Journal of Experimental Psychology:
Human Perception and Performance

VOL. 2, NO. 3 AUGUST 1976

Metacontrol of Hemispheric Function in Human Split-Brain Patients

Jerre Levy
University of Pennsylvania

Colwyn Trevarthen
University of Edinburgh, Scotland

Four commissurotomy patients were tested for ability to match tachistoscopically presented stimuli with pictures in free vision, according to either structural appearance or functional/conceptual category. Patients were given ambiguous, structural, or functional instructions on any given run of trials with simultaneous double stimulus input to the two cerebral hemispheres. With ambiguous instructions, appearance and function matches were performed by the right and left hemispheres, respectively. When instructions were specific, appearance instructions tended to elicit appearance matches and right-hemisphere control. When function instructions were given, left-hemisphere control and function matches tended to be elicited. In three of the four patients, however, there was a significant number of dissociations between controlling hemisphere and strategy of matching.

Previous studies of split-brain patients have revealed that the right hemisphere is superior for visual–spatial transformations (Bogen & Gazzaniga, 1965; Levy-Agresti & Sperry, 1968; Nebes, 1971) and for the recognition of complex visual patterns (Levy, Trevarthen, & Sperry, 1972), while the left hemisphere is superior for speech and calculation (Sperry, Gazzaniga, & Bogen, 1969), for semantic decoding of written words, and for phonetic analysis (Levy & Trevarthen, Note 1). These findings confirm and extend earlier conclusions regarding hemispheric specialization drawn from studies of unilaterally brain-damaged patients (Bogen, 1969; Hécaen, 1969).

In split-brain studies to date, tests for hemispheric specialization have measured cerebral abilities by comparing response accuracies of the two hemispheres for particular tasks in which a single, correct response was available to each hemisphere. Typically, each hemisphere has been tested separately to determine the extent of its abilities, a method allowing assessment of capacity differences between the two sides of the brain, but precluding assessment of the relative dispositions of the two hemispheres to take control of processing and to respond. Levy and Trevarthen (Note 1) and Levy et al. (1972), utilizing a double presentation technique similar to one employed in earlier experiments with monkeys (Trevarthen, 1962, 1965) in

This research was aided by the Frank P. Hixon Fund of the California Institute of Technology and by U.S. Public Health Service Grants MH 02273 and MH 46980-01.

The subjects examined were patients of Doctors Philip Vogel of the California College of Medicine and Joseph Bogen of the Ross-Loos Medical Group, Los Angeles. The authors express their appreciation to Professor Roger W. Sperry in whose laboratory of psychobiology this study was conducted. We are much indebted to him for his encouragement and advice.

Requests for reprints should be addressed to Jerre Levy, Department of Psychology, 3813 Walnut Street, University of Pennsylvania, Philadelphia, Pennsylvania 19174.

which two different stimuli are simultaneously presented, one in each half of the visual field, have been able to determine not only how well each hemisphere can handle a particular task (hemispheric ability), but the degree to which each half-cerebrum tends to assume control of processing and behavior (hemispheric dominance). Although the double-presentation paradigm has permitted the determination of dominance (in the sense defined above), as well as ability differences, it has not addressed itself to the problem of what we would call *metacontrol.*

By metacontrol, we refer to the neural mechanisms that determine which hemisphere will attempt to control cognitive operations. Although, theoretically, it is conceivable that no such independent mechanism exists, and that so-called "dominance" is merely a reflection of either total incapacity of one hemisphere to respond at all, or of a speed contest between the two halves of the brain in which one half consistently wins, data from Levy et al. (1972) tend to refute this. In a test of pattern recognition of patterns constructed of vertically oriented permutations of three Xs and squares, they found that in a free-response situation, when either hemisphere could have taken control of responding, the right hemisphere was strongly dominant. However, when the left hemisphere was forced to take control of responding, by requiring a verbal description of the pattern stimulus, the left hemisphere performed at a significantly superior level as compared with the right hemisphere under free-response conditions. Thus, there was a *negative* correlation on this test between dominance, on the one hand, and ability, on the other. This result strongly suggests that a capacity difference between the two sides of the brain is not the sole determinant of hemispheric dominance; that, in fact, a hemisphere assumes control of processing as a result of set or expectation as to the nature of processing requirements *prior* to actual information processing, and that it remains in control even if its performance, for whatever reasons, is considerably worse than that which could have been produced by the opposite side of the brain. If so, this would imply that hemispheric specialization refers not only to quantitative ability differences and qualitative strategy differences, but to metacontrol processes as well, that is, to a dispositional specialization.

Though understanding is very incomplete regarding the anatomy of a possible switching mechanism, given the known complexity of activation functions attributable to the reticular systems of the brain stem, it is reasonable to guess that activating impulses can be asymmetrically routed to one or the other hemisphere under the influence of descending neural activity from cortical regions. An elegant example of such reciprocal hemisphere–brain-stem control comes from the double ablation experiment of Sprague (1966). A phenomenon found with human commissurotomy patients, which Trevarthen has called "perceptual erasure," suggests that the generation of a response in one hemisphere may lead to profound modifications of perceptions in the other hemisphere via brain-stem systems (Trevarthen, 1974). In earlier work with these patients, difficulty in testing the right hemisphere was sometimes encountered due to confabulated responses by the left. Attempts to inhibit such interfering responses via distracting tasks generally led to such a reduced level of consciousness in the right half of the brain, that it was almost impossible to elicit any responses whatsoever from it (Levy, 1970). In tests with bilateral presentation of stimuli, fluctuations in the balance of perceptual processes in the two hemispheres of central origin are commonly observed (Kinsbourne, 1974; Trevarthen, 1974; Trevarthen & Sperry, 1973). In the intact brain, it would be expected that asymmetric activation would be, in part, maintained via callosally mediated inhibition or shunting. In the commissurotomy patient the inactive hemisphere might be kept in its inactive state either by deficient "arousal" or this in combination with actual inhibitory input from brain-stem regions. In any case, if asymmetric activation can be initiated and possibly maintained by set or expectation alone, it must be the case that there is within each hemisphere, a specialized disposition to act that comes into play before ability differences can be manifested. It follows, therefore, that such dispositional specialization is to a certain extent separate from ability or strategic specializations.

In order to explore the nature of this postulated metacontrol system, we designed a test in which the two hemispheres would necessarily compete for the control of the response. Two possible correct responses were available to each hemisphere, one reflecting one processing strategy, the other reflecting another processing strategy; one or the other strategy could be selectively called for by instructions given the subject. Based on previous work, we felt relatively certain that the right hemisphere was specialized to respond to visuo–structural similarities between two stimuli, and that the left hemisphere was specialized to respond to functional–conceptual similarities between two stimuli. These we may call *the typical response modes of the hemispheres.*

We sought to answer several questions. (a) With instructions ambiguous with respect to strategy, which hemisphere would control the response and what strategy would it use? (b) With unambiguous instructions, would the instructions be effective in eliciting the appropriate strategy? (c) With unambiguous instructions, would one or the other hemisphere be selectively activated to take control of responding? (d) Would unambiguous instructions ever be followed by a dissociation between the controlling hemisphere and the strategy utilized, either activating the appropriate hemisphere but not its typical strategy, or the appropriate strategy but not the hemisphere that typically integrates it?

Method

Subjects

The same four patients, C. C., A. A., N. G., and L. B., were tested as in a previous article where the individual case descriptions are given (Levy et al., 1972). These patients had all undergone total forebrain commissurotomy for control of intractable epilepsy. In all cases, the surgery was effective in reducing the severity and frequency of seizures.

It should be mentioned that these patients had all been repeatedly tested for a number of years on a large variety of tests, and one in particular, L. B., was quite knowledgeable regarding the nature of his surgery and the functional consequences. The other three subjects, although experienced in test taking, have little or no understanding of neuroanatomy, the nature of commissurotomy surgery, or the functional consequences of such surgery. Their IQs range from borderline to low normal, and they appear to be usually unaware of the various disabilities they display in the testing situation. Even when they occasionally perceive some failure, they do not attribute any particular significance to it. As an example, some years ago, N. G. was tested by the first author for her ability to name objects placed in her left hand. She gave a series of confabulated responses and at the end of testing asked, "How did I do?" She was told, "Just fine." She grinned broadly and said, "Please tell my husband how good I am because he's always saying I'm stupid, and I bet he couldn't do as well as I did."

On the other hand, L. B. (at least his left hemisphere) has an above average verbal IQ on the full verbal scale of the Wechsler Adult Intelligence Scale and a scaled score of 16 on the Similarities subtest (yielding a prorated verbal IQ of 130). It is clear that he has a high analytic intelligence, and he is able to describe his surgery and the theoretical consequences quite accurately. However, one has a very strong impression that his intellectual understanding is completely separate from his ordinary self-consciousness. In conversation, it appears that his "I" refers to the same "I" he referred to prior to surgery. His left hemisphere experiences itself as a whole, unified stream of consciousness with no awareness of being split away from any part of itself. Although he may say, upon questioning, "I cannot name objects in the left visual field because the information is conveyed to my right hemisphere which has no language centers and, because of surgery, that information cannot reach my left hemisphere," this intellectual knowledge had no effects on the left hemisphere's consciousness of itself. The impression left with an investigator is that L. B.'s knowledge of reality has no more effect on his perceptions than does a psychologist's knowledge of the mechanisms underlying perceptual constancies have on brightness perception.

For the above reasons, we do not feel that L. B.'s understanding or the experience of the other subjects invalidates any generalizations that may be drawn from their performances. We believe that the basic effects seen in this and in earlier investigations would occur equally in totally naive split-brain patients.

Apparatus and Stimuli

A modified two-channel tachistoscope, described previously (Levy et al., 1972), was used for stimulus presentation, one field consisting of a blue fixation field with a red fixation point, the other consisting of the stimulus field in which white stimulus cards with black line drawings were presented against a black velvet, light-absorbing background, so that stimuli would appear briefly against the blue field with no perceivable light flash. Visual fixation was verified by means of continuously recorded electrooculograms. See Levy et al. (1972) for a complete technical description.

Stimuli (shown in Figures 1 and 2) were black line drawings of common objects in which the left and right halves of each stimulus were made up of two different half-pictures joined at the vertical midline. The chimeric stimuli were exposed for 150 msec with the vertical midline accurately superimposed over the fixation point, so that the left half of the stimulus was projected entirely to the right hemisphere and the right half of the stimulus to the left hemisphere. Under these conditions, as we showed previously (Levy et al., 1972; Trevarthen, 1974; Levy & Trevarthen, Note 1), each hemisphere seems to effect a perceptual completion of the half-stimulus it receives and, by all tests we could give, appears to perceive a whole stimulus.

Procedure

Subjects were told that they would see some picture in the "machine" and that they were to choose, by pointing, from the pictures that lay on the table before them in free vision, the one that was similar to the stimulus they had seen. The instructions varied as to specificity, in some cases consisting of the direction merely to "select the one which is similar to, goes with, or is like in some way the one you see" (ambiguous instruction); in others consisting of the instruction to "pick the thing that *looks* similar to what you see" (appearance instruction); and sometimes consisting of the instruction to "pick the thing you would *use* with or that normally goes with what you see" (function instruction). For each stimulus picture, there existed a choice picture that was similar to it in appearance (visuo-structural similarity) and another that either belonged to the same conceptual category or had some functional relation with it (conceptual-functional similarity). Thus, in each trial, either hemisphere could respond, and either strategy of matching could be used.

Whole stimuli (shown in Figures 1 and 2) were displayed in free vision to 10 graduate students who were asked to select from the choice pictures those which matched a stimulus in appearance and those which matched it in functional category. All 10 students matched the stimuli and choices according to the matches shown in the figures, although one added that the scissors and knife and fork were both made of metal and that, therefore, they could be said to belong to the same superordinate category. Nevertheless, we felt that the

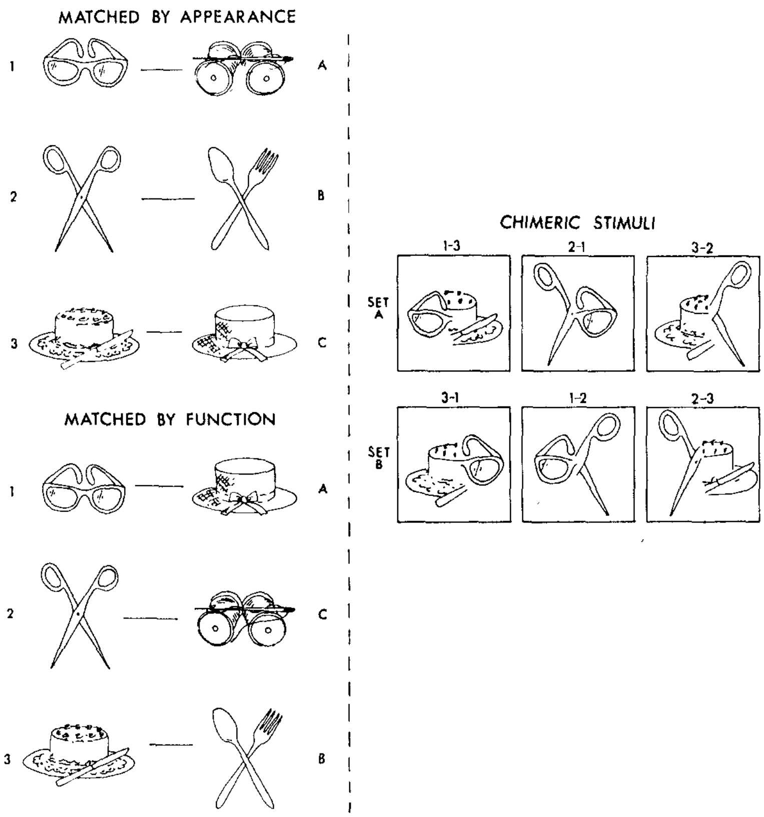

FIGURE 1. Version 1 of appearance-function matching test.

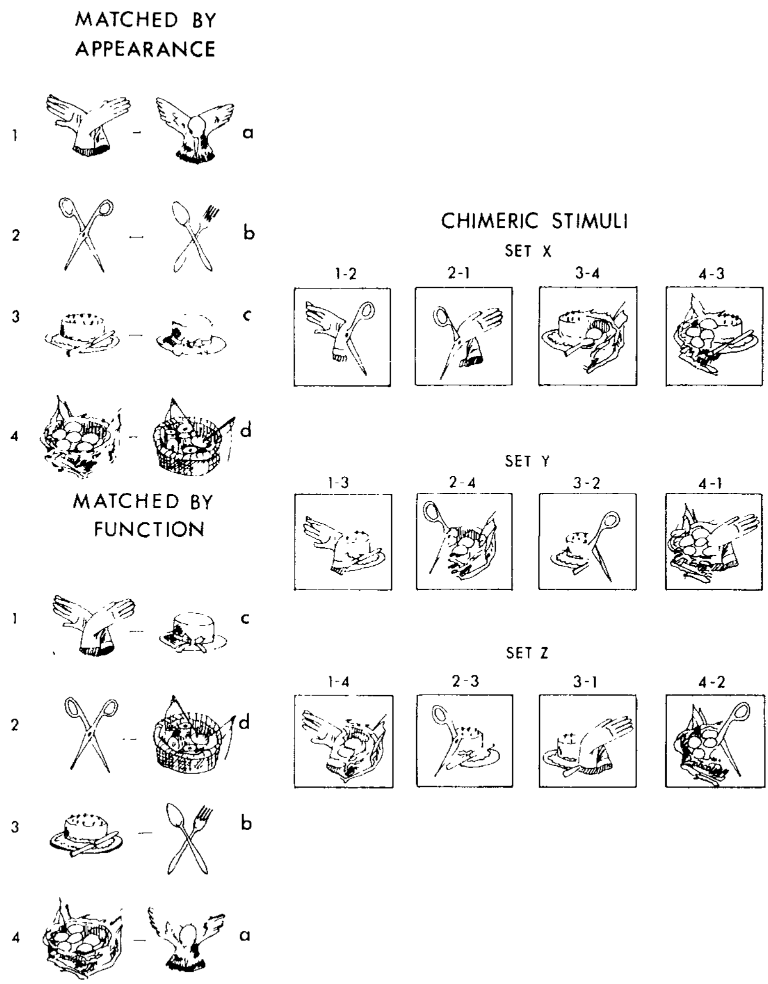

FIGURE 2. Version 2 of appearance–function matching test.

matches were sufficiently consistent to warrant the paradigm and analysis employed.

Figure 1 shows the stimuli for Version 1 of the test, used only with patient N. G. and with ambiguous instructions. The primary purpose of this test was (a) to determine the spontaneous strategy of matching that would be used, (b) to ascertain which hemisphere would assume control of behavior, and (c) to test the hypothesis that appearance matching, if it occurred, would be performed by the right hemisphere, and that conceptual–functional matching, if it occurred, would be performed by the left hemisphere.

Version 2 of the test (shown in Figure 2) was administered to all subjects and was given with appearance instructions on some runs and with function instructions on other runs. We sought to determine the effectiveness of instructions in (a) producing the appropriate strategy of matching and (b) in eliciting appropriate hemispheric control. We were particularly interested in seeing whether an instruction-induced set would consistently produce both the appropriate strategy as well as the appropriate hemispheric control, or whether, on some occasions, there might be a dissociation between the two.

OBSERVATIONS

Version 1

Possible responses to three of the six chimeras (Figure 1, Set A) could be matched as left-field-appearance, right-field-functional, or bilaterally as left-field-functional and right-field-appearance. As an example, consider Chimera 3–2 in Set A, in which a cake is displayed in the left field and scissors in the right field. If a subject selects the knife and fork as a response, this matches the left field functionally and right field in appearance. If he chooses the hat, this is a unilateral appearance match with the left field; if he chooses the thread, this is a unilateral functional match with the right field. The other three chimeras in Figure 1 (Set B) could be matched as left-field-functional, right-field-appearance, or bilaterally as left-field-appearance and right-field-functional. Chimera 2–3 (Set B), with the scissors on the left and cake on the right, can be seen to match any of the three choices in a reversed direction from Chimera 3–2 (Set A). Thus, on any given trial, any of the three possible choices matched some aspect of the chimera, and there was no possibility of an "error" response. If, however, the right hemisphere inherently prefers appearance matches, and the left hemisphere inherently prefers functional matches, then it would be expected that unilateral responses would be given to Set A stimuli, while bilateral responses would be given to Set B stimuli.

A total of 48 trials, 24 Set A and 24 Set B, were given to N. G. with the following instructions: "You will see a picture in the machine which is similar to, goes with, or is like in some way, one of the three pictures here (experimenter pointing to the three choice pictures). You are to point to the choice which goes with what you see." The instructions were, therefore, ambiguous with respect to the strategy to be used for matching. On half of the Set A and Set B trials, N. G. pointed with her right hand and on half with her left hand. There were no differences in responses as a function of pointing hand, and the left- and right-hand trials were consequently combined. Figure 3 depicts the results.

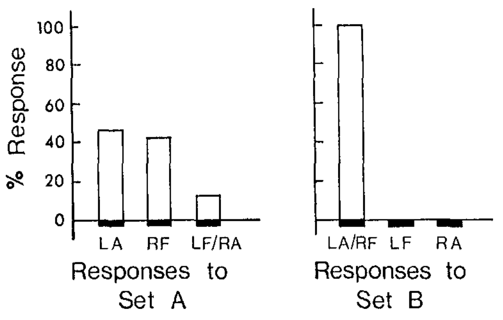

FIGURE 3. N. G.'s responses to Version 1. (L = left-field match, R = right-field match, A = appearance match, and F = function match.)

On 45 out of the 48 trials, N. G. either made a left-appearance, right-functional, or bilateral left-appearance/right-functional match. Only on three trials was the mode of matching as a function of field different from the above. These three trials were all a choice of the spools of thread when the chimeric stimulus consisted of scissors in the left field and eyeglasses in the right field. It should be noted that the scissors, in addition to belonging to the same conceptual category as the spools of thread, also have a certain similarity in appearance as well. The angle of the blades is similar to the angle of the spools, and the finger and thumb holes resemble the bottoms of the spools. It is, therefore, not certain that even these three responses were in fact left-functional/right-appearance responses. They may instead represent left-appearance responses.

In any case, the results decisively show that matching by the right hemisphere is normally done by N. G. in terms of visuo-structural similarity and by the left hemisphere in terms of conceptual–functional similarity. Each hemisphere was capable of controlling the response and when it did so, it interpreted the instructions and responded in accordance with its own preferred mode of operation. N. G.'s results strongly support the view that whenever a hemisphere spontaneously assumes control of behavior, it processes information in accordance with a strategy appropriate to the specialization of that hemisphere.

These findings, however, do not necessarily imply that instructions as to strategy will always evoke the appropriate mode of matching or the appropriate hemisphere. When a hemisphere assumes control spontaneously, the postulated metacontrol mechanism may cause it to do so only if, for whatever reasons, the activated hemisphere is prepared for information processing and is ready to process according to its particular specialization. If, on the other hand, the subject is instructed to use a cognitive strategy for which one hemisphere is specialized, the possibility exists that, because of internal, time-variant processes, the demand from without may be incongruent with the internal state. If this were to occur, the instructions may result in less than optimal cognitive processing, either activating the appropriate hemisphere but failing to elicit the appropriate strategy, or eliciting the appropriate strategy but failing to activate the appropriate hemisphere. Such a dissociation could, of course, occur only if those systems of the brain that selectively activate one or the other hemisphere are, to some extent, independent of the mechanisms responsible for quantitative and qualitative differences in capacity of the two sides of the brain. In order to explore the consequences of external demands, Version 2 of the test was given.

Version 2

Of the 12 possible chimeras (see Figure 2) the four of Set X would necessarily yield unilateral responses (left-appearance, right-appearance, right-functional, or left-functional); the four of Set Y would yield either bilateral atypical responses (left-functional/right-appearance), erroneous responses, or unilateral typical responses (left-appearance or right-functional); and the four of Set Z would yield either bilateral typical responses (left-appearance/right-functional), erroneous responses, or unilateral atypical responses (left-functional or right-appearance). The sets of stimuli and possible responses are shown in Table 1. Again, as for Version 1 of the test, a chimera within a particular Version 2 X, Y, or Z set could be matched only in certain ways. For example, Chimera 1–3, a Set Y chimera, with gloves on the left and the cake on the right, can yield a left-appearance response if the bird is picked, a right-functional response if the knife and fork is picked, a left-functional/right-appearance response if the hat is picked, and an error response if the sewing basket is picked. The designation "typical" or "atypical" in Table 1 is for the purpose of helping the reader keep in mind the kinds of responses in which matching strategies and hemispheres are congruent versus those in which they are not, and they refer only to correct responses. Obviously, an erroneous response is neither typical or atypical. Set Z chimeras were discarded in order to restrict responses as much as possible to unilateral answers, so that we could determine unambiguously which hemisphere was in control of the response.

For any given run of trials subjects were instructed either to "pick the thing that *looks like* what you see" (appearance instruction) or to "pick the thing you would *use with* or *goes with* what you see" (function instruction).

Table 2 shows the distribution of responses of each subject under the two sets of instructions. The frequencies in parentheses are the a priori chance-expected frequencies. Some subjects were brought in for repeated tests when the pattern of response required clarification. Others were occasionally unable to complete a particular run of trials. These exigencies account for the differences

TABLE 1
POSSIBLE RESPONSES TO CHIMERA SETS X, Y, AND Z FROM VERSION 2 FOR THE APPEARANCE–FUNCTION MATCHING TEST

Type of response	Stimulus chimera: Set X[a]	Set Y[b]	Set Z[c]
Typical	left-appearance right-functional	left-appearance right-functional	error left-appearance/right-functional
Atypical	left-functional	left-functional/right-appearance	left-functional
	right-appearance	error	right-appearance

[a] The stimulus chimeras for Set X = 1–2, 2–1, 3–4, 4–3.
[b] The stimulus chimeras for Set Y = 1–3, 2–4, 3–2, 4–1.
[c] The stimulus chimeras for Set Z = 1–4, 2–3, 3–1, 4–2.

TABLE 2
DISTRIBUTION OF SUBJECTS' RESPONSES ON VERSION 2 OF THE APPEARANCE-FUNCTION MATCHING TEST

Response	Appearance instruction				Function instruction			
	A. A.	C. C.	N. G.	L. B.	A. A.	C. C.	N. G.	L. B.
LA	15 (4)	19 (8)	16 (20)	55 (28)	17 (17)	3 (8)	2 (8)	0 (16)
RA	1 (2)	2 (4)	10 (10)	29 (14)	4 (9)	14 (4)	0 (4)	1 (8)
LF	0 (2)	1 (4)	16 (10)	1 (14)	7 (9)	0 (4)	0 (4)	11 (8)
RF	0 (4)	0 (8)	23 (20)	6 (28)	32 (17)	0 (8)	30 (8)	40 (16)
Bilateral or error	0 (4)	10 (8)	15 (20)	21 (28)	9 (17)	15 (8)	0 (8)	12 (16)
Total trials	16	32	80	112	69	32	32	64

Note. Numbers in parentheses represent chance-expected frequencies. There were 16 trials per unit run. L = left-field response, R = right-field response, A = appearance match, F = functional match.

in the numbers of trials completed by subjects for a given test.

Because the chance probabilities of responses in any given category are unequal, the absolute distribution of responses conveys little understanding of the subjects' behavior. In addition, bilateral or erroneous responses do not provide information regarding controlling hemisphere or strategy of matching used. Therefore, Figure 4 displays the response distribution, with bilateral or erroneous responses excluded, as proportional increases or decreases of observed responses relative to proportions expected.

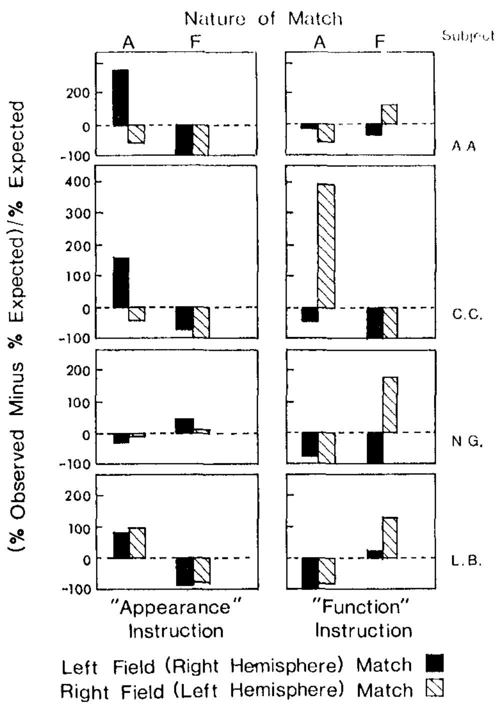

FIGURE 4. Percentages above or below chance-expected proportions for left and right hemispheres on original Version 2 under two instruction conditions. (A = appearance match and F = function match.)

It will be seen that for all subjects except N. G., appearance instructions elicited a predominance of appearance matches almost entirely to left-field (right-hemisphere) stimuli for A. A. and C. C. and equally distributed between the hemispheres for L. B. For all subjects except C. C., function instructions elicited a predominance of right-field (left-hemisphere) functional matches.

The significance of the distribution of subjects' responses was tested for each subject individually by χ^2 tests, in which a variety of relationships were assessed. In all cases, bilateral and erroneous responses were excluded from consideration unless otherwise noted. In order to determine whether there was a significant association between instructional condition and controlling hemisphere, a 2 × 2 table was set up with instruction (appearance or function) as one dimension and hemisphere as the other dimension. All subjects, including N. G. and C. C., manifested a significant Instructional Condition × Hemisphere interaction, $\chi^2_{AA}(1) = 14.61$, $\chi^2_{CC}(1) = 21.30$, $\chi^2_{NG}(1) = 17.41$, and $\chi^2_{LB}(1) = 21.66$; for all subjects, $p < .001$ and $\chi^2_{TOT}(4) = 74.98$, $p < .001$. Similarly, a 2 × 2 table with instruction as one dimension and matching strategy as the other was set up to assess whether subjects correctly matched according to instructions. All subjects except C. C. manifested a significant Instructional Condition × Strategy of Matching interaction, $\chi^2_{AA}(1) = 21.36$, $\chi^2_{CC}(1) = .02$ (with a Yates correction), $\chi^2_{NG}(1) = 11.90$, and $\chi^2_{LB}(1) = 112.14$; for all subjects, $\chi^2_{TOT}(4) = 145.42$, $p < .001$ for all except C. C. The significant Instructional Condition × Hemisphere interactions indicate that all subjects had a greater tendency to use the right hemisphere than the left under appearance instructions and/or a greater tendency to use the left hemisphere than the right under function instructions. The significant Instructional Condition × Strategy of Matching interactions for A. A., L. B., and N. G. indicate that appearance and functional matches tended to emerge with appearance and function instructions, respectively.

The lack of a significant interaction for C. C. can be seen from Table 2 and Figure 4 to be due to his consistent use of an appearance matching strategy, regardless of instruction. Although N. G.'s response distribution under appearance instruction did not differ significantly from chance, because of the fact that it did differ under function instruction, both the Instruction × Hemisphere and Instruction × Strategy interactions were significant.

Since left-appearance and right-functional responses were twice as likely a priori as right-appearance or left-functional responses, the interaction between hemispheres and strategies could not be tested with a 2 × 2 design. Instead, responses were allocated to one of two categories, one category containing left-appearance and right-functional responses and the other category containing right-appearance and left-functional responses. The observed frequencies in these categories were then tested against their expected frequencies. In spite of the effectiveness of instructions in eliciting either unihemispheric control and/or the appropriate processing strategy, the Hemisphere × Strategy interaction, summing across instructional conditions, was only significant for A. A., $\chi^2_{AA}(1) = 10.76$, $p < .001$; $\chi^2_{CC}(1) = 1.85$, $p > .10$; $\chi^2_{NG}(1) = 1.86$, $p > .10$; $\chi^2_{LB}(1) = 1.01$, $p > .10$. Thus, except for A. A., strategies and hemispheres were not consistently associated. For A. A., the association was significant both under appearance instructions, $\chi^2(1) = 5.27$, $p < .025$; and under function instructions, $\chi^2(1) = 6.08$, $p < .025$.

The lack of overall association in the other three subjects was caused by differing factors.

For C. C., 38 of his total of 39 unilateral responses were appearance matches, yet under appearance instructions, his right hemisphere was in control, while under function instructions his left hemisphere was in control. The effectiveness of instructions in eliciting appropriate hemispheric control, and their ineffectiveness in eliciting the appropriate matching strategy, implies absence of a significant localization of strategy within one or the other hemisphere.

For N. G., the lack of interaction is due solely to her performance under appearance instructions. Under function instructions, the interaction was significant, $\chi^2(1) = 16.01$, $p < .01$, all responses being allocated to the right-functional (30 responses) or left-appearance (two responses) category. However, under appearance instructions, N. G. continued to make functional matches (39 of 65 responses) and distributed her responses approximately equally between the hemispheres. Of the 32 right hemisphere responses she gave, fewer than chance were appearance matches and more than chance were functional matches, $\chi^2(1) = 3.99$, $p < .05$, while her 33 left-hemisphere responses were randomly distributed between strategies. It would appear that appearance instructions for N. G. produced cognitive confusion, inducing more right-hemisphere control than was seen with function instructions but failing, to a certain extent, to induce the appropriate matching strategy. It seems that control of the response shifted between the hemispheres as a function of instruction and that the controlling hemisphere was then unable to selectively utilize its specialized strategy. It is of interest that N. G. produced significantly more bilateral responses and errors under appearance instructions than under function instructions, $\chi^2(1) = 6.94$,

$p < .02$. She apparently has a function matching bias, just as C. C. has an appearance matching bias. For both these subjects, instructions were effective to differing extents in producing shifts of hemispheric control without a concomitant shift in matching strategy.

The lack of a significant Hemisphere × Strategy interaction for L. B. can be best understood by considering his functional and appearance matches separately. He produced a total of 58 functional matches, of which 46 (chance-expected frequency = 38.67) were produced by the left hemisphere and 12 (chance frequency = 19.33) by the right hemisphere, $\chi^2(1) = 4.17$, $p < .05$. Thus, when functional matches were made, they tended to be made by the left hemisphere. However, of his 85 appearance matches (84 of which occurred under appearance instructions), 30 were produced by the left hemisphere (chance-expected frequency = 28.33) and 55 (chance frequency = 56.67) by the right, $\chi^2(1) = .15$. It seems that although the left hemisphere tends to perform functional matches, either hemisphere is capable of controlling appearance matches. Instructions were extremely effective for L. B. in producing the appropriate mode of matching, but were only partially effective in activating the appropriate hemisphere.

Under function instructions, the left hemisphere was in control of responses significantly more often than the right, $\chi^2(1) = 17.31$, $p < .001$, and although under appearance instructions, the right hemisphere was in control significantly more often than the left, $\chi^2(1) = 4.85$, $p < .05$, the deviation from random expectations was considerably less. What this seems to imply is that L. B. has a left-hemisphere bias. In effect, the left hemisphere would rather maintain control of behavior, even if this means utilizing a processing strategy for which it is nonspecialized, than to yield control to the right hemisphere.

If the above interpretation is correct, then L. B.'s results do not imply that the hemispheres are unspecialized for appearance matching, but rather that, for whatever reasons, L. B.'s right hemisphere simply has difficulty in gaining control of behavior. In an attempt to explore this possibility further, we administered to L. B. a modified form of Version 2 of the test, in which response hand was manipulated.

Revised Version 2

The revised test expanded the original Version 2, by including Set Z of the chimeric stimuli, so that there were a total of 12 tachistoscopic stimuli instead of 8.

L. B. was given 36 trials under function instructions with the left hand responding and 60 trials under appearance instructions with responding hand varied. With the revised test, chance-expected proportions are: left-appearance = 1/6, left-functional = 1/6, right-appearance = 1/6, right-functional = 1/6, left-functional/right-appearance = 1/12, left-appearance/right-functional = 1/12, and error = 1/6.

Under function instructions, L. B. produced 23 right-functional responses, 11 left-appearance/right-functional responses, 1 left-functional response, and 1 left-functional/right-appearance response. Since out of 36 trials, L. B. produced no unilateral left-appearance responses, and since there were only 24 opportunities to make right-functional responses (Sets X and Y of the stimuli), it is fairly obvious that the 11 left-appearance/right-functional responses to Set Z stimuli were based solely on the right-field stimulus; in terms of actual processing, L. B. was making unilateral functional matches with his left hemisphere. The revised test thus confirms L. B.'s results under function instructions on the original Version 2.

L. B. was tested for three separate runs under appearance instructions. In the first run of 24 trials he was required to point to his choice with his right hand. In earlier testing we typically had subjects use the hand ipsilateral to the theoretically superior and dominant hemisphere for a given task simply as a conservative measure. As on the original Version 2, L. B. correctly made appearance matches with his left hemisphere. He gave 12 right-appearance responses, 8 left-functional/right-appearance responses, 1 left-appearance response, and 3 left-appearance/right-functional responses, thus offering little evidence that he was utilizing his right hemisphere at all.

In an attempt to break the hold that the left hemisphere seemed to have on his behavior, a second run of 24 trials was given immediately after the first in which L. B. had to point with his left hand. A dramatic change occurred: There was a single error, but 23 of the 24 responses were either left-appearance or left-appearance/right functional. Thus, left-hand pointing was powerfully effective in releasing the right hemisphere.

The question, of course, was whether the right hemisphere would be able to retain its behavioral control if pointing was switched back to the right hand. A final run of 12 trials under appearance instructions was given with right-hand pointing. On all 12 trials L. B. gave left-appearance or left-appearance/right-functional responses (8 of the former and 4 of the latter). It appeared that our "training" procedure had produced a change in the control capacity of the right half of the brain. This cannot be interpreted as simply a brief activation effect, since if it were, our second run of trials with left-hand pointing should have produced the same results as the first run with right-hand pointing. In addition, the last 12 trials of the 36 function instruction trials were given immediately *after* the third appearance instruction run, and all of these resulted in right-functional or left-appearance/right-functional responses.

We conclude from these observations that, though L. B. may have a left hemisphere that tends to dominate behavior, the right hemisphere *can* be released, and it *is* selectively released by appearance instructions when the left hand has been brought into play and produces appearance matches.

We also used the revised Version 2 to investigate N. G.'s failure to perform appearance matches under appearance instructions and her use of her right hemisphere under such instructions to perform function matches (see Figure 4). On 24 trials under function instructions she replicated her previous performance: All 24 responses were right-functional or left-appearance/right-functional with no errors. On 24 trials under appearance instructions, she made 5 errors, gave 15 right-appearance or left-functional/right-appearance responses, 2 right-functional responses, 1 left-appearance response, and 1 left-appearance/right-functional response. These results are quite different from her earlier ones on the original Version 2. There (see Figure 4) she tended to make functional matches under appearance instructions, though using her right hemisphere. Here, she correctly made appearance matches but used her left hemisphere, producing results similar in certain respects to L. B.'s on the original Version 2.

Figure 5 summarizes the results of L. B. and N. G. on the Revised Version 2 test. For the sake of graphic simplicity left-appearance/right-functional responses under function instructions are simply called right-functional responses, while left-functional/right-appearance responses are called left-functional responses. Similarly, under appearance instructions left-appearance/right-functional responses are called left-appearance, and left-functional/right-appearance responses are called right-appearance. Although this procedure assumes that bilateral responses are based on a matching strategy appropriate to the instruction, L. B.'s and N. G.'s actual results, described above, seem to justify the assumption. Only Run 3 of L. B.'s responses under appearance instructions (right-hand pointing) are presented. L. B.'s results now look very similar to those of A. A. on the original Version 2, while N. G.'s are similar to L. B.'s on the original Version 2.

The change in L. B.'s response pattern is mainly a quantitative change that is an amplification of his performance on the original test. His performance under function instructions is unchanged, while the effectiveness of appearance instructions in producing right-hemisphere control has increased from 62% on the original test to 100% on the revised test, presumably as a result of giving him practice with the left hand.

In contrast, N. G.'s performance on the revised test is a qualitative change from that on the original Version 2. On the original test of Version 2 her responses under appearance instructions were randomly allo-

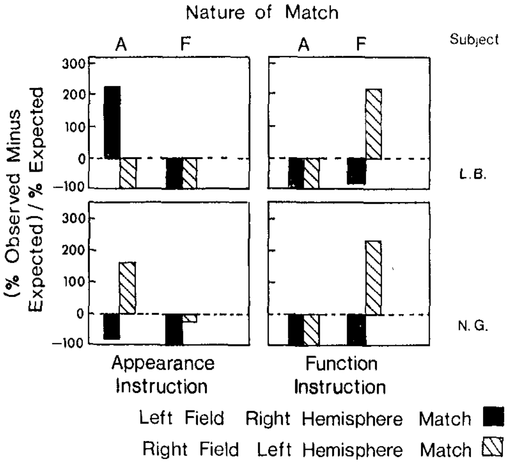

FIGURE 5. Percentages above or below chance-expected proportions for two response categories for left and right hemispheres on revised Version 2 under two instruction conditions. (A = appearance match and F = function match.)

cated across categories, though a plurality of responses were functional matches with the right hemisphere. In the original test she did show a significant association between instructional condition and hemispheres, and a smaller significant association between instructional condition and strategy. However, in the revised test, the only effect of instruction was to shift the strategy of matching, but almost all matches were done by the left hemisphere. As suggested previously, appearance instructions for N. G. seem to produce variable performance and cognitive confusion. She manifested three different patterns of results on three different tests. On Version 1 with ambiguous instructions, she showed an extremely strong association between hemispheres and matching strategy. On the original Version 2, she showed a functional matching bias, the effect of appearance instructions being to shift behavioral control from the left to right hemisphere, which then proceeded to make function matches. On the Revised Version 2, she showed a left-hemisphere bias, the effect of appearance instructions being to shift strategies from functional to appearance matching; processing was retained by the left hemisphere.

DISCUSSION

It is clear from the results that instructional condition was a significant determinant of hemispheric control. In addition, except for subject C. C., instructions were effective in inducing the appropriate matching strategy. Further, although N. G. on Version 1, A. A. on the original Version 2, and L. B. on the Revised Version 2 displayed a significant Hemisphere × Strategy interaction, it is equally obvious that dissociations between hemispheres and strategies were not uncommon.

On the original Version 2, C. C., L. B., and N. G. all manifested such dissociations. C. C. switched hemispheres appropriately when instructions changed, but after switching continued in the same matching strategy, always relying on similarity of appearance. N. G. tended toward the same pattern, switching from left to right hemisphere when instructions changed from function to appearance, but persisting in functional matches. L. B. switched strategies appropriately and tended to retain processing in the left hemisphere.

The various observations taken together can leave little doubt that metacontrol systems exist, that these systems tend to activate that hemisphere which is appropriate for some task, and that they do so independently of whether the then activated hemisphere actually utilizes its specializations. On some occasions, however, the metacontrol systems can fail to arouse the appropriately specialized hemisphere, in spite of the fact that the other one must then proceed to perform in a cognitively inappropriate mode. It is clearly the case that, in general, dominance of one hemisphere over behavior cannot merely be due to a skill or speed contest between the two halves of the brain, but must depend on the *expectations* as to cognitive requirements, irrespective of whether those cognitive specialities are actually utilized. It would appear that hemispheric activation does not depend on the hemisphere's real aptitude, but on what it *thinks* it can do.

Metaphorically, one may conceive of the two cerebral hemispheres as supplicants asking a single intentional system for activation. The intentional system may be thought of as a judge receiving two mutually exclusive petitions, each of which presents justifications as to why the request should be met. In the commissurally intact brain, we may suppose that the two supplicants are bound by a contract by which they agree, via callosally mediated communications and in conformity with brain-stem control, to work alternately; while in the commissurotomized patient, selective hemispheric activation is determined solely by the adjudication of brain-stem centers. In cases where one supplicant is sufficiently insistent on having behavioral control, it may in fact be successful in obtaining it, even if it then finds itself confronted with a problem ill-suited to its nature. Such maladaptive adjustment to circumstances would be expected to follow neocommissurotomy as a consequence of the depletion of higher control mediated through the neocortical commissures (Trevarthen, 1974).

In summary, our results show that the right and left hemispheres are specialized for detecting structural and functional similarities, respectively; that task instructions selectively activate one or the other side of the brain, as well as appropriate strategies; and, finally, that such instructions do not necessarily activate both together. This can be seen most clearly in C. C.'s pattern of results, where both the left and right hemispheres manifested appearance matching strategies. In spite of their similarities in matching, the hemispheres selectively took control of behavior as a function of *expectations* regarding the nature of the problem to be solved.

Cerebral lateral specialization pertains not only to ability and manifest behavioral differences between the two sides of the brain but also, even when these differences may be (for whatever reasons) attenuated or lost, to propensities to act as a function of task requirements. We conclude that a hemisphere's dominance over behavior depends only indirectly on specialization of capacity. We suggest that the hemispheres are also specialized with respect to intentions to act in particular ways, and that these dispositions are independent of, though usually correlated with, differential aptitudes. It is dispositional lateralization, and not aptitudinal lateralization, that determines cerebral dominance for a task. Once behavioral control is gained, it is the aptitudinal specialization that determines how and how well some task will be done.

Our findings have relevance to theoretical issues of long standing. Although the empirical view of perception held sway over American psychology throughout most of its development, during the past quarter century, almost all perceptual theories have emphasized the constructive, generative processes of the perceiver in the organization of the percept. The early papers of Bruner and colleagues (Bruner, Busiek, & Minturn, 1952; Bruner & Goodman, 1947; Bruner & Postman, 1949; Bruner, Postman, & Rodrigues, 1951) made clear that internal processes, manifested as needs, values, or expectations, played a major determining role in perception. More recent investigations of Haber (1965), Hershenson and Haber (1965), Hershenson (1969), and Standing, Sell, Boss, and Haber (1970) confirm beyond question that the quality of a percept is strongly dependent on the knowledge and psychological set of an observer. These findings, as well as numerous others (see Neisser, 1967; Paivio, 1971), seem to force the conclusion that not only is perception an active, constructive process, but one in which the rules of generation vary as a function of the internal state of the subject. The generation of consciousness appears to depend on constraints imposed by values, knowledge, expectations, and intentions. The metacontrol systems we have postulated constitute an extension of these perceptual organizing factors into the dimension of asymmetric cerebral control.

REFERENCE NOTE

1. Levy, J., & Trevarthen, C. *Perceptual, semantic and phonetic aspects of elementary language processes in split-brain patients.* Manuscript submitted for publication, 1976.

REFERENCES

Bogen, J. E. The other side of the brain II: An appositional mind. *Bulletin of the Los Angeles Neurological Society,* 1969, *34,* 135–162.

Bogen, J. E., & Gazzaniga, M. S. Cerebral commissurotomy in man: Minor hemisphere dominance for certain visuo-spatial functions. *Journal of Neurosurgery,* 1965, *23,* 394–399.

Bruner, J. S., Busiek, R. D., & Minturn, A. L. Assimilation in the immediate reproduction of visually perceived figures. *Journal of Experimental Psychology,* 1952, *44,* 151–155.

Bruner, J. S., & Goodman, C. C. Value and need as organizing factors in perception. *Journal of Abnormal and Social Psychology,* 1947, *42,* 33–44.

Bruner, J. S., & Postman, L. J. On the perception of incongruity: A paradigm. *Journal of Personality,* 1949, *18,* 206–223.

Bruner, J. S., Postman, L. J., & Rodrigues, J. Expectation and the perception of color. *American Journal of Psychology,* 1951, *64,* 216–227.

Haber, R. N. The effect of prior knowledge of the stimulus on word recognition processes. *Journal of Experimental Psychology,* 1965, *69,* 282–286.

Hécaen, H. Aphasic, apraxic and agnostic syndromes in right and left hemisphere lesions. In P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of clinical neurology* (Vol. 4). Amsterdam: North-Holland, 1969.

Hershenson, M. Stimulus structure, cognitive structure, and the perception of letter arrays. *Journal of Experimental Psychology,* 1969, *79,* 327–335.

Hershenson, M., & Haber, R. N. The role of meaning in the perception of briefly presented words. *Canadian Journal of Psychology,* 1965, *19,* 42–46.

Kinsbourne, M. Mechanisms of hemispheric interaction in man. In M. Kinsbourne & W. L. Smith (Eds.), *Hemispheric disconnection and cerebral function.* Springfield, Ill.: Charles C Thomas, 1974.

Levy, J. *Information processing and higher psychological functions in the disconnected hemispheres of commissurotomy patients.* Unpublished doctoral dissertation, California Institute of Technology, 1970. (Ann Arbor, Mich.: University Microfilms No. 70–14, 844)

Levy, J., Trevarthen, C., & Sperry, R. W. Perception of bilateral chimeric figures following hemispheric deconnection. *Brain,* 1972, *95,* 61–78.

Levy-Agresti, J., & Sperry, R. W. Differential perceptual capacities in major and minor hemispheres. *Proceedings of the U.S. National Academy of Sciences,* 1968, *61,* 1151.

Nebes, R. D. Superiority of the minor hemisphere in commissurotomised man for the perception of part–whole relationships. *Cortex,* 1971, *7,* 333–349.

Neisser, U. *Cognitive psychology.* New York: Appleton-Century-Crofts, 1967.

Paivio, A. *Imagery and verbal processes.* New York: Holt, Rinehart & Winston, 1971.

Sperry, R. W., Gazzaniga, M. S., & Bogen, J. E. Interhemispheric relationships: The neocortical commissures; syndromes of hemisphere disconnection. In P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of clinical neurology* (Vol. 4). Amsterdam: North-Holland, 1969.

Sprague, J. M. Interaction of cortex and superior colliculus in mediation of visually guided behavior in the cat. *Science,* 1966, *153,* 1544–1547.

Standing, L., Sell, C., Boss, J., & Haber, R. N. Effects of visualization and subvocalization on perceptual clarity. *Psychonomic Science,* 1970, *18,* 89–90.

Trevarthen, C. Double visual learning in split-brain monkeys. *Science,* 1962, *136,* 258–259.

Trevarthen, C. Functional interactions between the cerebral hemispheres of the split-brain monkey. In E. G. Ettlinger (Ed.), *Functions of the corpus callosum.* London: Churchill, 1965.

Trevarthen, C. Functional relations of disconnected hemispheres with the brain stem and with each other: Monkey and man. In M. Kinsbourne & W. L. Smith (Eds.), *Hemispheric disconnection and cerebral function.* Springfield, Ill.: Charles C Thomas, 1974.

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

(Received November 17, 1975)