ranging from the affective connotations of a scene (Zaidel, 1976) or an object (Sperry, Zaidel, & Zaidel, 1979) to associations (Myers & Sperry, 1985), categorical relations (Sergent, 1987, 1990, 1991), as well as functional and abstract relations (Cronin-Golomb, 1986). For example, in the California series, Johnson (1984) has reported that N.G. could cross-compare line and circle patterns as well as numbers and letters (including small sample sizes) with both verbal and manual responses, although she could not verbally identify left visual field (LVF) stimuli presented to her right hemisphere (RH). Neither A.A. nor L.B. could perform these tasks with above chance accuracy. On the other hand, L.B. could verbally identify some stimuli that were presented to his RH even though he could not cross-compare stimuli in the two visual fields.

We will discuss two types of data involving interhemispheric transfer that were elicited from the patients. The first results from "crossed" hand by visual field conditions. Here, one hemisphere "sees" the stimuli and the other hemisphere controls the responding hand. Good performance (in the absence of cross-cueing, cf. D. Zaidel, 1989) can result from three scenarios. First, the hemisphere that saw the stimuli may be able to control the response hand via ipsilateral motor pathways, so that performance reflects the ability of the hemisphere to which the stimuli were presented. Second, visual information may be transferred subcallosally, so that performance reflects the ability of the hemisphere that controls the response hand, not the one that received the stimuli initially. Third, the task may be performed by the hemisphere that saw the stimulus, and a motor command to respond is transferred subcallosally to the other hemisphere.

The second type of data on interhemispheric transfer comes from presenting each member of the to-be-compared stimulus pair to a different hemisphere. Here, sensory or cognitive information must be shared by the hemispheres for better-than-chance performance. Thus, assuming that processing remains the same, if performance in the unilateral crossed conditions is due to ipsilateral motor control or subcallosal transfer of a motor command, the subjects may not be able to do the task in the bilateral conditions. However, if performance in the crossed conditions is due to subcallosal transfer of visual or cognitive information, the subjects may be able to perform the bilateral task. Clarke and Zaidel (1989) tested the same patients whose data are presented here using simple reaction times to unpatterned light flashes in crossed and uncrossed conditions. They concluded that one of the subjects (L.B.) uses ipsilateral motor pathways in the crossed conditions, and that the other two subjects (A.A. and N.G.) show evidence of subcallosal transfer of visual information that is sensitive to the eccentricity of the stimuli in the visual field, but not to its intensity.

In the present experiment the split-brain subjects were shown pairs of letters and had to decide if they were physically identical (the Shape task) in one condition, and if they were nominally identical when each was a different case (the Name task) in the other condition. In two thirds of the trials the stimuli were presented unilaterally and patients had to respond with the homolateral hand on one third (''pure'' hemisphere conditions) and with the contralateral hand on the other one third of the trials (the ''crossed'' hemispheres conditions). One third of the trials involved bilateral presentations where each hemisphere saw one letter, so that comparison forced interhemispheric communication. The subjects responded with their right hand on half of these trials and with their left hand on the other half. Since the Shape task requires physical identity while the Name task requires categorical identity, and since previous reports have suggested that these patients transfer abstract, categorical information but not visual information subcallosally, we predicted better performance in the bilateral condition for the Name task than for the Shape task.

METHOD

Subjects

Three complete commissurotomy patients from the California series were tested, A.A., N.G., and L.B. The case histories of these patients have been described elsewhere (Bogen & Vogel, 1975; Clark & Zaidel, 1989). MRI verification of complete commissurotomy is available for all three patients (Bogen, Schultz, & Vogel, 1988). The subjects were paid for their participation.

Design

Four blocks of 192 trials were run with each subject. Each block represented a decision type (Name or Shape) by response hand condition. Within each block, 64 of the 192 trials appeared in each visual field condition (LVF, RVF, bilateral presentation). Of the 64 stimuli, 32 were *same* and 32 were *different* pairs.

Materials and Apparatus

The stimuli were letter pairs drawn out of the set: A, B, D, E, F, G, H, I, J, L, M, N, Q, R, T, Y, and their lowercase counterparts. These letters were chosen because their upper- and lowercase do not have the same shape. This is to ensure that Name decisions about stimuli such as ''Aa'' are not done via a template matching mechanism. The stimuli were newly created for each block for each subject by a random generation of the ascii number codes of the letter set, with the frequency of occurrence of each particular letter or letter pairing not controlled. For Name decisions, the generation occurred with one contraint: all of the stimuli requiring a ''same'' response consisted of an upper- and lowercase pair of the same letter (e.g., ''Aa''). All of the stimuli requiring a ''different'' response consisted of two different letters, with case not controlled. For Shape decisions, all stimuli requiring ''same'' responses were the same letter, both either in upper- or in lowercase. Two types of *different* stimuli in the Shape decision occurred with equal frequency: upper and lower case of the same letter (Aa) and pairs of different letters (AG, Ab, or aj).

The stimuli were presented by an IBM-XT personal computer using a Computerized Tachistoscope package developed by Steve Hunt. An Amdek Video-310A monitor was used, with black letters appearing on an orange background (reversed video). The letter pairs in the unilateral conditions were presented side by side, offset from 3 to 5° of visual angle from fixation and were approximately 1.0 × 1.0 cm in size (1 × 1° of visual angle). In the bilateral condition each member of the stimulus pair was presented in a different peripheral field, 3° away from fixation. The viewing distance was 57 cm.

Procedure

For each patient, a short series of trials (36 total, 12 in each visual presentation condition) were run in order to determine the appropriate exposure duration for the stimuli. For each exposure duration, the subjects ran one block with one hand responding and then one block with the other hand responding. The decision criterion for choice of exposure duration was 75% (9 items) correct responses in the RVF with right-hand responses and in the LVF with left-hand responses. The longest exposure duration was 150 ms, and this was the duration used on the experimental trials for A.A. and N.G. For L.B., the stimuli were exposed for 80 msec in the Name task and 60 msec in the Shape task. On the first day, once exposure duration for both decision tasks had been determined, the patients began the experimental trials. Before each task, an additional block of 36 practice trials was run. Each experimental task contained 192 trials. These were divided into 4 miniblocks of 48 trials each. Within each miniblock, 16 stimulus pairs (8 same and 8 different) appeared in each visual field condition. On the first day unilateral trials were mixed with central trials (not analyzed in this experiment) and on the second day, unilateral trials were mixed with bilateral trials. Each trial was initiated by the experimenter. A trial consisted of the following sequence: a fixation cross appeared for 2000 msec, a 100-msec beep alerted the subject that the stimulus was about to appear, the stimulus pair was shown for the predetermined exposure duration, and then the screen became blank. The subjects were given 3000 msec to respond. Then the experimenter initiated the next trial. On the second day, all of the subjects ran the conditions in the same order, with the same stimulus exposure duration. Only the data from the second day are presented.

RESULTS AND DISCUSSION

"Pure Hemisphere" Conditions

The accuracy scores of the patients in the different hand by visual field conditions for each task are shown in Table 1. The LVF left-hand and the RVF right-hand conditions are the "pure hemisphere" conditions, where the RH performed the task in the former case and the LH in the latter. As can be seen, N.G. and L.B. show a LH advantage for the Name task, but also RH competence. A.A.'s LH shows poor performance on the Name task, while his RH has a high correct rejection rate (due to a strong bias to respond "different," he was correct on 16/32 *same* trials and 31/32 *different* trials, $\chi^2_{(1)} = 4.79$, $p < .05$). For the Shape task, all of the patients evince better overall performance in the RH, but also show LH competence. These data converge with previous reports of lateralized versions of these tasks with normal subjects, where both hemispheres are able to perform these tasks (Boles, 1981, 1986; Eviatar & Zaidel, 1992).

TABLE 1
Number Correct (out of 32) and Percent Accuracy of Responses for the Split Brain Patients in Each Hand by Visual Field Condition ("Pure" Hemispheric Conditions Are in Bold Type)

	Left hand			Right hand		
	Same	Different	% Correct	Same	Different	% Correct
			N.G.			
Name task						
LVF	**20**	**26**	**71.8***	21	20	64*
RVF	24	23	73.4*	**26**	**30**	**87.5***
BVF	15	18	51.6	17	22	60.9
Shape task						
LVF	**26**	**24**	**78.1***	23	29	81.25*
RVF	26	23	76.6*	**21**	**23**	**68.75***
BVF	22	22	68.75*	22	26	75*
			A.A.			
Name task						
LVF	**16**	**31**	**73.4***	14	23	57.8
RVF	26	19	70.3*	**21**	**17**	**59.4**
BVF	25	4	45.3	27	2	45.3
Shape task						
LVF	**27**	**27**	**84.4***	23	29	81.25*
RVF	22	25	73.4*	**18**	**28**	**71.9***
BVF	19	15	53	24	10	53.1
			L.B.			
Name task						
LVF	**26**	**30**	**87.5***	20	30	78.1*
RVF	24	32	87.5*	**27**	**32**	**92.2***
BVF	15	13	43.75	18	19	57.8
Shape task						
LVF	**26**	**32**	**90.6***	20	31	79.7*
RVF	17	29	71.9*	**25**	**27**	**81.25***
BVF	17	9	40.6	27	8	54.7

* Better than chance performance, $\alpha = .05$, two-tailed binomial.

The response times of correct responses of the patients are shown in Table 2. Due to experimental error, L.B.'s response times were not tabulated for the sessions that included bilateral presentation. His response times are from the first experimental session, where all the procedures were identical, except that the bilateral items were presented in central visual field. We used only the lateralized trials, which were identical in both sessions. The response times were analyzed separately for each patient, with items as the random variable and task (Name vs. Shape), visual field (LVF, RVF, BVF), and response hand as between-group variables.

TABLE 2
Mean Response Times (in ms) for the Split Brain Patients in Each Hand by Visual Field Condition ("Pure" Hemispheric Conditions Are in Bold Type)

	Left hand			Right hand		
	Same	Different	Mean	Same	Different	Mean
			N.G.			
Name task						
LVF	**1127**	**1102**	**1114**	1045	896	970
RVF	964	920	942	**1158**	**814**	**986**
BVF	1055	914	984	1028	909	968
Shape task						
LVF	**967**	**836**	**902**	707	687	697
RVF	824	1012	918	**920**	**774**	**847**
BVF	1110	814	962	687	733	710
			A.A.			
Name task						
LVF	**1647**	**1114**	**1380**	1240	1138	1189
RVF	1725	1451	1588	**1346**	**1329**	**1338**
BVF	1382	1228	1305	1169	1382	1276
Shape task						
LVF	**1301**	**888**	**1094**	972	922	947
RVF	1488	1575	1532	**1418**	**1317**	**1368**
BVF	1532	1811	1672	1230	1453	1342
			L.B.			
Name task						
LVF	**1033**	**806**	**920**	891	693	792
RVF	981	829	905	**788**	**669**	**728**
Shape task						
LVF	**758**	**620**	**689**	875	654	764
RVF	785	707	746	**823**	**854**	**838**

For the Name task, both N.G. and L.B. show a significant LH advantage (N.G., $F(1, 525) = 3.8$, $p = .051$; L.B., $F(1, 576) = 15.4$, $p < .0001$). A.A.'s responses were also faster in the RVF-rh (LH) condition than in the LVF-lh (RH) condition, but not significantly so. For the Shape task A.A. and L.B. show a RH advantage (A.A., $F(1, 467) = 7.9$, $p = .005$; L.B., $F(1, 576) = 9.98$, $p = .002$). N.G. shows a nonsignificant (55 msec) LH advantage.

Bilateral Presentations

It can be seen (Table 1) that none of the patients were able to perform the Name task in the bilateral presentation condition, and A.A. and L.B. could also not compare letters by shape across the visual fields. N.G. was able to achieve above chance performance when comparing letters by shape. Johnson (1984) also reported that N.G. was the only patient able to cross compare physical attributes of stimuli across the visual fields but this was limited to a small and easily verbalizable stimulus set where cross-cueing could not be ruled out. Our results differ from his in that the stimulus set here is larger, so that performance is unlikely to reflect response transfer or cross-cueing between the hemispheres. Our results confirm the findings of Clarke (1990) showing accurate *same/different* comparisons of nonsense Vanderplas shapes that were too numerous, varied, and hard to verbalize to be easily cross-cued. Analysis of the errors revealed that N.G.'s responses are not biased: she made the same amount of errors on *same* and *different* stimuli. However, both L.B. and A.A. made systematic errors in the bilateral condition. Both tended to say "same" more often than "different" (A.A., Name task, lh: $\chi^2_{(1)} = 15.2, p < .01$; rh: $\chi^2_{(1)} = 21.5, p < .01$; Shape task, rh: $\chi^2_{(1)} = 5.6, p < .01$; L.B., Shape task, rh: $\chi^2_{(1)} = 10.3, p < .01$).

N.G.'s ability to cross-compare shapes and not names is remarkable. It suggests that visual information can transfer subcallosally and be available for the Shape task but not for the Name task. This could suggest modularity or even intrahemispheric disconnection between the processors of shape comparisons and those of name comparisons. Alternatively, it is possible that the transferred visual information is limited to the level of initial representations, or Marr's primal sketch, allowing figure-ground and contour discrimination without specifying the identity of the stimulus. Indeed, N.G.'s comparison of bilateral *different* shapes did not reveal a congruity effect (slower rejection of *same*-Name/*different*-Shape pairs ("Aa") than of *different*-Name /*different*-Shape pairs (Ag)), suggesting that nominal identity was not processed, and so did not affect responses.

Crossed Hemisphere–Hand Conditions

The accuracy scores for the crossed conditions, where the stimuli were presented to one hemisphere but the response was made with the contralateral hand, show patterns similar to the pure conditions. Again, both N.G. and L.B. show bilateral competence for the tasks, with better performance in the RVF for the Name task and better performance in the LVF for the Shape task. A.A. also shows this pattern, but performance in the LVF with the right hand is below chance. A.A.'s performance with his right hand is always below chance for the Name task. A.A. has damage to the motor area in the LH. Nebes and Sperry (1971) tested his ability to respond manually to a variety of stimuli presented in crossed hand–visual field conditions. In all the tasks that involved language use they found better control of the left hand by the LH than of the right hand by the RH. Zaidel (1989) also reports that A.A.'s scores on a version of Benton's test for stereognosis were always low with the right hand. Here we see that task difficulty affected right hand performance: performance was above chance on the easy Shape task and below chance on the harder Name task.

Only N.G. reveals a significant difference in response times between crossed and uncrossed conditions. However, the response time difference is opposite than expected; the crossed conditions (956 ms) are actually faster than the pure, uncrossed conditions (1050 msec), $F(1, 525) = 3.8$, $p = .05$. Table 2 shows that this is due to long response times in the LVF-left hand condition, and for *same* stimulus pairs in the RVF-right hand condition. This difference between responses to *same* and *different* stimuli in the RVF-right hand condition is interesting. One of the major issues under study with *same/different* paradigms is the consistent finding that normal subjects can classify identical stimuli as "same" faster than they can classify nonidentical stimuli as "different" (the fast-*same* effect). We compared response times to *same* and *different* stimuli in the conditions where performance was above chance. In general, the patients do not show the same pattern as normals, with responses to *different* stimuli generally faster than response times to *same* stimuli. The only exception is N.G.'s performance in the RVF left-hand condition of the Shape task, where "same" responses were 188 msec faster than "different" responses, $F(1, 525) = 4.0$, $p = .05$. Because the fast-*same* effect is so ubiquitous, these findings suggest that the patients were performing these tasks differently from the way they are done by normal subjects. This could mean that the normal pattern reflects some complex form of interhemispheric interaction.

In order to further explore N.G.'s responses to *same* and *different* stimuli we categorized *different*-Shape stimuli into two types: congruent (where both the shapes and the names of the letters were *different*, e.g., "Ag") and incongruent (where the shapes of the letters were *different*, but the name was *same*, e.g., "Aa"). An analysis of response times in these cells for all conditions revealed an effect of congruity only in the RVF left-hand condition. Here congruent stimulus pairs (Ag = 823 msec) were responded to significantly faster than incongruent stimulus pairs (Aa = 1180 msec), $F(1, 135) = 9.7$, $p < .005$. This is surprising, given that each hemisphere can match both shapes and names. It may be that the congruity effect is interhemispheric and occurs only within a narrow range of relative timing of the different processes. A similar observation has been made in regard to the consistency effect (global interference with local decisions) in the Global-Local task of Navon (Robertson, Lamb, & Zaidel, 1993; Zaidel, in press).

CONCLUSIONS

All three split-brain subjects were able to perform both tasks in the crossed hemisphere-hand conditions, and only N.G. was able to cross-compare letters in the bilateral condition. These findings suggest that she is able to transfer visual information subcallosally and that L.B. and A.A. cannot, so that they performed the crossed conditions either by ipsilateral control of the hands or by subcallosal transfer of a motor command. N.G.'s performance contradicts Sergent's (1990) report that she was unable to match digits across the visual fields. However, Sergent presented each digit 7° of visual angle from fixation, whereas here each letter was only 3° from fixation. Clarke and Zaidel (1989) showed that N.G.'s ability to transfer information between the hemispheres is affected by the eccentricity of the stimuli in the visual fields. Contrary to reports of other researchers (Cronin-Golomb, 1986; Sergent, 1990; Teng & Sperry, 1973), L.B. could not perform the tasks in the bilateral condition.

To summarize, we can reach several general conclusions. First, each disconnected hemisphere can perform letter matches using both nominal and physical decision criteria. This is in conjunction with generally better performance of the RH than the LH on the Shape task and better performance of the LH than the RH on the Name task. Second, we found no evidence that higher level codes (letter identities) can transfer subcallosally whereas lower level codes (letter shapes) cannot. In fact, none of the patients could cross-compare letter names, and N.G. was able to cross-compare letter shapes. Third, the patient's response times do not reveal a fast-*same* effect, which is usually a robust finding with normal subjects. This suggests that the fast-*same* effect may be a result of interhemispheric communication via callosal transfer. Normal subjects also generally reveal a congruity effect in the Shape task, where *same*-Name/*different*-Shape pairs ("Aa") result in longer "different" response times than *different*-Name/*different*-Shape pairs as a result of interference caused by the name identity. Only N.G. showed this effect, and only in the RVF left-hand condition. This suggests that the congruity effect may also be interhemispheric. Finally, in general, the crossed visual field-response hand conditions resulted in both lower accuracies and slower response times. It is not possible to determine unequivocally whether a given crossed visual field-hand condition involves visual or motor transfer (or ipsilateral control) or even both. It is likely that the predominant channel of transfer varies across patient and task.

REFERENCES

Bogen, J. E., & Vogel, P. J. 1975. Neurological status in the long term following complete cerebral commissurotomy. In F. Michel & B. Schott (Eds.), *Les syndromes de disconnexion calleuse chez l'homme*. Lyon: Hopital Neurologique. Pp. 227–251.

Bogen, J. E., Schultz, D. H., & Vogel, P. J. 1988. Completeness of callosotomy in the long term shown by magnetic resonance imaging. *Archives of Neurology*, **45**, 1203–1205.

Boles, D. B. 1981. Variability in letter matching asymmetry. *Perception & Psychophysics*, **29**, 285–288.

Boles, D. B. 1986. Confusion and visual field effects in rhyme and name letter matching. *Perception & Psychophysics*, **39**, 123–128.

Clarke, J. M. 1990. Interhemispheric functions in humans: Relationships between anatomical measures of the corpus callosum, behavioral laterality effects, and cognitive profiles. Unpublished Doctoral Dissertation, Department of Psychology, University of California, Los Angeles.

Clarke, J. M., & Zaidel, E. 1989. Simple reaction times to lateralized light flashes: Varieties of interhemispheric communication routes. *Brain*, **112**, 849–870.

Cronin-Golomb, A. 1986. Subcortical transfer of cognitive information in subjects with complete forebrain commissurotomy. *Cortex*, **22**, 499–519.

Eviatar, Z., & Zaidel, E. 1992. Letter matching in the hemispheres: Speed-accuracy trade-offs. *Neuropsychologia*, **30**, 699–710.

Johnson, L. E. 1984. Bilateral visual cross-integration of human forebrain commissurotomy subjects. *Neuropsychologia*, **22**, 167–175.

Myers, J. J., & Sperry, R. W. 1985. Interhemispheric communication after section of the forebrain commissures. *Cortex*, **21**, 249–260.

Nebes, R. D., & Sperry, R. W. 1971. Hemispheric disconnection syndrome with cerebral birth injury in the dominant arm area. *Neuropsychologia*, **9**, 247–259.

Robertson, L. C., Lamb, L. R., & Zaidel, E. 1993. Interhemispheric relations in processing hierarchical patterns: Evidence from normal and commissurotomized subjects. *Neuropsychology*, **7**, 325–342.

Sergent, J. 1987. A new look at the human split brain. *Brain*, **110**, 1375–1392.

Sergent, J. 1990. Furtive incursions into bicameral minds: Integrative and coordinating role of subcortical structures. *Brain*, **113**, 537–568.

Sergent, J. 1991. Processing of spatial relations within and between the disconnected cerebral hemispheres. *Brain*, **114**, 1025–1043.

Sperry, R. W., Zaidel, E., & Zaidel, D. 1979. Self recognition and social awareness in the deconnected minor hemisphere. *Neuropsychologia*, **17**, 153–166.

Teng, E. L., & Sperry, R. W. 1973. Interhemispheric interaction during simultaneous bilateral presentation of letters and digits in commissurotomized patients. *Neuropsychologia*, **11**, 131–140.

Trevarthen, C. B., & Sperry, R. W. 1973. Perceptual unity of the ambient visual field in human commissurotomy patients. *Brain*, **96**, 547–570.

Zaidel, D. W. 1989. Observations on right hemisphere language functions. In F. C. Rose, R. Whurr, & M. A. Wyke (Eds.), *Aphasia*. London: Whurr Publishers. Pp. 170–187.

Zaidel, E. 1989. Long-term stereognosis in the split brain: Hemispheric differences, ipsilateral control, and sensory integration across the midline. Unpublished manuscript, University of California, Los Angeles.

Zaidel, E. In press. Interhemispheric control in the normal brain: Evidence from redundant bilateral presentations. In C. Umilta and M. Moscovitch (Eds.), *Attention and Performance XV: Conscious and Nonconscious Processes*. Crambridge, MA: MIT Press.