

DISSOCIATION OF LANGUAGE AND COGNITION

A PSYCHOLOGICAL PROFILE OF TWO DISCONNECTED RIGHT HEMISPHERES

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SUMMARY

Two split-brain patients who differ in their right hemisphere language capacity were tested on a variety of simple cognitive tasks. Both isolated right hemispheres performed poorly on most tests. The results suggest that the presence of language in the right hemisphere, a brain system that ordinarily does not possess such competence, need not necessarily confer the full complement of cognitive skills associated with the language processing skills of the left hemisphere.

INTRODUCTION

A continuing challenge to the study of human cognition is an elucidation of how language processes influence cognitive, perceptual and mnemonic skills. Traditional approaches have included both the assessment of language disorders in adults and children (Lenneberg, 1967), as well as attempts to characterize language acquisition in children (Slobin, 1973). While these methods have provided a great deal of insight into human language function, conclusions regarding the dependence of cognitive processes on the presence of language are complicated by the possibility that language and cognitive processes could be evolving or deteriorating simultaneously in the subjects studied. Based on such observations, it cannot be determined how language as such interacts with and enhances general cognitive skills.

Certain aspects of this problem can be examined by studying the disconnected right hemisphere which normally does not possess language skills. In fact, in isolation following callosal section, the right hemisphere typically is unable to process language altogether (Gazzaniga, 1983). To date it has been observed that a right hemisphere without language is only minimally responsive to perceptual and cognitive testing. This finding characterizes the majority of split-brain cases and after postoperative assessment such patients are not usually followed neuropsychologically. While these patients' right hemispheres can detect simple stimuli and in some cases may be able to carry out specialized right hemisphere tasks such as

visual constructional tasks (Gazzaniga *et al.*, 1965), their range of function has not been carefully documented. In the present context, however, none of the following tests could be carried out by patients in whom right hemisphere language was absent.

There is also a small subset of split-brain patients who do possess language in the right hemisphere, and it is of interest to assess what kinds of cognitive operations a right hemisphere that possesses language skills can carry out. The present report is centred on two patients, V.P. and J.W., who have been studied in our laboratory (Sidtis *et al.*, 1981; Holtzman and Gazzaniga, 1982). Both are part of a small group of patients in the national split-brain population who possess right hemisphere language, and one of them, V.P., also has the ability to access speech from the right hemisphere (Sidtis *et al.*, 1981; Gazzaniga, 1983). Examination of the cognitive capacities of these right hemispheres allows insights into what language confers to a brain system in terms of facilitating overall cognitive skills.

The present results suggest that a right hemisphere with language and the ability to access speech is slightly more capable of general cognitive ability than a right hemisphere with fewer language skills. At the same time, a right hemisphere with these language skills remains dramatically limited in general cognitive skills, and falls short of possessing the overall cognitive ability of the left hemisphere.

PATIENTS

J.W. is an alert 30-year-old right-handed male with a history of staring spells, reportedly since starting school. After his first grand mal seizure, the attacks became increasingly frequent and then intractable (Wilson *et al.*, 1982). Midline section of the corpus callosum was performed in two stages (Dr Donald Wilson, Dartmouth Medical School). The posterior half of the corpus callosum including the splenium was sectioned first, with the remaining anterior portion sectioned in a second operation ten weeks later.

V.P., a right-handed 29-year-old female, experienced recurrent seizures at 9 years of age. Anticonvulsant drugs controlled the seizures until 1979 when she began experiencing grand mal, petit mal, and myoclonic episodes while on multiple anticonvulsants. She underwent partial anterior callosal section in early April 1979, followed by complete section of her callosum in a second operation seven weeks later (Dr Mark Rayport, Medical College of Ohio).

METHODS

Special Tests of Cognitive Skills

A set of tests was administered to each hemisphere of J.W. and V.P. The overall objective was to determine whether the presence of right hemisphere language conferred the normal range of cognitive skills that usually accompany language function. Four tests, which are described in detail below, were selected for testing possible differences in cognitive capacity. One test, a measure of knowledge of current events, examined the simple capacity of each half-brain to learn new associations. The other tests all required the manipulation of two pieces of information and, therefore, a computation. One test each was selected from the verbal, mathematical and visual-spatial spheres of cognitive capacity.

All tasks described below involved lateralized presentation of visual stimuli. For pictures, the subjects were seated 1 m from a screen on which pictorial stimuli were projected from the rear and

presented to the left or right of a central fixation point. The stimuli were displayed by means of a standard slide projector fitted with an electronic shutter. Stimuli were presented at least one degree to the right or left of fixation for 150 ms. For words, an Apple II Computer was used to display stimuli on a 15 inch monitor. The subject fixated a point at the centre of the screen and eye movements were carefully monitored. Before each test the subject was provided with extensive instructions and examples of the type of judgement required. These tests were run under free field conditions. During the practice trials the occasional incorrect responses were corrected and by the end of these trials the subjects were performing perfectly.

Language Profile

Both patients continue to be examined on their language capacity. In tests completed to date, the right hemispheres of both V.P. and J.W., as assessed by the Peabody Picture Vocabulary Test, possess a highly sophisticated lexicon which is essentially identical to the one they each possess in the left hemisphere. In addition, in a series of special tests it was determined that the right hemisphere semantic system can generate antonyms-synonyms, and superordinate as well as subordinate associations of lexical items. It is also equally proficient at all of the tasks in both the auditory and visual modality. V.P.'s right hemisphere, in addition to these skills, is able to carry out verbal commands, possesses syntactic abilities and can access speech. All these studies are reported in detail elsewhere (Gazzaniga, 1983; Gazzaniga *et al.*, 1983).

RESULTS

Inferential Capacity

Tests were performed to determine whether the right hemisphere could infer new meaning from the presentation of 2 different stimuli. In the first test, 8 pairs of pictures were flashed to either the left or right hemisphere. On each trial J.W. and V.P. were instructed to choose 1 picture out of 3 that best depicted the consequence of combining the 2 stimulus pictures. For example, a picture of logs and a picture of matches were sequentially lateralized and the free field choices were: a bonfire, a wood pile, and a lit cigarette.

The results of this test revealed different results for J.W. and V.P. In V.P. each hemisphere performed similarly with a score of 7/8 (88%). J.W. on the other hand was only able to perform the task with the left hemisphere (RVF: 7/8, LVF: 2/8, χ^2 corrected for continuity = 4.06, $df = 1$, $P < 0.05$).

In a second test of inferential reasoning, 2 words instead of 2 pictures were used for all test stimuli. An example of a trial in the test is as follows: the words 'water' and 'pan' were serially presented either to the left or the right hemisphere with an interstimulus interval of 1 s. Placed in front of the subject was a card with possible choices printed out. Prior to the presentation of the lateralized stimuli, the subject read aloud each word on the list. The choices for these stimuli were 'boil', 'melt', 'tan', 'swim', 'fry' and 'eat'. For each trial, a simple associative response was possible for each of the 2 words presented (for example, 'water' = boil or swim; 'pan' = boil or fry). There was, however, only one correct choice if the interrelation between the 2 stimuli was correctly inferred ('water' + 'pan' = boil). Each pair of stimuli was presented twice to each hemisphere, first with one word order and then the reverse order. There was a total of 40 trials to each hemisphere.

With words, J.W.'s right hemisphere was again unable to perform the task while the left hemisphere performed quite well (LVF = 12/40, RVF = 37/40). V.P.'s left hemisphere also performed well (38/40) but her right hemisphere performance dropped to 20/40 (chance = 16.6%). It appeared, however, that V.P.'s right hemisphere devised a strategy whereby she typically picked one of the 2 simple associations that went with the first stimulus word presented. For example, when 'water' and 'pan' were presented in that order to the right hemisphere, it would choose either 'boil' or 'swim'. When 'pan' and 'water' were presented in another condition, it would choose either 'boil' or 'fry'. In light of this observation, a performance of 50 per cent represents chance.

A third version of this test was administered to determine whether there is a difference between the picture/word and word/word testing method, especially for V.P. In this experiment a new set of 16 visual-pictorial and 16-word stimuli were developed for lateralized presentation to each half-brain. Four choices were possible for each test set. The experiment was first carried out with picture stimuli. For example, a picture of a person and a picture of a fish would be briefly flashed to either the left or the right hemisphere. The subject was then instructed to choose one picture out of a set of 4 that would best represent the inferred interrelation of the two stimuli presented. In this example the correct choice was a picture of a person fishing as opposed to a person bathing, water boiling or food frying. The stimulus card was placed in front of the subject before the presentation of each stimulus. The other pairs of lateralized picture stimuli that went with this response card were: person + water, water + pan, pan + fish.

In a follow-up session, the experiment was administered with lateralized word stimuli and the 4 pictorial choices. For example, the word 'person' and the word 'fish' would be presented and again the subject's task was to choose the picture that best depicted the concept to be inferred. Following this test, two control tests were carried out. In a test for memory function following presentation of the 2-word stimulus set, a card with the 4 possible stimulus words (e.g. person, water, pan, fish), was placed in front of the subject. The timing was such that it came when a response on the experimental trials had already been completed. The subject had to point to both words in order for the response to be scored correctly. In the second control test, the subjects were required to define the concepts to be inferred. Here the word 'fishing' was lateralized to either the left or right hemisphere and the subject was required to point to a picture of a person fishing as opposed to a person bathing, water boiling, or fish frying. The results are shown in Table 1.

Since the performances of both J.W. and V.P. did not differ significantly for the two presentation modalities, the results were combined. In both subjects the performance of the right hemisphere was significantly worse than that of the left hemisphere (V.P. $\chi^2 = 14.71$, $P < 0.001$; J.W. $\chi^2 = 15.94$, $P < 0.001$). At the same time, both right hemispheres could define the inferred concept. Also, both could remember the 2-item stimuli set over the time needed to solve the problem. Furthermore, in tests carried out on J.W., the right hemisphere could easily combine

into meaning, compound words serially flashed to the right hemisphere. Thus such compound words as 'keyboard' flashed so that 'key' was seen followed moments later by 'board' found the patient was able to draw out a piano keyboard.

In all preceding test variations the difference between J.W.'s left and right hemisphere was consistently larger than the difference between V.P.'s left and right hemisphere. J.W.'s right hemisphere was unable to perform an inferential task in any of the modalities. V.P., on the other hand, appeared able to solve the problems in the first test. It is still not clear at this date whether or not V.P.'s initial good performance was more apparent than real.

TABLE 1. INFERENTIAL CAPACITY OF ISOLATED LEFT AND RIGHT HEMISPHERE

<i>Stimulus condition</i>	<i>V.P.</i>		<i>J.W.</i>	
	<i>LVF*</i>	<i>RVF*</i>	<i>LVF</i>	<i>RVF</i>
Lateralized picture/ picture choice	9/16	15/16	7/16	14/16
Lateralized word/ picture choice	9/16	16/16	7/16	15/16
Total	18/32	31/32	14/32	29/32
Defining inferred concepts	13/16	14/16	16/16	16/16
Memory for lateralized stimulus words	13/16	14/16	14/16	16/16

*LVF = left visual field. RVF = right visual field.

Mathematical Capacity

In a simple mathematical task, V.P. and J.W. were asked to 'add', 'subtract', 'divide' or 'multiply' a number singly presented to either the left or the right hemisphere. The free field choices were the numbers 1 to 20, 25 and 30 and placed on a card in front of the subject. Eight numbers were presented one at a time to each visual field for each of the mathematical functions. For example, each subject was instructed 'subtract one from the following number', and a number, say 8, was then presented to either the left or right visual half field. The correct manual response would be to point to the number 7 on the answer sheet.

The results are in Table 2. The left hemisphere was capable of the task, whereas the right hemisphere performed poorly at the mathematical operations even though V.P.'s right hemisphere could easily name all stimuli and J.W.'s could point on the answer sheet to each number presented. The difference between the hemispheres was significant for each subject (V.P.: $\chi^2 = 29.93$, $P < 0.001$; J.W.: $\chi^2 = 49$, $P < 0.001$).

TABLE 2. MATHEMATICAL SKILLS

	V.P.		J.W.	
	LVF*	RVF*	LVF	RVF
Pointing to answer				
Addition	3/8	8/8	0/8	8/8
Subtraction	3/8	8/8	1/8	8/8
Multiplication	1/8	8/8	0/8	7/8
Division	3/8	7/8	1/8	7/8
Reading numbers presented	16/16	16/16	Not possible	15/15
Pointing to numbers presented	16/16	16/16	15/15	15/15

*LVF = left visual field. RVF = right visual field.

Tests of Primary Mental Abilities

Each hemisphere of V.P. and J.W. was tested on their ability to solve simple concepts of spatial relations (adapted from the *Primary Mental Abilities Test*, 1962). Specifically, 16 geometric drawings of discrete designs were presented to either the left or the right hemisphere tachistoscopically. The task was to point to one of 4 possible drawings that best completed the design that had been lateralized. For every trial, the completed design made a square. These tests, while being possible to solve perceptually, also lend themselves to a verbal analysis.

Both V.P. and J.W.'s left hemispheres were significantly better than the right hemisphere at solving the problem (V.P.: RVF = 13/16, LVF = 7/16, $\chi^2 = 4.8$, $P < 0.05$; J.W.: RVF = 14/16, LVF = 8/16, $\chi^2 = 5.24$, $P < 0.05$).

Current Events

A test for current events from news headlines over the past two years was administered. The purpose of the test was to determine whether the right hemisphere, as well as the left, had acquired new information since the operation. In this test, a word was presented to either hemisphere and V.P. and J.W. were instructed to point to the correct answer out of 6 choices. For example, the word 'hostage' was presented and the choices were: 'Iran', 'Russia', 'England', 'Australia', 'Cuba'. Other current events questions were about the Olympics, the Royal Wedding, Skylab and the South-East Asian refugees.

Both V.P.'s and J.W.'s left and right hemispheres performed equally well on the test (V.P.: LVF = 39/55, RVF = 38/55; J.W.: LVF = 12/22, RVF = 13/20). The left and right hemispheres tended to miss the same questions.

DISCUSSION

The present study allows for observations of how the presence of language in a half-brain that normally does not possess such skills might enable it to carry out general cognitive acts such as mathematics, inferential reasoning and the acquisition

of new general knowledge. The traditional view is that a brain system possessing language skills such as semantics and some syntax confers competence in cognitive processing in general (*see* Premack, 1983, for general discussion and debate). Results from the present study suggest otherwise. The striking failure of the right brain to make simple inferences, to carry out simple mathematical tasks, or to solve simple geometric problems stands in marked contrast to its ability to define words, learn new information, and even exceed left hemisphere performance on other specialized tests (Gazzaniga and Smylie, 1983).

Inferential reasoning might seem difficult if it were determined that the concept to be inferred was not represented in the brain system under study. Yet, in the present context, it was determined that the concept to be inferred from inspection of the 2-word stimuli was known to the right hemispheres of both J.W. and V.P. The failure in inferential reasoning was especially startling for V.P., since it has been demonstrated that her right hemisphere successfully grasps semantic relations, possesses some syntax and detects semantic incongruity as measured by the event related potential, N_{400} (Kutas and Hillyard, 1984).

The present results also stand in contrast to the level of cognitive competence seen in language trained chimpanzees as opposed to chimpanzees not given language training (Premack, 1983). Premack reports instances of inferential reasoning in the language trained chimp that could not be performed by the right hemisphere in the present cases. If these cross species comparisons are valid it raises the intriguing issues about the normal development of the right hemisphere. Clearly, it is a brain system that *can* perform such tests following early left hemispherectomy and, of course, in roughly half of the normal left-handed population. Yet, in the developing right-handed child, we suggest that it might be deferring problem solving and rational thinking to the left hemisphere during development. Upon testing of the right hemisphere as an adult, a situation uniquely made possible by split-brain surgery, the severe cognitive deficits of the right hemisphere are revealed.

It is also of interest to consider how the present results allow for fresh observations concerning the organization of semantic memory. There are some common assumptions in the research approaches used in the study of semantic memory. The most troubling is the notion that reaction time differences reflect properties of the semantic network (*see* Anderson and Bower, 1973). The view that longer reaction times reflect more complex processing within the semantic network may be in error. What seems more likely is that increased reaction times may emerge when computational systems other than those present in the semantic network have been activated for work on the task in question.

An alternative notion coming out of the present work is that when increased abstraction of language stimuli is required, these demands are met not by the language system itself, but rather by other cognitive systems that carry out computations on the language stimuli. In this view the 'language system' is considered to be a 'dumb' system that acts more as a simple data structure system. The so-called activities of language such as the facilitation of thought are to a large

extent performed by other brain systems. This characterization of the relation between language and cognition would predict instances in which language is functional: thus the system could define language stimuli, and generate speech, but the organism could be totally impaired on general cognitive function. This condition, of course, commonly occurs in the early stages of cortical dementia (Joynt and Shoulson, 1979) and in subcortical dementia (Albert *et al.*, 1974).

It would appear that the conferring of language competence to a brain system does not necessarily mean that simple routine cognitive abilities are equally conferred. In the past, distinguishing how normal language is linked or not linked to other conceptual skills such as mathematics or inferential reasoning has been extremely difficult to analyse in the aphasic patient, since the lesion producing the language disorder could also be injuring other computational systems specialized for specific cognitive acts. The present results suggest that when these are dissociated such cognitive competencies are part of independent computational systems (*see also* Broadbent and Weiskrantz, 1982). Language usually reports on these computations with efficiency and accuracy, but the language system is not the system that is carrying out the activities.

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