Neuropsychologia, Vol. 30, No. 2, pp. 187–200, 1992.
Printed in Great Britain.

0028-3932/92 $5.00+0.00

READING WITH A LIMITED LEXICON IN THE RIGHT HEMISPHERE OF A CALLOSOTOMY PATIENT

KATHLEEN BAYNES,* MARK JUDE TRAMO and MICHAEL S. GAZZANIGA

Program in Cognitive Neuroscience, Dartmouth Medical School, Hanover, NH 03756, U.S.A.

(*Received* 18 *May* 1991; *accepted* 26 *September* 1991)

Abstract—The generality of the observation that there is a lexicon present in the right hemisphere of callosotomy patients has been the subject of some dispute. In the series operated on at Dartmouth Hitchcock Medical Center, only two patients have been shown to have a right hemisphere lexicon. This paper reports the existence of a visual and an auditory lexicon in a new patient D.R. and discusses its significance in understanding the role of the right hemisphere in normal and dysfunctional language.

INTRODUCTION

SINCE THE INITIAL observation that the right hemisphere of some commissurotomy patients harbored independent linguistic and cognitive systems [13, 20, 21], the delineation of the capacities of the right hemisphere has been a provocative source of hypotheses about language and cognitive processes. Two of the three first patients reported, N.G. and L.B., had some language function in their right hemispheres [13, 20]. In both patients the right hemisphere could comprehend spoken and written language but could not speak. Comprehension of nouns was good, but comprehension of adjectives was more difficult, and neither subject could respond to verbal commands. The right hemispheres of N.G. and L.B. were unable to reliably match sentences and pictures requiring comprehension of the active and passive voice, the future tense, or the plural morpheme. Both subjects were able to differentiate affirmative and negative sentences [14]. Despite original optimism regarding the generality of these findings, SPERRY *et al.* [39] (p. 288) noted that "extended observations reveal an impressive array and range of individual variation for so small a patient series".

In extending the observations made in the West coast series of split-brain patients to a series initiated at Dartmouth Hitchcock Medical Center [44], Gazzaniga and colleagues continued to observe great variability in right hemisphere language. GAZZANIGA [11] stressed the relative rarity of linguistic skill in the isolated right hemisphere and the range in sophistication of the language skills that was found. Of the Dartmouth patients, only two have demonstrated right hemisphere language capacity. These two patients P.S. [18, 23, 24] and J.W. [2, 15, 22, 34, 35] read words accurately in their left visual field (LVF) at 150 msec exposure durations. Both can make a variety of semantic and syntactic judgements. P.S. has demonstrated that he can generate speech from his right hemisphere [23, 24]. One other patient studied by Gazzaniga and colleagues V.P. has language skills similar to those of P.S.

*Address for correspondence: Kathleen Baynes, Program in Cognitive Neuroscience, Dartmouth Medical School, Hanover, NH 03756, U.S.A.

[2, 11, 22, 34, 35]. The variation in the range of right hemisphere language functions has led these investigators to propose that the right hemisphere of callosotomy patients provides insights into the relationships of functional subcomponents of language and the relationship between language and other cognitive functions, but may not provide a good model for localization of normal function.

In contrast, ZAIDEL [45, 46, 48–50] has emphasized the similarities in the linguistic abilities found in the West coast series of patients. These observations have been used to support the case for a distinctive right hemisphere lexicon that may play a role in normal reading and in the errors produced by some dyslexic patients [4–7, 30, 33].

Because of the strong position regarding the rarity of right hemisphere reading supported by this laboratory [1, 11], we believe that it is important to report the observation of a language system in the patient D.R.

Neurological history

Subject. D.R., born 4 December, 1944, is a right-handed woman who underwent a single stage callosotomy in 1983 for intractable primary complex partial seizures. In 1962, she began to experience brief episodes of altered consciousness variably associated with unpleasant olfactory hallucinations, motor automatisms, abdominal discomfort, and emotional outbursts involving rage, fear, or mirth. Secondary generalization of her seizures was abolished by anticonvulsants, but she continued to have several complex partial seizures per day despite trials of phenytoin, carbamazepine, phenobarbital, primidone, valproic acid, and clorazepate in various combinations.

The birth, developmental, and past medical histories are unremarkable. There is no family history of epilepsy. D.R. obtained a Bachelor of Science degree with a major in accounting. She was employed as an accountant until her mid-thirties, when her seizures began to compromise her job performance and precluded driving. At present, she is divorced, lives alone, and is independent in activities of daily life.

In 1976, the Wechsler Adult Intelligence Scale [42] was reported to show a Full Scale IQ of 117, with a Verbal IQ of 123 and a Performance IQ of 107. In 1983, at the time of her first admission to Dartmouth Hitchcock Medical Center, the neurological examination was normal. A Wechsler Adult Intelligence Scale IQ of 108 (Verbal IQ = 114, Performance IQ = 100) and a Halstead-Reitan Impairment of 0.3 were obtained. Audiometry showed normal pure tone sensation and speech discrimination thresholds. Serial electroencephalograms (EEGs) showed occasional bursts of high-voltage sharp waves emanating from the right temporal lobe superimposed upon diffuse theta activity with right greater than left temporal predominance; during one EEG, D.R. had symptoms typical of her attacks that correlated with bilaterally synchronous paroxysms. Computerized X-ray tomography of the brain showed a low-density, non-enhancing, circinate mass without associated edema in the region of the quadrigeminal cistern. Subsequent magnetic resonance imaging (MR) corroborated the original impression that this lesion represents a lipoma, referable to which there remain no discernible clinical signs.

At surgery, all but the inferior aspect of the rostrum of the corpus callosum was reported to be cut. Immediately post-operatively, there was mutism and a mild left hemiparesis, leg greater than arm, both of which resolved over days. Inability to name objects placed in the left hand and apraxia of the left hand and foot persisted to the tenth post-operative day, when she was discharged.

In 1983, D.R. was administered our standard language battery. Her right hemisphere was able to match lateralized pictures to identical free field pictures, but could not match lateralized words to identical free field words. Her right hemisphere was unable to use a lateralized word to choose free field pictures. However, there was some indication that her right hemisphere could use a lateralized picture to choose the correct free field word, suggesting limited reading ability.

In the 7 years since callosotomy, complex partial seizures have remained frequent, but no generalized convulsions have occurred, even during several months of observation off anticonvulsants. Three months post-callosotomy, EEG showed diffuse theta activity and frequent sharp waves bilaterally and asynchronously. Six years post-callosotomy, multiplanar/multiecho MR confirmed the surgical report that all but a small inferior portion of the rostrum was transected (Fig. 1).

At the time of the present observations, D.R. was maintained on carbamazepine and clorazepate, with carbamazepine blood levels in the so-called 'therapeutic range'; she was also taking propanolol for hypertensive vascular disease. She reported experiencing brief alterations in consciousness lasting several seconds and occurring several times per week which were variably associated with anxiety and unpleasant abdominal sensations; she denied recent olfactory hallucinations, motor automatisms, or emotional outbursts. Neurological examination was remarkable for inability to name objects placed in the left hand, inability to name letters and numbers drawn on the left hand, a mild apraxia of the left hand, and mild end-gaze horizontal nystagmus. Her Wechsler Adult Intelligence Scale—Revised [41] Full Scale IQ was 89 (Verbal IQ 105, Performance IQ 72). On the Wechsler Memory Scale—Revised [43], her General Memory index score was 100 (Verbal = 121, Visual = 70, Attention and Concentra-

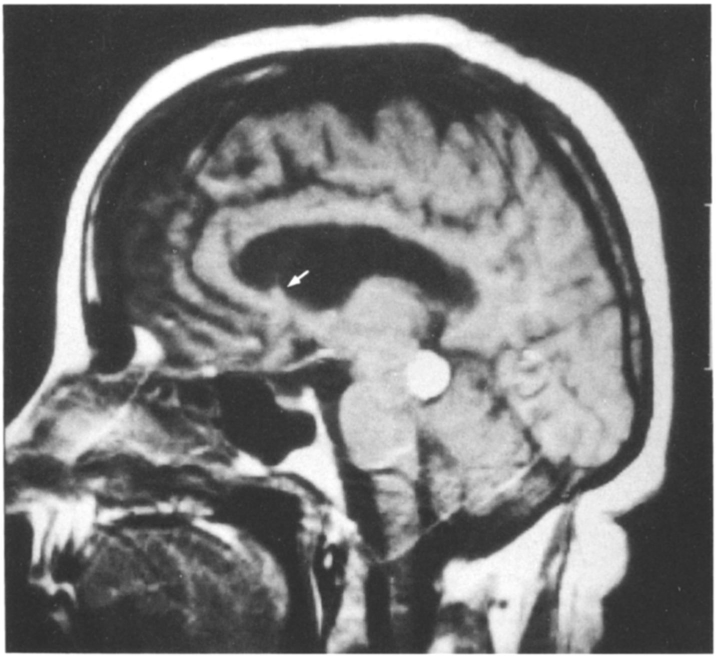

Fig. 1. T1 weighted midsagittal MR of callosotomy patient D.R. Transection of the splenium, body, and genu of the corpus callosum appears to be complete, but the signal emanating from the inferior rostrum (arrow) corroborates the surgical report of partial rostral sparring. The circinate hyperintense signal in the region of the quadrigeminal cistern probably represents a lipoma.

tion = 87, Delayed Recall = 83). The Wide Range Achievement Test placed her reading level at grade 16.8 [26]. She named 55 of 60 items of the Boston Naming Test [27]. Performance on the Mesulam Cancellation Tests [29] was within normal limits.

Evidence for reading in D.R.'s right hemisphere

The observations made shortly after surgery (see above) could be interpreted to suggest that D.R. had some limited reading in her right hemisphere, but it was not able to read rapidly enough to comprehend tachistoscopically presented words. If a picture was presented to her LVF, she could point to the matching word from a free field display of 12 words with 75% accuracy, although she was unable to demonstrate any comprehension of words displayed in the LVF. In order to determine whether or not D.R.'s right hemisphere was reading, a more detailed examination of her word and picture matching ability was undertaken.

EXPERIMENT 1

Materials

A set of 160 pictures with names of less than six letters in length was selected from the SNODGRASS and VANDERWART [38] pictures. These words were divided into eight sets of 20 pictures matched for length and frequency [28]. Two lists were randomly assigned to each of four display conditions and within each condition, a list was assigned to the right or to the left visual field. For the word–word and picture–word conditions, 160 additional concrete nouns were matched in length and frequency to be used as foils on the three choice, answer sheets. For the picture–picture and word–picture conditions, 100 foils were selected from the remaining Snodgrass pictures and 40 foils were selected from the word targets in each of the first two conditions. This meant that of the 160 picture foils, 40 of them would also be viewed twice as words, once as the lateralized word and then as a response choice and 40 of them would be viewed once as a lateralized picture and once as a response choice word. Of the stimuli lateralized to the right hemisphere in the word–word and picture–word trials half would be viewed as picture foils by the right hemisphere and half by the left. For left hemisphere stimuli the situation was reversed. Experiment 1a consisted of picture–picture trials, Experiment 1b of word–word trials, Experiment 1c of word–picture trials, and Experiment 1d of picture–word trials. In all cases, the trial names are derived by listing the format of the lateralized stimuli first followed by the format of the free-field response trials.

For this experiment and those that follow, items were stored on a Macintosh SE and displayed using the Psychlab program [25]. Lateralized stimuli were displayed for 150 msec at least 2 degrees of visual angle to the right or left of the fixation point. Word stimuli, displayed in capital letters, were from three to six letters in length unless otherwise specified and subtended approximately 2.5 to 5 degrees of visual angle. Picture stimuli were displayed in a window that maximally subtended 4 degrees of visual angle vertically and 5.2 degrees horizontally.

Procedure

In Experiments 1a, 1b, 1c, and 1d, D.R. was asked to fixate on a central point. When D.R. appeared to be ready, the trial was initiated by the experimenter and the word or picture to be lateralized was displayed briefly on the screen. She was presented with three free field choices immediately following the display and asked to point to the one that matched the displayed stimulus. Her left hand was used throughout to maximize right hemisphere performance.

Results

Results will be tested to determine whether they differ significantly from chance in each condition within a visual field. Only results that differ at the $P<0.01$ level of significance will be reported.

D.R. performed at above chance levels when a picture was presented in the LVF and she was offered the free field choice of a picture or a word (picture–picture, $z=5.57$, binomial $P<0.001$; picture–word, $z=4.82$, binomial $P<0.001$). However, when a word was presented tachistoscopically in the LVF, she was unable to match it with a free field word or a picture at above chance levels (word–word, $z=1.11$, ns; word–picture, $z=0.29$, ns). D.R. was able to match all combinations of RVF words and pictures at above chance levels (picture–picture,

Table 1. Matching words and pictures within a hemisphere

Task	Visual field LVF	RVF
Experiment 1a Flash: PICTURE Point: PICTURE		
Percent correct	85%*	100%*
n	20	20
Experiment 1b Flash: WORD Point: WORD		
Percent correct	45%	94%*
n	20	18
Experiment 1c Flash: WORD Point: PICTURE		
Percent correct	30%	63%*
n	20	19
Experiment 1d Flash: PICTURE Point: WORD		
Percent correct	80%*	100%*
n	20	20

LVF = left visual field, RVF = right visual field.
*Binomial $P < 0.01$.

$z = 9.02$, binomial $P < 0.001$; word–word, $z = 6.95$, binomial $P < 0.001$; picture–word, $z = 9.02$, binomial $P < 0.001$; word–picture, $z = 2.74$, binomial $P < 0.01$). This corroborated the observations made in 1983 shortly after her surgery. It appeared that when the isolated right hemisphere was presented briefly with a picture, the matching word could be selected from a free field choice of three words with significant accuracy.

One explanation for the observed results is that the right hemisphere was able to recognize objects but not words and that some ability to transfer information derived from lateralized pictures into the reading left hemisphere allowed selection of words displayed free field in Experiment 1d. Evidence of rostral sparing of the corpus callosum demonstrated with MR scanning provides a possible avenue for some interhemispheric transfer of information. However, patient V.P. who also has some sparing of callosal fibers [16] has demonstrated only very restricted transfer of information [17].

Alternatively, the right hemisphere not only identified the lateralized objects, but read the free field word choices as well. If the latter supposition were true, D.R.'s right hemisphere could read with extended viewing time, but not in the 150 msec time frame required to assure lateralization. To be certain that her right hemisphere was responsible for the single word reading observed, it was necessary to investigate the possibility that D.R. was using some form of interhemispheric transfer to select the correct item from a free field display.

Reading or interhemispheric transfer of information? To determine whether interhemispheric transfer was a likely source of the good performance matching pictures tachistoscopically presented in the LVF to free field words, Experiments 2 and 3 were undertaken. Both experiments examined within and between field matching of words and pictures, but required different types of response. Experiment 2 required a two-choice response and Experiment 3 required a same–different response.

EXPERIMENT 2

Materials

Materials were drawn from the same set of SNODGRASS and VANDERWART [38] pictures. Two sets of 48 words (picture names) were selected and divided into eight groups of 12. Four of the groups were used in Experiment 2a and four in Experiment 2b. Experiments 2a and 2b each consisted of 24 trials in which both the stimulus and the response were lateralized to the same hemisphere (12 LVF and 12 RVF) and 24 trials in which the stimulus was displayed to one hemisphere and the response to the contralateral hemisphere (12 RVF→LVF and 12 LVF→RVF). In Experiment 2a, the stimulus consisted of a single word and the response consisted of two pictures, one of which matched the word. In Experiment 2b, the stimulus was a picture and the response consisted of two words. The stimulus appeared for 150 msec followed by a 2000 msec pause and then the two response choices were displayed for 150 msec. The responses were displayed 2 degrees above and below the fixation point counterbalanced by the position of the correct response.

Procedures

D.R.'s task was to observe the display and then to point to the position on the screen where the correct answer had appeared (either the upper or lower portion of the screen in the appropriate visual field) with the hand ipsilateral to the response display. In both experiments, there was a long (2000 msec) pause between the stimulus and the response. D.R. was told to concentrate on the stimulus during the interval in an attempt to encourage any transfer of information that might occur. When D.R. participated in Experiments 2a and 2b on 6 February 1989, many trials were lost due to her failure to 'see' the stimulus or the response; these failures occurred on both LVF and RVF field trials. If D.R. indicated that she had seen something, but was uncertain, she was encouraged to guess. However, after some displays, she was unaware that a trial had occurred and these trials were discarded. A maxium of 10 trials in one condition (Experiment 2b, LVF) were discarded for this reason. Both experiments were repeated on 7 April 1990 and the results from the two days were combined, yielding a maximum of 24 trials in each condition.

Table 2. Matching words and pictures within and between hemispheres

Task	Visual field LVF	RVF	RVF→LVF	LVF→RVF
	Two choice responses Within		Between	
Experiment 2a				
WORD/2 PICTURES				
% correct	44%	100%	45%	40%
n	18	20	22	15
Experiment 2b				
PICTURE/2 WORDS				
% correct	38%	88%*	63%	57%
n	13	17	16	14
	Same/different judgements			
Experiment 3a				
WORD/PICTURE				
% correct	63%	83%*	40%	55%
n	24	24	25	22
Experiment 3b				
PICTURE/WORD				
% correct	38%	88%*	75%	40%
n	16	16	16	15

LVF = left visual field, RVF = right visual field.
*Binomial $P < 0.001$.

Results

When the picture was presented to the LVF and the word to the RVF, there was no evidence that the right hemisphere was able to transfer cues to the left hemisphere (LVF→RVF, 2b, $z=0.53$, ns). Therefore, it appears that the ability to match pictures to words in Experiment 1 reflects the right hemisphere's capacity to read when given sufficient time. In Experiments 2a and 2b, D.R. was above chance only when both the stimulus and the response were presented to the RVF or the left hemisphere (RVF, 2a, $z=9.02$, binomial $P<0.001$; 2b, $z=3.71$, binomial $P<0.001$).

EXPERIMENT 3

Materials and procedure

In Experiments 3a and 3b, the materials and procedure were similar except for the response requirements. A single word or picture was presented for 150 msec in the right or the left visual field, followed by a 2000 msec pause, and finally a single word or picture was presented to the RVF or the LVF. D.R.'s task was to indicate with the hand contralateral to the final display whether the word and the picture represented the same or different items by pointing to a free field response card on which 'SAME' and 'DIFFERENT' were printed.

Results

There was no trace of an ability to transfer information when a LVF picture was followed by a RVF word (LVF→RVF, 3b, $z=0.78$, ns). Of course, the brevity of the display mitigated against good LVF performance when a word was lateralized. Once again D.R. was above chance when both items were displayed in the RVF (RVF, 3a, $z=3.65$, binomial $P<0.001$; 3b, $z=3.61$, binomial $P<0.001$). There was one transfer effect that approached significance. When the picture was displayed first in the RVF followed by the word in the LVF, there was a trend for D.R.'s decisions to be accurate (RVF→LVF, 3b, $z=2.14$, binomial $P<0.05$). Not only is the direction in which transfer would have occurred not relevant to the point under investigation, to make use of any information that might have been transferred from the left hemisphere, D.R.'s right hemisphere would have had to read a word displayed for 150 msec. If it were possible for her right hemisphere to read words presented at this exposure duration, all of the conditions of Experiments 2 and 3 should have been possible for her to respond to accurately. It therefore appears unlikely that there was an explicit transfer of information from her left hemisphere to her right.

We concluded that the transfer hypothesis did not provide an explanation for D.R.'s right hemisphere ability to match lateralized pictures to free field words and that her right hemisphere was indeed reading the free field words. Moreover, this behavioral demonstration of reading ability confirms previously established physiological results, in that the presence of reading ability in D.R.'s right hemisphere is consistent with the observation of a P300 in an oddball word recognition task [12]. Having established a right hemisphere reading lexicon in D.R., her auditory lexicon was examined.

Auditory comprehension. Auditory comprehension is reported in some patients with extensive left hemisphere lesions [52] and in the right hemisphere of some split brain patients [11, 47]. ZAIDEL [47] has suggested that an auditory lexicon that is superior to the visual lexicon is characteristic of right hemisphere language. If D.R.'s right hemisphere were language competent, it should be able to access the meaning of auditory words. The next experiment was designed to test this hypothesis.

EXPERIMENT 4

Materials and procedures

Forty pictures were selected from the SNODGRASS and VANDERWART [38] pictures. Each picture was displayed twice, each time preceded by a word pronounced by the experimenter; once the word was the name of the displayed picture and once the word was chosen from a list matched on frequency to the list of picture names. Pictures were displayed at least 2 degrees to the right or left of the fixation point and remained on the screen for 150 msec. Each picture was displayed once in each visual field so that if a picture appeared in one visual field preceded by its correct name, the picture appeared in the other field preceded by an incorrect name. Order of presentation was random with the restriction that half of the trials to either field were in blocks responded to by either hand.

Table 3. Percent correct of same–different judgements matching auditory words and pictures

Response hand		Visual field LVF	RVF
	n		
Right			
% correct	20	70%	100%
Left			
% correct	20	85%	95%
Combined			
% correct	40	78%*	98%†

Note: As the difference between response hands did not reach significance for either hemisphere, only the combined scores were tested further.
LVF = left visual field, RVF = right visual field.
*$z = 3.85$, binomial $P < 0.001$.
†$z = 8.26$, binomial $P < 0.001$.

Results

D.R. was more accurate responding to either visual field with the ipsilateral hand, but not significantly so (LVF, 15% left hand advantage, $z = 1.63$, ns; RVF, 5% right hand advantage, $z = 1.45$, ns). As the hand advantage did not reach significance, only the combined results were examined further. Although D.R.'s responses were more accurate overall in the RVF trials ($z = 4.09$, binomial $P < 0.001$), she was able to accurately match spoken words and LVF pictures as well ($z = 3.85$, binomial $P < 0.001$). These results indicate that D.R.'s right hemisphere is able to access the lexicon via auditory input.

Lexical decision. Lexical decision tasks have been used to demonstrate access to a visual word form system in some patients that are unable to read [6]. The ability to make lexical decisions has been reported in the right hemisphere of some split brain patients as well [9, 32]. As D.R.'s right hemisphere seemed to be able to derive some information from tachistoscopically presented words, it raised the question of whether her right hemisphere had a visual word form system that would allow her to perform a lexical decision task accurately. We therefore attempted to determine (1) whether D.R.'s right hemisphere could make accurate lexical decisions and (2) if these decisions were affected by frequency.

EXPERIMENT 5

Materials

Twenty nouns were selected such that half of them had an AA frequency on the THORNDIKE–LORGE frequency list [40] and the other half had a mean frequency of 12.1 (range 4–20). Words were from three to six letters in length.

Non-words were created by changing one letter of each word to form a pronounceable non-word. Letters altered were evenly distributed among first, last, and medial positions within each word.

Procedures

Letter strings were presented randomly to one or the other visual field for 150 msec and D.R. responded by pressing a key labelled 'YES' when she believed the letter string formed a word and 'NO' when it did not form a word. Response hand and visual field were counterbalanced.

Table 4. Percent 'YES' responses in a lexical decision task

Response hand		Visual field LVF	Visual field RVF
		Words	
Right	*n*		
Frequent	10	30%	100%
Infrequent	10	50%	90%
Total	20	40%*	95%†
Left			
Frequent	10	90%	80%
Infrequent	10	80%	50%
Total	20	85%*	65%†
		Non-words	
Right	20	55%	70%
Left	20	60%	70%

Note: Percents with the * and † differ from one another at the $P<0.001$ level of significance.
LVF = left visual field, RVF = right visual field.

Results

Words were accurately recognized in either visual field, although response hand heavily influenced hemispheric accuracy. D.R. recognized 95% of the words presented in the RVF when responding with her right hand, but only 65% when responding with her left hand (RVF, 30% right hand advantage, $z=3.62$, binomial $P<0.001$). On LVF trials, 85% of the words were recognized when responding with her left hand, but only 40% when responding with her right hand (LVF, 45% left hand advantage, $z=4.64$, binomial $P<0.001$). Considering only the trials responded to by the ipsilateral hand, both RVF and LVF trials yielded above chance word recognition (RVF, $z=5.22$, binomial $P<0.001$; LVF, $z=3.60$, binomial $P<0.001$). The consistent advantage observed for responses with the hand ipsilateral to the display is of interest because it argues for the successful lateralization of the stimulus materials and control of the response selection by the hemisphere that viewed the display. It was present throughout these experiments, although it was not always at a level of statistical significance.

Frequent words were recognized with slightly more accuracy than infrequent words in each visual field, but the difference did not reach significance (RVF, $z=1.49$, ns; LVF, $z=0.89$, ns). D.R.'s right hemisphere is able to make lexical decisions, but did not demonstrate an effect of frequency.

DISCUSSION

Patient D.R. has a right hemisphere auditory and visual lexicon as do P.S. and J.W. in the Dartmouth series. Although D.R.'s right hemisphere lexicon supports more limited performance than that of any other of the Dartmouth patients we have studied to date, the presence of a language system in her right hemisphere is important in evaluating claims about the contribution of the right hemisphere to normal language processing and its role in errors made by some brain damaged subjects.

If the right hemisphere plays a consistent role in normal language processing, it would be expected that all right hemispheres of adult commissurotomy patients and hemispherectomy patients would have a similar lexicon. In the Dartmouth series, D.R. is only the third patient to date in which any right hemisphere language capacity has been demonstrated and it is quite different from the other two cases. Other patients with comparable intelligence have not displayed right hemisphere language skills [19]. In the West Coast series. LVF lateralized language data have been reported consistently from two patients [47]. Although extensive right hemisphere language skills have been described in the remaining right hemisphere of one childhood hemispherectomy patient [37], many adult hemispherectomy patients have little or no usable language skills [8, 36, 53]. Finally, sodium amytol testing suggests the presence of little or no right hemisphere language in most patients even with early left hemisphere damage [31].

Furthermore, disconnecting the hemispheres does not result in defective left hemisphere speech, reading, or comprehension. Any task that depends heavily on a number of subprocesses requiring interhemispheric integration will show a decline when the hemispheres are separated. This sort of effect has been demonstrated for so-called right hemisphere tasks like wire figures and Block Design that in some patients can require a left hemisphere contribution for successful completion. Pre-surgically, such patients can perform these tasks adequately with either hand. Post-surgically, both hands are impaired on these tasks because the needed interhemispheric integration cannot be accomplished [10]. If there were a crucial contribution from the right hemisphere to reading functions, some observable dysfunction would be expected. ZAIDEL [47] has argued that L.B. and N.G. have declined in their reading ability, but significance levels are marginal and L.B. has shown a marginal decline in general intellectual function as well. D.R. reports that she no longer reads for pleasure, but neuropsychological testing (see Neurological History) documents that her general intellectual level has declined. Despite the intellectual decline, reading scores have remained stable. Her pre-surgical reading score on the WRAT administered on 30 August 1983 placed her at a 16.2 grade level. Post-surgically, here grade level on WRAT-R administered on 2 April 1989 is 16.8. Moreover, even if a decline were observed, it might be accounted for by the splitting of the visual fields rather than any higher order function.

That is not to say that there may not be variable language representation in the right hemisphere [35]. ZAIDEL and SCHWEIGER [51, 33] have suggested that there may be a few defining features of right hemisphere language and a continuum of characteristic features that may or may not be present. If variability is the rule, caution in generalizing from results is needed. At one extreme, COLTHEART [5] does not believe that language data from the split brain population are relevant to the issue of the right hemisphere's role in normal or dyslexic language, because of the markedly abnormal neurological history that precipitates such surgical intervention. He suggests that we can learn about normal language only from those components that never occur in the right hemisphere. However, GAZZANIGA *et al.* [19] have noted that the neurological histories of some of the callosotomy patients with right hemisphere language are normal through adolescence.

Our position is that mental processes are organized so that some units work in relative isolation processing particular kinds of information in particular ways. A further assumption is that brain damage does not create new processes but rather allows investigators to look at normal processes working with a dysfunctional or missing component. The latter assumption is a paraphase of what CARAMAZZA [3] has called the transparency assumption. Although such an assertion must be made less strongly in the case of patients who have developed language under neurologically abnormal conditions, it is also a necessary assumption of split-brain research. We assume that the processes that we observe are "normal" although they may be uniquely distributed. This reasoning is essential to our position that generalizing about *localization* of function from the split-brain population is ill-advised. It is however completely possible to study the function of components that may be isolated from left hemisphere processes and to study the dependencies that exist between such components.

D.R. is an important case because she gives us yet another perspective on the reading process. Further study of the processes that support D.R.'s fragile reading behavior may permit us to better understand whether there are differences in the way the mental lexicon is accessed that support entry to different kinds of linguistic information and subsequently limit its use in sentence length comprehension and production. Analysis of prelexical processing in patient J.W. suggests that the slow but accurate visual word comprehension observed in his right hemisphere is supported by processes that may be serial rather than parallel in nature [32]. Comparison of prelexical processes in these two patients and in a patient with greater generative capacity like V.P. [35] may help us to understand the processes that underlie the development of normal speech and language.

Acknowledgements—This research was supported by Javits Neuroscience Investigator Award 1-RO1 NS 22626-03 to Michael S. Gazzaniga and R29 DC00811 to K. Baynes.

REFERENCES

1. BAYNES, K. Language and reading in the right hemisphere: Highways or byways of the brain? *J. Cognit. Neurosci.* **2,** 159–179, 1990.
2. BAYNES, K. and GAZZANIGA, M. S. Right hemisphere language: Insights into normal language mechanisms? In *Language, Communication, and the Brain*. F. PLUM (Editor), pp. 117–126. Raven Press, New York, 1988.
3. CARAMAZZA, A. The logic of neuropsychological research and the problem of patient classification in aphasia. *Brain Lang.* **21,** 9–20, 1984.
4. COLTHEART, M. Deep dyslexia: A review of the syndrome. In *Deep Dyslexia*, M. COLTHEART, K. E. PATTERSON, and J. C. MARSHALL (Editors), pp. 23–47. Routledge, London, 1980.
5. COLTHEART, M. Deep dyslexia: A right-hemisphere hypothesis. In *Deep Dyslexia*, M. COLTHEART, K. E. PATTERSON and J. C. MARSHALL (Editors), pp. 327–406. Routledge, London, 1980.
6. COSLETT, H. B. and SAFFRAN, E. M. Evidence for preserved reading in 'pure alexia'. *Brain* **112,** 327–359, 1989.
7. COSLETT, H. B. and SAFFRAN, E. M. Preserved object recognition and reading comprehension in optic aphasia. *Brain* **112,** 1091–1110, 1989.
8. CROCKETT, H. G. and ESTRIDGE, N. M. Cerebral hemispherectomy. *Bull. Los Angeles Neurol. Soc.* **19,** 71–87, 1951.
9. EVIATOR, Z., MENN, L. and ZAIDEL, E. Concreteness: Nouns, verbs, and hemispheres. *Cortex* **26,** 611–624, 1990.
10. GAZZANIGA, M. S. Organization of the human brain. *Science* **245,** 947–952, 1989.
11. GAZZANIGA, M. S. Right hemisphere language following bisection: A 20-year perspective. *Am. Psychol.* **38,** 525–537, 1983.
12. GAZZANIGA, M. S. The dynamics of cerebral specialization and modular interaction. In *Thought Without Language*, L. WEIZKRANTZ (Editor), pp. 430–450. Clarendon Press, Oxford, 1988.
13. GAZZANIGA, M. S., BOGEN, J. E. and SPERRY, R. W. Dyspraxia following section of the cerebral commissures. *Arch. Neurol.* **16,** 606–612, 1967.
14. GAZZANIGA, M. S. and HILLYARD, S. A. Language and speech capacity of the right hemisphere. *Neuropsychologia* **9,** 273–280, 1971.

15. GAZZANIGA, M. S., HOLTZMAN, J. D. and SMYLIE, C. S. Speech without conscious awareness. *Neurology* **37,** 682–685, 1987.
16. GAZZANIGA, M. S., HOLTZMAN, J. D., DECK, M. D. F. and LEE, B. C. P. MRI assessment of human callosal surgery with neuropsychological correlates. *Neurology* **35,** 1763–1766, 1985.
17. GAZZANIGA, M. S., KUTAS, M., VAN PETTEN, C. and FENDRICH, R. Human callosal function: MRI-verified neuropsychological functions. *Neurology* **39,** 942–946, 1989.
18. GAZZANIGA, M. S., LEDOUX, J. E. and WILSON, D. H. Language, praxis, and the right hemisphere: Clues to some mechanisms of consciousness. *Neurology* **27,** 1144–1147, 1977.
19. GAZZANIGA, M. S., NASS, R., REEVES, A. and ROBERTS, D. Neuropsychologic perspectives on right hemisphere language following surgical section of the corpus callosum. *Sem. Neurol.* **4,** 126–135, 1984.
20. GAZZANIGA, M. S. and SPERRY, R. W. Language after section of the cerebral commissures. *Brain* **90,** 131–138, 1967.
21. GAZZANIGA, M. S. and SPERRY, R. W. Language in human patients after brain bisection. *Fed. Proc.* **24,** 522, 1965.
22. GAZZANIGA, M. S., SMYLIE, C. S., BAYNES, K., MCCLEARY, C. and HIRST, W. Profiles of right hemisphere language and speech following brain bisection. *Brain Lang.* **22,** 206–220, 1984.
23. GAZZANIGA, M. S., VOLPE, B. T., SMYLIE, C., HOLTZMAN, J. and WILSON, D. Evidence for paracallosal verbal transfer after callosal section: A possible consequence of bilateral organization. *Brain* **105,** 53–63, 1982.
24. GAZZANIGA, M. S., VOLPE, B. T., SMYLIE, C. S., WILSON, D. H. and LEDOUX, J. E. Plasticity in speech organization following commissurotomy. *Brain* **102,** 805–815, 1979.
25. GUM, T. and BUB, D. *Psychlab. Manual.* Montreal Neurological Institute, Montreal, 1988.
26. JASTAK, S. and WILKINSON, G. S. *Wide Range Achievement Test—Revised: Administration Manual.* Jastak Ass., Inc., Wilmington, Del., 1984.
27. KAPLAN, E., GOODGLASS, H. and WEINTRAUB, S. *Boston Naming Test–Revised.* Lea & Febiger, Philadelphia, 1983.
28. KUCERA, H. and FRANCIS, W. N. *Computational Analysis of Present Day American English.* Brown University Press, Providence, R.I., 1967.
29. MESULAM, M.-M. *Principles of Behavioral Neurology.* F. A. Davis Co., Philadelphia, 1985.
30. PATTERSON, K. What is right with "deep" dyslexic patients? *Brain Lang.* **8,** 111–129, 1979.
31. RASMUSSEN, T. and MILNER, B. The role of early left-brain injury in determining lateralization of cerebral speech functions. *Ann. New York Acad. Sci.* **299,** 355–369.
32. REUTER-LORENZ, P. and BAYNES, K. Modes of lexical access in the callosotomized brain. *J. Cognit. Neurosci.*, in press.
33. SCHWEIGER, A., ZAIDEL, E., FIELD, T. and DOBKIN, B. Right hemisphere contribution to lexical access in an aphasic with deep dyslexia. *Brain Lang.* **37,** 73–89, 1989.
34. SIDTIS, J. J., VOLPE, B. T., WILSON, D. H. and GAZZANIGA, M. S. Cognitive interaction after staged callosal section: Evidence for transfer of semantic activation. *Science* **212,** 344–346, 1981.
35. SIDTIS, J. J., VOLPE, B. T., WILSON, D. H., RAYPORT, M. and GAZZANIGA, M. S. Variability in right hemisphere language function after callosal section: Evidence for a continuum of generative capacity. *J. Neurosci.* **1,** 323–331, 1981.
36. SMITH, A. and BURKLAND, C. W. Dominant hemispherectomy. *Science* **153,** 1280–1282, 1966.
37. SMITH, A. and SUGAR, O. Development of above normal language and intelligence 21 years after left hemispherectomy. *Neurology* **25,** 813–815, 1975.
38. SNODGRASS, J. G. and VANDERWART, M. A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *J. Exp. Psychol.: Hum. Learn. Mem.* **6,** 174–215, 1980.
39. SPERRY, R. W., GAZZANIGA, M. S. and BOGEN, J. E. Interhemispheric relationships: the neocortical commissures; syndromes of hemispheric disconnection. In *Handbook of Clinical Neurology*, P. J. VINKEN and G. W. BRUYN (Editors), pp. 273–290. North-Holland, Amsterdam, 1969.
40. THORNDIKE, E. L. and LORGE, I. *The Teacher's Word Book of 30,000 Words.* Teachers College Bureau of Publications, Columbia University, New York, 1944.
41. WECHSLER, D. *Manual for the Weschsler Adult Intelligence Scale—Revised.* The Psychological Corporation, New York, 1981.
42. WECHSLER, D. *Manual for the Wechsler Adult Intelligence Scale.* The Psychological Corporation, New York, 1955.
43. WECHSLER, D. *Manual for the Wechsler Memory Scale—Revised.* The Psychological Corporation, New York, 1987.
44. WILSON, D. H., REEVES, A., GAZZANIGA, M. S. and CULVER, C. Cerebral commissurotomy for the control of intractable seizures. *Neurology* **27,** 708–715, 1977.
45. ZAIDEL, E. Auditory vocabulary of the right hemisphere following brain bisection or hemidecortication. *Cortex* **12,** 191–211, 1976.
46. ZAIDEL, E. Disconnection syndrome as a model for laterality effects in the normal brain. In *Cerebral Hemisphere Asymmetry: Method, Theory, and Application*, J. E. HEILEGE (Editor), pp. 95–149. Praeger, New York, 1983.

47. ZAIDEL, E. Language functions in the two hemispheres following complete cerebral commissurotomy and hemispherectomy. In *Handbook of Neuropsychology*, F. BOLLER and J. GRAFMAN (Editors), Vol. 4, pp. 115–150. Elsevier Sciences Publishers, B.V., 1990.
48. ZAIDEL, E. Lexical organization in the right hemisphere. In *Cerebral Correlates of Conscious Experience*, P. BUSER and A. ROUGEUL-BUSER (Editors), pp. 177–197. Elsevier, Amsterdam, 1978.
49. ZAIDEL, E. Reading by the disconnected right hemisphere: An aphasiological perspective. In *Dyslexia: Neuronal Cognitive and Linguistic Aspects, Wenner-Gren Symposium Series*, Vol. 35. Proceedings of an International Symposium, Stockholm, 3–4 June 1980, Y. ZOTTERMAN (Editor), pp. 67–91. Pergamon Press, Oxford, 1982.
50. ZAIDEL, E. The split and half brains as models of congenital language disability. In *The Neurological Basis of Language Disorders in Children: Methods and Directions for Research*. NINCDS Monograph No. 22, C. L. LUDLOW and M. E. DORAN-QUINE (Editors), pp. 55–89, U.S. Government Printing Office, Washington, D.C., 1979.
51. ZAIDEL, E. and SCHWEIGER, A. On wrong hypotheses about the right hemisphere: Commentary on K. Patterson and D. Besner, "Is the right hemisphere literate?" *Cognit. Neuropsychol.* **1,** 351–364, 1984.
52. ZANGWILL, O. L. Intelligence in aphasia. In *Disorders of Language, Ciba Foundation Symposium*, A. V. S. DEREUCK and M. O'CONNOR (Editors), pp. 261–274. Little, Brown & Co., Boston, 1964.
53. ZOLLINGER, R. Removal of the left cerebral hemisphere: Report of a case. *Arch. Neurol. Psychiat.* **34,** 1055–1064, 1935.