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Collaboration between the hemispheres of a callosotomy patient

Emerging right hemisphere speech and the left hemisphere interpreter

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Summary

Split brain patients who are initially unable to produce speech in their right hemispheres sometimes develop the ability to do so. Patient J.W., the subject of this report, is such a patient. At the time of his callosotomy, J.W. had a language dominant left hemisphere; his right hemisphere could understand both spoken and written language, but he was unable to speak. Fourteen years after his surgery, we found that J.W. was capable of naming ~25% of the stimuli presented to his left visual field (LVF). Now, 1 year later, we find that he can name about 60% of such stimuli. This late-developing speech ability appears to be the consequence of long-term neural plasticity. However, the subject's extended verbal responses to LVF stimuli seem to result from a collaboration between the hemispheres and to involve the left hemisphere interpreter.

Keywords: right hemisphere speech; split brain; interpreter

Abbreviations: LVF = left visual field; RVF = right visual field; S and V = Snodgrass and Vanderwart

Introduction

Early work with patients who have undergone hemisphere disconnection in an effort to control epilepsy clearly established that the two hemispheres of the human brain can function simultaneously yet separately (Gazzaniga and Sperry, 1966), and moreover, that each hemisphere is specialized for particular functions (Sperry *et al.*, 1969; Gazzaniga, 1970). In general terms, the left hemisphere appears to be dominant in terms of language and speech functions and to possess the capacity to 'interpret' the actions produced by both hemispheres. The right hemisphere, while extremely limited in its problem solving capacities, appears to be superior to the left in terms of visuo-spatial processing and attentional processes (Gazzaniga, 1989). Later investigations that focused on these same callosotomy patients showed a growth in right hemisphere capabilities, which suggests the dynamic nature of hemispheric functioning. For example, some callosotomy patients have shown evidence of an ability to produce speech out of their previously silent right hemispheres 26–36 months postoperatively (Gazzaniga *et al.*, 1979), and an increasing ability to verbalize LVF materials between 12 and 30 months postoperatively (Gazzaniga *et al.*, 1984). In the Caltech series of patients there have been mixed reports about the presence or absence of right hemisphere speech with some investigators claiming its presence (Butler and Norsell, 1968; Johnson, 1984) while others do not (Levy *et al.*, 1971; Zaidel, 1990). In our series of pateints we continue to find evidence for right hemisphere speech. The right hemisphere of patient J.W., though previously silent (Sidtis *et al.*, 1981*a*), has gained the ability to speak (Baynes *et al.*, 1995). This ability appears to be increasing several years later than the dynamic periods of previously reported cases. The present study documents the current state of his right hemisphere speech capability.

Patient J.W. is a 41-year-old male who underwent a two-stage callosotomy in 1979 when he was 26 years old (Sidtis *et al.*, 1981*a*, *b*) and MRI has confirmed the completeness of callosal section (Gazzaniga *et al.*, 1984). At the time of his surgery over 15 years ago, J.W. was found to have a language and speech dominant left hemisphere. However, immediately following full callosal section (carried out in two stages) his right hemisphere was able to understand spoken and written language, although it was unable to speak (Sidtis *et al.*, 1981*b*). Approximately 7 years later, J.W.'s right hemisphere had gained enough access to the left hemisphere speech apparatus to initiate some simple responses, although the left hemisphere remained unaware that its speech system was expressing right hemisphere knowledge (Gazzaniga *et al.*, 1987). Approximately 7 years subsequent to that development, Baynes *et al.* (1995) found that J.W. was capable of naming ~ 25% of the stimuli presented to his LVF. At present, J.W. can name LVF stimuli of various kinds with even greater frequency.

Patient J.W. has been studied extensively and was familiar with all the testing procedures used in these experiments. Two sets of experiments were conducted in 1995 for the present report. In the first set, J.W. was asked to name and describe stimuli presented to the right visual field (RVF) and LVF. In a separate testing session he was also asked to name objects palpated with the left and right hands. In the second set of experiments, he was asked to compare stimuli presented successively to his LVF and RVF, and to judge whether the stimuli were the same or different.

Methods

For all experiments but the tactile naming test, an image stabilizer coupled to a Purkinje image eyetracker with 1 arcmin of resolution ensured the proper lateralization of stimuli (*see* Fendrich *et al.*, 1992). If the subject attempted to move his eyes toward a lateralized stimulus, the image of that stimulus shifted by an amount equal to the eye movement, maintaining its retinal position. The subject was seated in a dimly lit room and viewed a monitor with his right eye through the stabilizer optics, while his left eye was patched. The monitor was placed so that 1 cm on the screen corresponded to 1° of visual angle. A bite-plate headrest assembly was used to position the subject's head. During the naming experiments, the subject was videotaped using an unconcealed camera. Videotapes were used to transcribe the audio portion of each session.

For the tactile naming experiments the subject sat behind a cloth-covered frame with one hand resting out of view upon a thin layer of sound dampening foam.

The experiments reported here spanned numerous sessions over a period of almost 1 year. Significance levels were two-tailed and computed from a binomial distribution assuming a chance success rate of 50% unless otherwise noted.

Experiment I: single field naming

Naming familiar people

The goal of this task was to determine whether J.W.'s right hemisphere could recognize and name photographs of familiar people and neutral objects.

Table 1 *Naming of familiar photos, neutral objects, S and V figures and complex objects*

Picture set	Correct names in each visual field			
	Left visual field		Right visual field	
Familiar photographs	47%	8/17	100%	10/10
Neutral object photos	67%	6/9	81%	13/16
S and V flashed presentation	67%	14/21	–	–
S and V sustained presentation	68%	25/37	–	–
Complex objects	50%	12/24	–	–

Stimuli. The stimuli were 15 colour photographs of family and friends taken without J.W.'s knowledge from his personal photo album, and 16 colour pictures of neutral objects and animals taken from the International Affective Picture System (Lang *et al.*, 1988; Greenwald *et al.*, 1989). The pictures subtended 5–10° of visual angle in the horizontal plane and 6–11° in the vertical plane. The medial edge of each picture was placed 1° from the retinal midline, so that each target (i.e. face) was ~ 2° from the midline. The neutral pictures subtended 3–12° horizontally and 1–9° vertically. The medial edge of each neutral picture was placed 2° from the retinal midline.

Procedure. The photographs were stored on a Panasonic videodisk and displayed on a video monitor using a Panasonic videodisk player. Each stimulus was presented to each visual field for 3–4 s. The 16 neutral pictures were presented once in random order to the RVF. Nine of these were randomly selected and presented to the LVF. Seventeen familiar photographs were presented to the subject's LVF: each of the 15 familiar photos were presented and two were repeated. The order of presentation was randomized with the following exception: in an attempt to orient the left hemisphere to the neutral objects task and to minimize the possibility that it would start to guess familiar people randomly, the first three trials were presented to the RVF. Following left field testing, 10 of the familiar photographs were then shown to the RVF to ensure that the familiar photographs were clear enough to be seen under lateralized conditions.

Results

The data are presented in Table 1. Patient J.W. accurately named 81% of the neutral pictures presented to the RVF. He correctly named 67% of the neutral pictures and 47% of the familiar pictures shown to the LVF. The set of 10 familiar stimuli shown to the RVF as a control were correctly identified 100% of the time; this set included photos that were not correctly identified when presented in the LVF. While there is no way to judge the probability of correct naming by chance, this probabilility must be low. Thus, J.W.'s right hemisphere is often capable of naming people and neutral

Table 2 *Naming errors for S&V figures and complex objects*

Picture set	No. of errors related to target			
	Visual	Semantic	Visual + semantic	Unrelated
S&V pictures	0	6	1	13
Complex objects	4	1	3	4

objects when presented with the appropriate stimuli. No special capacity was observed for right hemisphere identification of familiar people over neutral objects.

Object and scene naming

The second series of naming tasks examined the effect of stimulus complexity on J.W.'s right hemisphere naming capacity. For these tasks, three sets of stimuli of increasing complexity were presented to the LVF.

Snodgrass and Vanderwart objects

Stimuli. The stimuli were 37 black and white pictures of common objects from the Snodgrass and Vanderwart (1980) set of simple line drawings (the S&V set). The pictures subtended 2–5° horizontally and 1–5° vertically. The medial edge of each object was placed ⩾2° from the midline.

Procedure. Stimuli were displayed using a Macintosh computer. In a preliminary experiment, 21 of the 37 stimuli were randomly presented stroboscopically; during a single trial, each stimulus was flashed five times for 1 s with a 1 s inter-flash interval. Stimuli were presented only to J.W.'s LVF (right hemisphere). In the primary experiment, we randomly presented all 37 stimuli to the right hemisphere continuously for 5 s each. In both experiments, J.W. was asked to describe what he saw in his LVF. He was periodically prompted for more specific information after his initial response.

Results. The subject's performance levels did not differ significantly between stroboscopic and continuous presentation. He correctly identified 68% of the S&V objects in the sustained presentation condition and 67% in the flashed condition (see Table 1). For analysis of errors, all the trials were collapsed into one group, yielding an overall result of 20 out of 58 errors. Three independent judges then rated the patient's responses as correct or incorrect; they also rated each incorrect response as unrelated to the target, semantically related, visually related, or semantically and visually related. Errors were classified according to the majority opinion among the judges. The results of the error analysis are displayed in Table 2.

Complex objects

Stimuli. The stimuli were 24 black and white pictures that contained more than one object and had several describable features, making them more complex than the S&V drawings (e.g. a cup of coffee on a saucer with steam rising from it). The pictures subtended 1–11° in the horizontal plane and 3–10° in the vertical plane. The medial edge of each object was placed ⩾1° from midline.

Procedure. Stimuli were presented for 1 s each in random order to the subject's right hemisphere with a Macintosh computer; following each stimulus presentation in his LVF, J.W. was asked to describe what he saw. He was periodically prompted for more specific information once his initial response was made.

Results. Patient J.W. identified and described 50% of the complex objects correctly. These results are also displayed in Table 1. As above, the errors were judged for their relationship to the target and they are presented in the bottom row of Table 2.

Complex scenes

Stimuli. The stimuli were eight black and white drawings depicting various animate scenes (e.g. a woman standing in front of an old fashioned washing tub doing laundry) and inanimate scenes (e.g. a glass, salt and pepper shakers, and a sugar bowl on a table). Each of the scenes subtended 7° vertically and 10.5° horizontally. The medial edge of each scene was placed ⩾2° away from the midline.

Procedure. The complex scenes were stored on a Panasonic videodisk and presented on a video monitor using a Panasonic videodisk player. The stimuli were presented in random order to J.W.'s right hemisphere continuously for 5 s each. Following each stimulus presentation, J.W. was asked to describe the scenes as they were presented. He was periodically prompted for more specific information after his initial response.

Results. This was the most difficult naming task for the subject. There was no scene that J.W. correctly identified and described entirely correctly. He initially identified one scene correctly but then incorrectly described it after being prompted for further information. The scene depicted a woman wearing a black dress and washing clothes in an old fashioned washer. Behind her was a clothes line with laundry hanging from it. The following is an excerpt from the subject's response to that item. The experimenter's comments are in parentheses:

'It was a person . . . Would it be someone hanging out their laundry? One person. Must have been a woman. (Did you see any laundry?) I think so. I think she was reaching up and that's what she was doing . . .'

For four of the remaining seven stimuli, the subject gave incorrect descriptions that were visually similar or visually and semantically related to the actual picture. For example, one scene depicted a woman standing behind another woman who was sitting at a table and crying. There was a stove and sink in the background. In response to this scene, the subject said:

'The first thing I thought of was a woman baking. I don't know why . . . (Was she sitting or standing or . . .) Standing up by a table or something.'

The subject's response does not capture the meaning of the scene, but it does convey some of its visual attributes. The following is an example of a response that was both visually and semantically similar to the stimulus. The scene depicted a race track with two racing cars driving around it and another car that had crashed and overturned. There was a grandstand off to the left behind the track.

'Looked like something moving like a vehicle or something or somebody running or something like that. (Did it look like one thing or . . .) At least one. It was centred on one. Maybe there was something in the background. (If you had to guess what it was, what would you guess?) Either somebody running, or, a curved picture. Looked like coming around a corner almost . . . someone running. Maybe it was a track. It was hard to tell.'

Tactile naming

This task examined the tactile identification and naming skills of J.W. for objects examined by his left and right hands.

Stimuli. Forty-eight sets of four easily manipulable items were assembled. One item in each set was the target of a question designed to require pre-semantic structural information or post-semantic functional or associative information. In each of the 24 sets of items used to examined pre-semantic knowledge, there was one small item, one round one, a long one and a soft one. In each of the 24 sets of items used to examine post-semantic knowledge there was one used for cutting, one for fastening, one associated with a spoon and one associated with a hammer. Sets were arranged in a fixed, semi-random order with hand and semantic status counter-balanced.

Procedure. The subject was seated behind a rigid 48×56 cm^2 frame covered with an opaque cloth with one hand resting out of view behind the cloth. The surface of the table was shielded by a thin layer of foam to minimize auditory cues. Four objects were placed on the foam pad within easy reach of the shielded hand. The subject was told to 'Find the object that is small, that cuts, etc.' He was told he had to touch all four items before he could make a selection. When he was sure he had the correct item he was to pick it up and hand it to the examiner without making any verbal response. After he had made his choice he was required to attempt to name the item.

Table 3 *Tactile selection and naming of objects*

Task (%)	Correctly selected/named items			
	Left hand		Right hand	
Select*	98%	47/48	94%	45/48
Name	46%	22/48	81%	39/48

*Chance = 25%.

Results. Since the pre-semantic and post-semantic results did not differ from one another they are collapsed into a single score for each hand in Table 3. For completeness, the breakdown is as follows. The left hand correctly chose 100% (24 out of 24) of pre-semantic objects and 96% (23 out of 24) of post-semantic objects. Of those left hand items the subject named 42% (10 out of 24) of pre-semantic and 50% (12 out of 24) of post-semantic items. The right hand correctly chose 100% (24 out of 24) of pre-semantic objects and 88% (21 out of 24) of post-semantic objects. Of those right hand items the subject named 79% (19 out of 24) of pre-semantic and 83% (20 out of 24) of post-semantic items.

Experiment II: interfield comparisons

Patient J.W. completed several series of trials in which interfield comparisons (RVF–LVF) were required. He was asked to compare two stimuli, one presented to each visual field, and judge whether they were the same or different. Three sets of stimuli were presented to the subject: the S&V pictures, unnameable (abstract) line drawings and unfamiliar faces. Because transfer of visual information to the dominant hemisphere could be responsible for some naming performance we set up the matching experiment to maximize the opportunities for transfer or cross-cueing. This would to allow us to observe its effect on matching judgements. The LVF stimulus was always presented first. The subject used only his left hand to respond throughout all interfield comparison studies. Previous work has shown little or no difference in scores when using either the left or right hand (Seymour *et al.*, 1994).

General procedures. As described above, in all the matching experiments stimuli were presented successively to the LVF then the RVF, and the subject used his left hand to respond. Each exposure lasted 1 s and the left exposure was followed 1 s after offset by the right. The subject indicated his response on each trial by tapping repeatedly with his index finger to indicate that the stimuli were the same and with his thumb to indicate that the stimuli were different.

Table 4 *Interfield comparisons*

Picture set	Correctly judged pairs				
	Overall	'Same' pairs		'Different' pairs	
S&V figures	59%	67%	35/52*	50%	26/52
Random line figures	60%	55%	11/20	60%	12/20
Unfamiliar faces	57%	68%	19/28**	46%	13/28

*$P < 0.02$. **$P > 0.08$.

Object Matching

Stimuli. The stimuli used in the object matching task were 78 black and white pictures of common objects or animals from the S&V set. Ten of the 78 stimuli had been used previously in the naming task. The pictures subtended 2–5° horizontally and 1–5° vertically, and the medial edge of each picture was placed ⩾2° from the midline. Two stimulus sets of 26 stimulus pairs were created. In each set, there were 13 pairs in which the stimuli were the same and 13 pairs in which the stimuli were different. No object was included in more than one pair within each set; across sets, stimuli that appeared twice in the same visual field were presented in one set as part of a 'same' pair and in the other set as part of a 'different' pair. Within these constraints, pairings were randomly determined.

Procedure. Stimuli were displayed using a Macintosh computer. Each stimulus set was presented twice, for a total of 104 trials. 'same' and 'different' trials were presented in random order.

Results. The overall results are presented in Table 4. Patient J.W. correctly judged only 59% (61 out of 104, $P > 0.09$) of the stimuli to be the same or different. However, while he responded to 'different' trials with only 50% accuracy (26 out of 52), he responded to 'same' trials with 67% accuracy (35 out of 52 correct, $P < 0.02$).

Line-drawing matching

Stimuli. The stimuli used in the line-drawing matching task were 10 black line configurations that could not be assigned a simple verbal label and did not resemble a nameable object. The stimuli occupied 4° in the horizontal plane and 4° in the vertical plane, and the medial edge of each figure was placed at least 2.5° from midline. Two stimulus sets were created, each comprised of 20 stimulus pairs: 10 'same' pairs and 10 'different' pairs. In each set, each drawing was presented once as part of a 'same' pair, and twice as part of a 'different' pair (one 'different' occurence for each visual field). 'Different' pairings were randomly determined for each stimulus set. Each stimulus set was presented once, for a total of 40 trials.

Procedure. Stimuli were displayed using a Macintosh computer and stimulus pairs were presented in a random order.

Results. The results are displayed in Table 4. Patient J.W. was unable to judge any better than chance whether stimuli were the same or different (24 out of 40 correct, $P > 0.25$). His performance on 'same' trials was 55% (11 out of 20), and his performance on 'different' trials was 60% (12 out of 20). To confirm that the line drawings were discriminable when peripherally presented, a series of 20 trials was also presented within each visual field using the same figures and pairings used in the between-field trials. Again, only the left hand was used. The subject correctly judged whether stimuli presented sequentially were the same or different with 75% accuracy in the RVF (15 out of 20 correct, $P < 0.04$), and with 85% accuracy in the LVF (17 out of 20 correct, $P < 0.003$).

Unfamiliar face matching

Stimuli. The stimuli were eight black and white photos of smiling faces from the 'Japanese and Caucasian Facial Expressions of Emotion' slide set developed by Matsumoto and Ekman, which has been cross-culturally validated (Matsumoto, 1989; Matsumoto and Ekman, 1989). The photos included two Japanese males, two Japanese females, two Anglo-American males, and two Anglo-American females, all of whom were unfamiliar to the subject. Faces subtended 11–13° in the vertical plane and 8–9° in the horizontal plane, and the medial edge of each picture was placed 2° from midline. Each slide was presented an equal number of times to each hemisphere. There were 28 stimulus pairs in which the stimuli were the same and 28 stimulus pairs in which the stimuli were different. The 'different' trials included all 28 unique combinations of faces.

Procedure. Photographs were stored on a Panasonic videodisk and displayed on a video monitor using a Panasonic videodisk player. The order of the same and different trials randomized.

Results. Overall J.W. was unable to judge significantly better than chance whether the unfamiliar faces were the same or different (32 out of 56 correct, $P > 0.30$). Taken individually, neither 'same' nor 'different' trial performance was above chance: 'same:' 68% (19 out of 28 correct, $P > 0.08$), 'different:' 46% (13 out of 28 correct, $P > 0.85$).

Discussion

The emerging capacity of patient J.W. to describe visual stimuli placed in the LVF stands in marked contrast to his inability to judge consistently whether two objects, two unfamiliar faces or two line drawings presented sequentially to each visual field are the same or different. This continuing development which has emerged some 12 years after split brain surgery suggests the brain is capable of remarkable late stage plasticity. Our earlier study, using many of the same stimuli reported here (Baynes *et al.*, 1995) revealed a smaller capacity to name left field stimuli. However, other patients we have examined have developed similar capacities much more quickly, within 2 years of their surgery.

In order to claim that the right hemisphere is the source of the naming responses we must rule out interhemispheric transfer and cross-cueing as ways in which the right hemisphere might convey information to the left which then speaks (Gazzaniga *et al.*, 1982). Specifically we must exclude the following possibilities: (i) improper lateralization of the stimulus material and (ii) subcortical transfer of cognitive information sufficient for stimulus identification (Gazzaniga *et al.*, 1979; Zaidel, 1990).

The first factor can be eliminated because with one exception all visual stimuli were presented at a minimum of 2° laterally using an image stabilizer. The medial edge of the familiar photographs sat 1° from fixation with the edge of the actual face 2° lateral. With proper calibration, the stabilizer insures that stimuli are presented to a specific location on the retina regardless of eye movements. The tactile naming studies were done with the hand out of view away from the body upon a foam pad to reduce auditory cues.

With respect to subcortical transfer, the results of the S&V object comparison task suggest some sort of interhemispheric interaction. Significant and near significant matching performance was seen for same-stimulus trials as opposed to the different trials in the S&V object and unfamiliar face matching tasks. It is not yet clear if this is a spurious result or if it reflects some kind of transfer, cueing or sub-vocalization strategy that patient J.W. has learnt. Although it has been proposed that callosotomy patients have the ability to transfer abstract information sub-cortically (Cronin-Golomb, 1986; Sergent, 1990), there is substantial data to the contrary (Corballis, 1994; Seymour *et al.*, 1994; Kingstone and Gazzaniga, 1995). Some of what appears to be interhemispheric transfer may be the result of the left hemisphere using effective response strategies when guessing (Seymour *et al.*, 1994). In short, in all previous studies, as well as this study, there is little evidence for transfer of basic sensory information

However, assuming there is some kind of interhemispheric interaction only for nameable stimuli, this would also argue for the presence of right hemisphere speech and suggest that there was either a phonological or articulatory interaction, perhaps through the common speech production system. In other words, if J.W.'s right hemisphere is now capable of deriving a phonological or articulatory signal interpretable by the left hemisphere speech system, this is still a remarkable change in the right hemisphere's language capacity.

Finally, if the results are not spurious, it should be kept in mind that any hypothesized mechanisms elevate the performance only 17% above chance levels and only for nameable stimuli. In contrast, the worst naming performance in the LVF was for familiar photographs with an accuracy of 47% (8 out of 17). The S&V objects were named with an accuracy of 66% (38 out of 58) and the complex objects at 50% (12 out of 24). The tactile naming performance was 46% (22 out of 48), clearly comparable with the visual performance (LVF). One would expect no more than a few stimuli (if any) to be named correctly by chance. Whatever mechanism might be responsible for interhemispheric interactions, the sytem is inefficient and marginal. Taken together, we believe the evidence for a right-hemisphere speech capacity is compelling.

It appears that J.W.'s naming performance became worse as the visual stimuli became more complex. For example, his performance was 68% correct on the S&V line drawings and went down to 50% correct in the complex objects task. Performance on family pictures was only 47% correct. When given stimuli that were substantially more complex (the complex scenes task) than the single objects presented, J.W.'s performance plummeted. A possible explanation for his difficulty in producing complex scene descriptions is that those stimuli could not be characterized properly by a single-word response. Producing a multi-word description may still exceed J.W.'s right hemisphere language capacities as has been shown in other patients (Gazzaniga, 1979).

If this is the case, then the left hemisphere must have produced the lengthy descriptions elicited from the subject in our right hemisphere naming experiments. This implies that J.W.'s responses to LVF stimuli are often the result of a collaboration between his hemispheres (Gazzaniga *et al.*, 1984). The mechanics of such a collaboration could consist of the left hemisphere generating complex descriptions based on one- or two-word 'clues' generated by the right hemisphere. Those clues would be most effective if they were produced before any left hemisphere speech was generated, but the right hemisphere might produce additional words during pauses in left hemisphere speech or in response to inaccurate left hemisphere statements. We can only speculate that the right hemisphere is generating just one- or two-word clues. However, it seems unlikely that a hemisphere incapable of using syntax to comprehend sentences and phrases (Gazzaniga, *et al.*, 1984, Baynes and Gazzaniga, 1988) would emit elaborate vocalizations.

The view that verbal responses to LVF stimuli result from hemispheric collaboration is consistent with earlier observations that the left hemisphere interprets behaviour elicited from the right hemisphere according to the left brain's sphere of knowledge. There is substantial data to support the existence of a left hemisphere interpreter (Gazzaniga *et al.*, 1985; Gazzaniga, 1995; Phelps and Gazzaniga, 1992; Metcalfe *et al.*, 1995). Explicit collaboration between the hemispheres in patient J.W. was produced experimentally by MacKay and MacKay (1979) in a paradigm that did not invoke the interpreter mechanism. Speech generated by the right hemisphere can provide the left with additional clues which the interpreter utilizes.

Overall, J.W.'s present capacity to name left field stimuli is comparable with the naming capacities of certain other patients who have undergone callosal section (Gazzaniga *et al.*, 1979, 1984). In previous cases, however, the development of right hemisphere speech capability occurred much earlier in the postoperative course. It remains unclear what kind of plasticity is reflected by the delayed emergence of right hemisphere speech. It should be noted, in this regard, that the presence of the event-related potential N400 wave has been correlated with the capacity for speech in other callosotomy patients (Kutas *et al.*, 1988). Several years ago, prior to displaying any capacity for right hemisphere speech, J.W.'s right hemisphere did not elicit an N400 event-related potential to semantically incongruent stimuli (Kutas *et al.*, 1988). A recent re-examination has shown that J.W. does now generate N400 responses to such stimuli (G. R. Mangun, M. Proverbeo and M. S. Gazzaniga, personal communication).

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