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The contribution of the right cerebral hemisphere to the recovery from aphasia: a single longitudinal case study

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Abstract

We examined the role of the right cerebral hemisphere in the recovery from aphasia of HJ, a 50-year-old right-handed and unilingual man who suffered from severe aphasia caused by an extensive left hemisphere (LH) lesion. He was followed-up over 10 months at 4-month intervals, with a lateralized lexical decision task (LDT), an attentional task, and a language battery. Testing started when HJ was 2 months poststroke. In the LDT, words were presented to central vision or lateralized to the left or right visual hemifield. At each test period, we examined the effect of the degree of imageability (high vs. low), and the grammatical class (noun vs. verb) of the targets on HJ's response times and error rates, with left visual field, right visual field, and central vision presentations. The results of the experiment showed that the pattern obtained with the LDT could not be accounted for by fluctuations in attention. There was an interaction of grammatical class with degree of imageability with left visual field displays only. The right hemisphere (RH) was faster with high-imageability words than with low-imageability words, regardless of their grammatical class. There was also an overall RH advantage on response times at 2 and 6 months after onset. This RH predominance coincided with a major recovery of language comprehension and the observation of semantic paralexias, while no major change in language expression was observed at that point. Ten months after onset, the pattern of lateralization changed, and response times for the LDT with either presentation site were equivalent. This LH improvement coincided with some recovery of language expression at the single-word level. The results of this study suggest that, in cases of severe aphasia caused by extensive LH lesions, the RH may play an important role in the recovery process. Furthermore, these results show that the contribution of the two cerebral hemispheres to recovery may vary overtime and affect specific aspects of language. © 2002 Elsevier Science (USA). All rights reserved.

Keywords: Aphasia; Recovery; Right hemisphere; Imageability; Grammatical class; Longitudinal

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1. Introduction

Aphasia caused by left hemisphere (LH) damage in right-handed subjects is generally followed by some degree of language recovery. It has proven difficult to identify the mechanisms underlying this recovery. Determining the neural substrate for recovery and its relationship with specific aspects of word processing may provide cues for language intervention. This paper reports on a literature review of the issue and then a study of language recovery in an aphasic patient.

It is generally accepted that the brain may use either of two ways to cope with language impairment following cerebral damage: the recovery of the language-relevant areas in the LH or the reorganization of the language-relevant network by recruiting supplementary brain areas in the LH or right hemisphere (RH). The former hypothesis was first proposed by Wernicke (1874), while the latter was advanced by Broca (1865), who raised the theoretical question of why a patient who became aphemic following a lesion in the left third frontal convolution could not learn to talk with his RH.

More than a century ago, Gowers (1887) provided empirical evidence of the role played by the RH in the recovery from aphasia, when he reported the case of a right-handed subject who became aphasic following an LH lesion, recovered language as time elapsed after his aphasia, and then lost this recovered language following a second lesion in the RH. Accordingly, Gowers proposed that recovery from aphasia could result from RH takeover of language aspects previously committed to the damaged regions of the LH. Since then, much clinical and experimental evidence has indicated that the RH may sustain a recovery from aphasia, particularly in cases of severe left cerebral damage.

Among clinical investigations, a series of studies similar to that of Gowers (1887) have reported cases of aphasic subjects who recovered some language functions and then lost the recovered language following a new lesion in the RH. These findings have consistently been interpreted as evidence for RH takeover following aphasia (Basso, Giardelli, Grassi, & Mairotti, 1989; Cambier, Elghozi, Signoret, & Hennin, 1983; Henschen, 1926; Levine & Mohr, 1979; Moutier, 1908; Nielsen, 1946; Nielsen & Raney, 1939). In spite of the interest of such clinical studies, one should interpret their observations with regard to the RH's role in recovery from aphasia with caution. The pattern described in these studies could very well result from diaschisis (Von Monakow, 1914), a neurophysiological phenomenon that causes a disruption of brain activity in cerebral regions that are distant from the damaged areas. Hence, the deterioration of a previously improved language function after a new RH lesion could result from the effect exerted by the latter upon the homologous regions in the LH, rather than from the destruction of newly acquired RH language functions after left brain damage. Given that the earlier studies reported changes in the aphasic condition in the short term following an RH lesion, the possibility that diaschisis may be responsible for the loss of recovered language cannot be excluded.

In a different type of clinical report, Cummings, Benson, Walsh, and Levine (1977) described the recovery of auditory comprehension and automatic speech in an individual who had become globally aphasic following an embolic infarction in the distribution of the left middle cerebral artery. Computerized tomography (CT) showed the total destruction of the LH language areas. From this, the authors concluded that the RH necessarily sustained the recovered language. As reported by Cummings et al., it is likely that the RH plays an important role in language recovery when aphasia results from the massive destruction of the LH; however, this may not be so when damage to the LH is not extensive. Residual portions of the LH may be responsible for language recovery in such cases.

Congruently, neuroimaging and neurophysiological studies have found that there is an inverse correlation between the size of the LH lesion and the degree of language recovery (Demeurisse, Capon, & Verhas, 1985; Heiss, Kessler, Karbe, Fink, & Pawlik, 1993). This observation supports the claim that the residual portions of the LH are crucial for the recovery from aphasia. For instance, Heiss et al. (1993) used positron emission tomography (PET) to study a group of acute aphasic subjects. They found that the resting metabolism of the LH outside the area of infarct was the single most important predictor of language performance on a word repetition task 4 months after stroke. Demeurisse and Capon (1987) conducted a longitudinal study in which they examined the correlation between clinical recovery and the changes in regional cerebral blood flow which signal cerebral activation. The authors found that the recovery of oral expression was positively correlated with the number of activated LH regions 3 weeks after the stroke. In contrast to the previous studies, however, bilateral participation in the recovery from aphasia was claimed by Weiller et al. (1995), who studied a group of recovering aphasics using PET and functional magnetic resonance imaging (fMRI). Over time, these authors found an increased activation in the left frontal language areas and right perisylvian areas of their subjects, during continuous silent lexical search and silent repetition of verbs. According to the authors, these findings indicate that both cerebral hemispheres contribute to the recovery from aphasia. Notwithstanding the interest of this study, given that the authors used a silent task, it is not possible to ascertain the extent to which the aphasic subjects could accomplish the task, and thus the interpretation of the results should be prudent.

Another experimental paradigm that has been used to examine the performance of the two cerebral hemispheres during the recovery from aphasia involves divided auditory or visual field presentations. Aphasic subjects given lateralized tasks have shown a left-ear advantage on auditory tasks (Castro-Caldas & Silveira Bothelo, 1980; Niccum, 1986), and a left visual field advantage on visual tasks (Schweiger & Zaidel, 1989). The left-side advantage has been taken as evidence of an RH takeover of language processing following aphasia. However, a left-side advantage may also have resulted from a shift of attentional resources to the left hemifield as a consequence of the LH lesion (Kinsbourne, 1970). The above observations therefore do provide definitive evidence of an RH takeover specific to language processing.

In summary, the literature is not unanimous with regard to the role of the RH in the recovery from aphasia. Neurophysiological and neuroimaging studies (Demeurisse & Capon, 1985; Heiss et al., 1993) suggest that it is the preservation of the LH that determines recovery, whereas clinical evidence (Basso et al., 1989; Cambier et al., 1983; Henschen, 1926; Levine & Mohr, 1979; Moutier, 1908; Nielsen, 1946; Nielsen & Raney, 1939) and lateralization studies (Castro-Caldas & Silveira Bothelo, 1980; Niccum, 1986; Schweiger & Zaidel, 1989) suggest that the RH may play a role in the recovery from aphasia.

Evidence from studies of neurologically intact subjects indicates that their RH is sensitive to lexical semantic information. Thus, divided field studies with normal subjects have found that the habitual right visual field advantage–LH superiority (Rvf-LH) attenuates or even disappears with visual presentations of concrete and/or high-imageability words (Day, 1977, 1979; Ellis & Shepherd, 1974; Hines, 1976; Mannhaupt, 1983; Young & Ellis, 1985). More specifically, Day (1979) found no difference between response times to left and right visual field presentations of high-imageability nouns, but found an Rvf-LH advantage with low-imagery nouns and verbs, regardless of their degree of imageability. The author concluded that the RH can process high-imageability nouns, while low-imageability nouns and verbs are exclusively processed by the LH. Other studies, however, have reported no significant effect of these variables (e.g., Boles, 1983; Eviatar, Menn, & Zaidel, 1990; Howell & Bryden, 1987; Koening, Wetzel, & Caramazza, 1992; Lambert & Beaumont, 1983; McMullen & Bryden, 1987).

This lack of consistency between studies may result from such methodological issues as the lack of control over lexical frequency. Hence, Nieto, Santacruz, Hernandez, Camacho-Rosales, and Barroso (1999) found an imageability effect with both nouns and verbs, arguing that Day (1979) failed to find an imageability effect with verbs because he did not control for lexical frequency in the verb category. Furthermore, Nieto et al. claim that Eviatar et al. (1990) failed to find a differential effect of grammatical class or imageability across the Rvf-LH and the left visual field-right hemisphere (Lvf-RH) because the set of verbs they used was actually made up of words that are both nouns and verbs. In summary, the results of lateralization studies with normal populations show that imageability, word class, and word frequency should all be taken into consideration and strictly controlled for when examining the role of the RH in the recovery from aphasia.

The purpose of the present study was to examine this very issue. We examined longitudinally the impact of degree of imageability and grammatical class on the lexical decision performance in HJ, a severely aphasic subject who suffered from a large lesion in the LH. HJ was followed at 4-month intervals for a period of 10 months, using a lateralized lexical decision task, an attentional task, and an aphasia test battery. The results of this experiment are discussed with reference to the RH's role in the recovery from aphasia.

2. Case report

HJ, a 50-year-old right-handed, French-speaking man was admitted in May 1997 for assessment of a right hemiplegia and aphasia. In April 1997, HJ had undergone a coronary bypass, after which he suffered sudden right hemiplegia and aphasia resulting from occlusive CVA. HJ had no history of cerebrovascular disease and no family history of left-handedness. He was French-speaking and had a university degree. A CT scan conducted in May 1997 showed a large infarct in the distribution area of the left middle cerebral artery. The infarct comprised the cortical perisylvian regions of the left frontal, parietal, and temporal lobes, thus including all of Broca's and Wernicke's areas. In June 1997, HJ underwent the Montreal–Toulouse protocol for language assessment (Béland & Lecours, 1990: see description below). Oral comprehension was limited to isolated words (5/9 correct on oral word comprehension), and he could discriminate between written words and nonwords (10/10 correct). There were no paraphasias or neologisms. Speech consisted of monosyllables and was effortful with some articulatory difficulty, but it remained intelligible, though meaningless. Oral word reading was impossible (0/5). HJ showed no clinical signs of hemianopia or visual neglect. HJ received language therapy during the 10 months of follow-up. Therapy was provided by a speech-language pathologist and consisted on tasks aimed at improving communication abilities. Both language comprehension and language expression were stimulated since the beginning of language therapy which coincided with T1, and stimulation of both aspects continued until the end of the experiment and for 2 years after aphasia onset. Given the severity of HJ's aphasia, the main efforts were concentrated on developing alternative functional communication via gestures and communication boards. HJ received four language therapy sessions of 60 min per week. Experimental testing was provided by someone blinded to HJ's involvement in language therapy.

3. Materials and methods

The experimental protocol made use of three tasks:
(a) an aphasia test battery, the Montreal–Toulouse Aphasia Battery (Béland & Lecours, 1990), which served to determine HJ's pattern of aphasia;
(b) a lateralized lexical decision task (LDT), in order to compare HJ's performance on Lvf-RH, Rvf-LH, and central vision presentations of isolated words;
(c) an attentional task, the nonverbal Stroop Test (NVST; Beauchemin, Arguin, & Desmarais, 1996), which served as an assessment of attentional resources.

Repeated measures were obtained on all three tasks at 2, 6, and 10 months postaphasia onset. These repeated measures are labeled T1, T2, and T3, respectively. The order of presentation of the tasks was the same at each test period. In this way possible order effects were controlled throughout the experiment . Each task is described in detail below.

(a) *The Montreal–Toulouse-86 Beta Version of the Montreal–Toulouse Aphasia Battery (*Béland & Lecours, 1990*)*. The MT Battery was devised for the clinical assessment of adult French speakers with language disorders. It includes 22 tasks for the appraisal of linguistic abilities in both encoding and decoding oral and written language. Even though the MT Battery was administered in its complete version, only the results of a subset of tasks are reported here, because they provide information about HJ's language comprehension and oral language expression abilities, which were the focus of this study. These tasks were:

(1) *Oral word comprehension*. On nine trials the subject had to point to the picture corresponding to an auditorily presented word. The examiner presented a card with six drawings on it and asked the subject to point to the picture representing the stimulus word. Stimuli were high-frequency, high-imageability nouns. The drawings on the card depicted the stimulus word and five distractors: a semantic distractor, a phonological distractor, a visual distractor, and two distractors unrelated to the target.

(2) *Oral sentence comprehension*. On 38 trials the subject had to point to the picture representing an auditorily presented sentence. The examiner presented a card with four drawings and asked the subject to point to the picture corresponding to the stimulus sentence. The drawings on the card depicted the stimulus sentence and three distractors. Stimuli were sentences that varied in syntactic complexity and length: there were nonreversible short sentences ($n = 4$) and reversible long sentences ($n = 32$). For nonreversible sentences, distractors depicted semantic alternatives to the target. For reversible sentences, distractors depicted reversible alternatives to the target or sentences in which either the subject had been changed (simple subject vs. complex subject) or the predicate had been changed (direct object vs. indirect object; simple predicate vs. complex predicate). The examiner stopped the task after three consecutive errors.

(3) *Written word comprehension*. Fifteen cards, each with pictures of six objects, were presented to the subject one at a time.[1] The subject was given a card with the name of the target and had to match it with the corresponding picture. Each set of six drawings included the target picture, a semantic distractor, a phonological distractor, a visual distractor, and two distractors unrelated to the target.

(4) *Written sentence comprehension*. On eight trials, the subject had to match a written sentence with the corresponding drawing. The examiner gave the subject a card with a written sentence and a card with four drawings. The subject was asked to

[1] The items used in the written comprehension subtest are different from those used in the oral comprehension subtest.

match the written card with the corresponding picture. Stimuli were written sentences that varied in syntactic complexity and length: nonreversible short sentences ($n = 3$) and complex reversible long sentences ($n = 5$). One of the drawings corresponded to the written sentence and the three others were distractors. For nonreversible sentences, distractors depicted semantic alternatives to the target; for reversible sentences, distractors depicted reversible alternatives to the targets or sentences in which either the subject had been changed (simple subject vs. complex subject) or the predicate had been changed (direct object vs. indirect object; simple predicate vs. complex predicate). The examiner stopped the task after three consecutive errors.

(5) *Oral picture naming*. On 31 trials the subject had to name a picture corresponding to a noun ($n = 25$) or a verb ($n = 6$). The task was stopped after three consecutive errors.

(6) *Written picture naming*. On 31 trials the subject had to write down the name corresponding to a picture. Targets were 25 nouns and 6 verbs.[2] The task was stopped after three consecutive errors.

(7) *Reading aloud*. On 33 trials the subject had to read aloud words ($n = 30$) and sentences ($n = 3$). The task was stopped after three consecutive errors.

(b) *Lexical decision task*. The LDT was run on a Power Macintosh 7300/180 computer. The subject was asked to indicate whether or not a letter string presented by itself on a computer screen corresponded to a word in French.

3.1. Materials and stimuli

Two hundred and forty words and 240 nonwords were selected for use as experimental stimuli. Nonwords were generated by altering one or two letters in a real word and were matched to words on digraph frequency (Mayzner & Tresselt, 1965). Nonwords were pronounceable, and they were formally and phonologically close to French words. Words, which varied in grammatical class, were either nouns ($n = 120$) or verbs ($n = 120$). Within each grammatical category, words were either of high imageability ($n = 60$) or low imageability ($n = 60$). Words and nonwords were matched for length, which varied from five to eight letters. Since the lexical frequency of nouns systematically tends to be higher than that of verbs (Beaudot, 1990), grammatical classes could not be matched for lexical frequency. However, within each grammatical class, low- and high-imageability words were matched pairwise according to lexical frequency (nouns: 270 vs. 295 per million for high and low imageability, respectively; verbs: 64 vs. 67 per million for high and low imageability, respectively). The degree of imageability of nouns was determined according to Hogenraad's norms of imageability (Hogenraad & Oranne, 1981). As no norms of imageability for verbs were available in French, 28 judges were asked to rate 250 verbs on a seven-point scale, using a French translation of the instructions of Paivio, Yuille, and Madigan (1968) for rating nouns, as modified for rating verbs. Mean imageability was 6.69 for highly imageable words and 4.15 for low-imageability words.

The resulting 480 stimuli were divided into five blocks, each containing 48 words (24 nouns and 24 verbs; 12 high-imageability foils and 12 low-imageability foils for each grammatical category), and 48 nonwords. Twenty practice items (10 words and 10 nonwords) were constructed in the same manner and served as a practice block.

[2] The items used in the oral and written naming subtests are the same.

A black dot presented at the center of the display screen served as a fixation point. The stimuli were presented in 24-point, bold, lower-case Geneva; they were oriented horizontally and shown in black on a white background. The target items were either presented in the center of the screen or lateralized to either side of the fixation point. For lateralized presentations, the distance between the fixation point and the closest extremity of the stimulus was 1.5° of visual angle at a viewing distance of 60 cm. In the case of central presentations (Cv), the central letter of the word was aligned with the center of the screen.

3.2. Procedure

The subject was seated in a chair at a distance of 60 cm from the screen. He was asked to respond by pressing with his left index finger on the "yes" or the "no" button, which corresponded to the keys 4 and 6 of the keyboard connected to the computer, to indicate that the target was a word or a nonword, respectively. He was encouraged to do so as quickly and accurately as possible while avoiding errors.

Stimuli were randomly presented either to the left or to the right of the fixation point, which appeared on the center of the screen at the beginning of each trial. HJ was trained to always look at the fixation point. A mirror placed behind the screen allowed the experimenter to monitor eye movements and to control for ocular fixation at the beginning of each trial. If an eye movement was detected while the target was being presented, the trial was rejected on-line by the experimenter and it was repeated at the end of the current block. Each experimental session began with a practice block during which the optimal presentation time for the target stimuli to be used in the experimental trial was determined. The first stimulus from the practice block was presented for 971 ms. The next stimulus would be presented at $971 - 21$ ms if the first answer was correct or $971 + 21$ ms if the first answer was incorrect. Subsequently, the value by which exposure duration was changed for the next trial was halved whenever a correct response followed an error on the previous trial, or vice versa. By the end of the practice block, the optimal presentation time was determined and it was kept constant during the experimental session. The optimal presentation time proved to be 950 ms at T1 and 929 ms at T2 and T3.

(c) *Nonverbal Stroop Test*. The nonverbal Stroop Test (Beauchemin et al., 1996) is a visuospatial version of the Stroop task. The Stroop task examines the interference effect that may be observed when two competing pieces of information are presented simultaneously and only one of them may be used as a basis for response (MacLeod, 1991). In order to give the correct answer, the subject has to attend to a particular aspect of the stimulus and ignore the irrelevant information that it also contains. Given that the conventional Stroop task consists in a color–word interference paradigm, results are largely a function of reading abilities. The nonverbal version of the Stroop task permits the assessment of attentional abilities within a nonverbal paradigm because it uses graphic, nonverbal stimuli and requires a manual response.

3.3. Stimuli and procedure

The NVST was controlled by a Power Macintosh computer. The stimuli were circles (1 cm wide) and arrows pointing to the left or right. They were shown in black on a white background. During two separate training blocks, the subject responded to the location of a circle presented to the left or the right of a central fixation point, or to the direction to which an arrow pointed, where the arrow itself was displayed at the fixation point. Next, in two separate experimental blocks of 64 trials each, the subject performed either the location or the direction tasks on arrows pointing left or right, which were displayed to the left or right of fixation. For each task, we contrasted a condition where the direction of the arrow and its location were incongruent and another condition where both sources of information were congruent. The subject responded with his left hand by pressing on one of two keys that were aligned horizontally, pointing to the left or to the right, respectively. A practice block ($n = 16$) including both congruent and incongruent trials preceded each experimental session.

4. Results

4.1. Montreal–Toulouse Protocol

For each test (T1, T2, and T3), the number of correct responses on each subtest as well as the types of errors committed (i.e., type of paraphasia, type of paralexia) were considered. These results are outlined in Table 1.

There was an improvement in comprehension over time, in both the oral and the written modalities. Specifically, it concerned written word and oral sentence comprehension and was mainly observed between T1 and T2. Oral and written naming were severely impaired at T1, as was reading aloud. HJ showed some improvement in these language tasks over time (see Table 1). At T2, HJ could give semantic alternatives to the target. Hence, he said *light* for *lamp* and *stairs* for *ladder* on the oral naming task. When reading words aloud, the only answers given were semantic paralexias (e.g., *book* for *school*, and *father* for *parents*). At T3, semantic errors persisted, and HJ was able to provide some correct answers, specifically on the naming tasks (see Table 1). Thus, HJ produced 9/31 correct responses on the oral naming task, plus 5/31 semantic paraphasias, and 9/33 correct on the oral reading task plus 8/33 semantic paralexias.

In summary, both language comprehension and language expression improved with time, but comprehension improved more between T1 and T2, whereas language expression started to improve at T3. By the end of the experiment, HJ showed functional oral comprehension abilities. Oral expression remained reduced and limited to single-word utterances and automatic speech.

4.2. Lexical decision task

An overview of the results from the LDT is shown in Table 2. There was a significant reduction in the global error rates (ER) over time ($x^2(2) = 12.24$, $p < .01$). This ER reduction with time was verified with lateralized presentations

Table 1
Correct responses on subtests of the MT Beta Protocol at each time of measurement

	T1	T2	T3
Oral word comprehension	6/9	7/9	9/9
Oral sentence comprehension	6/38	12/38	14/38
Written word comprehension	4/15	8/15	10/15
Written sentence comprehension	1/8	3/8	3/8
Oral picture naming	1/31	3/31	8/31
Written picture naming	0/31	2/31	3/31
Reading words aloud	0/33	3/33	8/33

Note. T1, 2 months postaphasia onset; T2, 6 months postaphasia onset; T3, 10 months postaphasia onset.

Table 2
LDT: correct response times (ms) and error rates (%) with central vision, left visual field and right visual field displays at each time of measurement

		T1	T2	T3
Lvf	Average RT	1243.8	979.8	1097.7
	SD	286.8	196.7	227.4
	ER (%)	31.6	21.3	18.9
Cv	Average RT	1165.6	969.2	1025.4
	SD	277.7	220.5	213.1
	ER (%)	23.3	23.5	20.5
Rvf	Average RT	1334.4	1118	1063.6
	SD	343.8	255.0	239.9
	ER(%)	47.5	40.0	36.4
Global	Average RT	1247.9	1022.3	1062.2
	SD	84.4	83.0	36.1
	ER (%)	35.4	29.5	25.2

(Lvf: $x^2 = 10.74$, $p < .05$, and Rvf: $x^2 = 11.07$, $p < .05$), but not with Cv displays ($x^2 = 3.1$, ns). ER with Rvf displays were much higher than ER with Lvf or Cv presentations at T1 ($x^2(2) = 1.3$, $p < .001$), at T2 ($x^2(2) = 7.5$, $p < .01$), and T3 ($x^2(2) = 10.5$, $p < .01$); in fact, accuracy with Rvf displays was at chance at T1 ($x^2(2) = 12.54$, $p < .1$), but above chance at T2 ($x^2 = 11.08$, $p < .05$) and T3 ($x^2 = 11.05$, $p < .01$). Furthermore, ER decreased significantly over time with nouns ($x^2 = 10.03$, $p < .01$) and with high-imageability verbs ($x^2 = 9.69$, $p < .05$). However, time elapsed after aphasia did not improve accuracy significantly with low-imageability verbs ($x^2 = .5$, $p =$ ns).

Average response times (RT) to correct answers were also gathered. Trials on which the RT was more than two standard deviations away from the mean RT for the condition they belonged to were eliminated from the analysis (4.5% of correct RT at T1, 3% at T2, and 3% at T3). For each time of measurement, correlations between RT and ER were gathered. There was no speed-accuracy tradeoff at any time of measurement (at T1, $x^2 = .845$, $p =$ ns; at T2, $x^2 = .737$, $p =$ ns, and at T3, $x^2 = .600$, $p =$ ns). The resulting sample of correct RT was submitted to a $3 \times 3 \times 2 \times 2$ ANOVA including the factors of Time Postaphasia Onset (T1, T2, and T3), Presentation Site Lvf, Cv, and, Grammatical Class (noun or verb), and Imageability (low or high).

The ANOVA applied on correct RT revealed a triple interaction of grammatical class $\times$ imageability $\times$ presentation site ($F(2, 438) = 3.81$, $p < .05$), as well as a triple interaction of time $\times$ grammatical class $\times$ presentation site ($F(4, 438) = 2.56$, $p < .05$). Moreover, there was a main effect of time elapsed after aphasia on RT ($F(2, 438) = 32.04$, $p < .001$).

The only statistically significant effect obtained with the simple effects analysis of the grammatical class $\times$ imageability $\times$ presentation site interaction was an interaction of grammatical class $\times$ imageability with Lvf displays ($F(1, 438) = 8.23$, $p < .01$; see Fig. 1). Thus, with Lvf displays, the degree of imageability had a clearly significant effect on RT with verbs ($F(1, 438) = 4.50$, $p < .05$), whereas the effect with nouns was marginally significant ($F(1, 438) = 3.78$, $p < -.052$). Hence, when targets were presented in the Lvf, RT with high-imageability verbs and nouns were faster than with low-imageability verbs and nouns, respectively. No other main effect or interaction in the tests performed with respect to the three-way interaction of grammatical class $\times$ imageability $\times$ presentation site reached significance.

Analysis of the simple effects of the time $\times$ grammatical class $\times$ presentation site interaction led to the following results: at T1, the only statistically significant effect was a main effect of presentation site ($F(2, 438) = 5.24$, $p < .01$) (see Fig. 2). A post

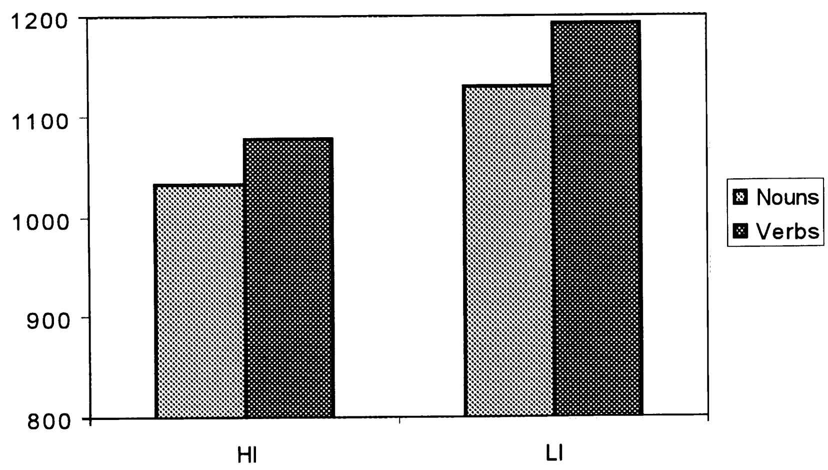

Fig. 1. LDT: imageability × grammatical class interaction with left visual field displays.

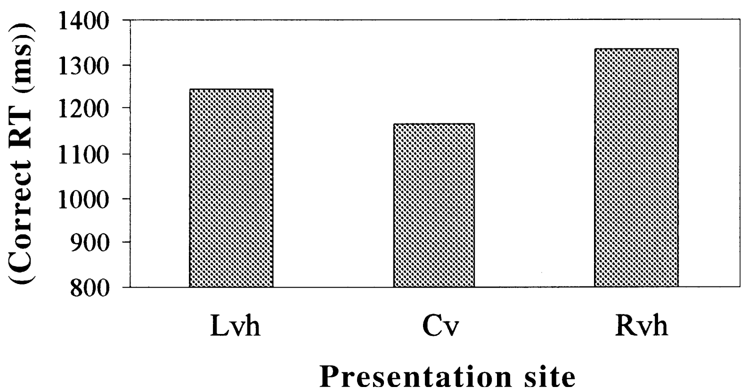

Fig. 2. LDT: presentation site effect at T1.

hoc Tukey (a) Test showed an advantage on Cv over Rvf displays ($p < .01$) and also on Lvf over Rvf displays ($p < .01$), but no difference between the performance on Cv and Lvf presentations.

A similar pattern was observed at T2. Thus, there was an effect of presentation site ($F(2, 438) = 5.73$, $p < .01$; see Fig. 3), and a post hoc Tukey (a) Test showed an advantage on Cv over Rvf displays ($p < .01$), but no difference between performance on Cv and Lvf displays ($p < .01$). As in the previous session, there was also an Lvf advantage over the Rvf ($p < .05$).

In contrast, no effect of presentation site on RT was observed at T3 ($F(2, 438) = 1.38$, ns) (see Table 2). However, there was a grammatical class effect at T3 ($F(1, 438) = 8.27$, $p < .01$), with shorter RT for nouns (1014 ms) than for verbs (1124 ms).

In order to examine the relationship between performance on the LDT with Cv presentations and performance with either cerebral hemisphere over time, Spearman correlation coefficients were used. Thus, average correct RT across grammatical class × imageability factors obtained with Cv displays at T1, T2, and T3 were correlated with the corresponding average correct RT with Rvf and Lvf displays, respectively. None of the correlations reached significance.

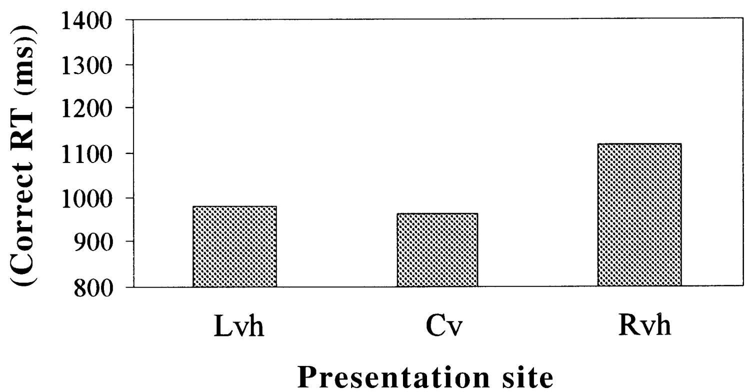

Fig. 3. LDT: presentation site effect at T2.

4.3. Nonverbal Stroop Task

Table 3 presents the results from the NVST. It should be noted that the error rates for the orientation task in the incongruent condition were at chance on every test session whereas they were very low in the congruent condition. This suggests that the patient may have misunderstood the orientation task and tended to respond according to the location of the target instead. Consequently, the results from the orientation task will not be considered any further.

By contrast, performance was very good throughout in the location task and error rates were too low to be analyzed by chi-square.

A 3×2 ANOVA with factors of Time elapsed after aphasia (T1, T2, and T3) and Congruence between the location and orientation information (congruent vs. incongruent) was applied on the correct RT observed in the location task. It showed an interaction of time $\times$ condition ($F(1, 485) = 8.18$, $p < .01$). The congruence between the location and orientation information affected performance at every experimental

Table 3
Nonverbal Stroop Test correct response times (ms), error rates (%), and congruency effect with the location and orientation tasks in the congruent and incongruent conditions at each time of measurement

		T1	T2	T3
Location task				
Congruent	RT	413.2	368.0	398.0
	SD	201.0	113.0	52.4
	ER	0.1	0.0	0.6
Incongruent	RT	611.0	591.0	596.2
	SD	158.7	94.3	70.1
	ER	0.6	0.1	0.2
Orientation task				
Congruent	RT	443.6	368.1	403.2
	SD	201.0	113.0	52.4
	ER	0.1	0.0	0.1
Incongruent	RT	520.6	482.0	492.0
	SD	158.7	94.3	70.1
	ER	49.0	45.0	49.0
Congruency effect	Location	197.7	223.0	198.1
	Orientation	76.9	114.0	88.8

session (at T1, $F(1,357) = 35.38$, $p < .001$; at T2, $F(1,357) = 4.72$, $p < .05$; at T3, $F(1,357) = 8.90$, $p < .01$). Thus, RT with the congruent condition were shorter than with the incongruent condition throughout the experiment. The magnitude of the congruence effect varied across sessions; specifically, it was slightly higher at T2 than at T1 and T3, which did not differ.

4.4. Relationship between the results on the lexical decision and attentional tasks

It has been argued that presentation site effects on language tasks in recovering aphasics may result from attentional factors with no implications for the linguistic abilities of either cerebral hemisphere. Thus, it has been claimed that a left-side advantage for language tasks may result from a shift of attentional resources to the left hemifield, as a consequence of the LH lesion (Kinsbourne, 1970) or simply from the superior attentional abilities of the RH (Seron & Jeannerod, 1994). In the case reported here, the results obtained with the LDT and those with the NVST tend to be closely related, but inversely. Thus, at T2, when RT with the LDT are shortest, the performance on the NVST is the worst (i.e., largest congruency effect). These inverse patterns suggest that performance variations on the LDT cannot be attributed to the recovery of attention.

5. Discussion

The goal of this study was to examine the role of the RH in the recovery from aphasia of HJ, who suffered from a severe aphasic disorder. The results show that HJ's performance on the lateralized LDT was jointly influenced by degree of imageability, presentation site, time elapsed, and grammatical class.

Time elapsed after aphasia contributed to a reduction in the ER with all word types except low-imageability verbs. There was also a reduction in the ER over time for Lvf-RH and Rvf-LH presentations, but the ER was lower for Lvf-RH presentations than for Rvf-LH presentations at all times.

With regard to response times, HJ showed shorter RT with high-imageability nouns and verbs than with low-imageability nouns and verbs, when these were presented to the Lvf-RH, whereas no effect of imageability on Rvf-LH presentations was observed. At T1 and T2, RT to Lvf-RH presentations were as fast as those to Cv displays and shorter than those to Rvf-LH presentations. During the same period, the results on the aphasia battery showed some improvement in oral and written comprehension but no major change in oral expression. At T3, RT to Rvf-LH displays improved considerably relative to T2, and there was no longer any presentation site effect. Concurrently, the results on the aphasia battery showed some improvement in oral expression, particularly oral naming. At T3, there was also a grammatical class effect on the LDT, with faster RT for nouns than for verbs.

With regard to the development of attentional resources over time, the results of the Location Task of the NVST only showed a slight decline at T2 (i.e., increased Stroop effect). Finally, performance on the NVST and LDT was closely but inversely related. Thus, when the NVST resulted in the greatest Stroop effect (i.e., T2), RT with the LDT were shortest. This pattern indicates that the results obtained on the LDT cannot be accounted for by fluctuations in attentional capacities over time. Therefore, the changes in the patient's performance on the LDT through time should be interpreted in terms of changes in linguistic rather than attentional capacities.

5.1. Lexical decision task

We shall first discuss the error data and then move on to a discussion of RT data. Both cerebral hemispheres improved over time, but the RH's superior accuracy was maintained throughout the experiment. From T1 to T3, there was also a reduction in the ER with high- and low-imageability nouns and high-imageability verbs, but not low-imageability verbs. Since this improvement did not differ as a function of presentation site (i.e., no time × site × grammatical × imageability interaction), it appears to be a function of both hemispheres' improving their linguistic capacity.

Regarding RT on the LDT, the RH was faster with high- than with low-imageability targets, regardless of their grammatical class (i.e., noun or verb), whereas no such effect was found for the LH. Nieto et al. (1999) made similar observations in their study with normal subjects. Conversely, Day (1977, 1979) reported that an Lvf × high-imageability effect was present only for nouns. However, while in this study, as in Nieto et al.'s, lexical frequency for high- and low-imageability targets was controlled for within each grammatical category, Day failed to control for lexical frequency across grammatical categories. Hence, Day (1977, 1979) described his stimuli as "fairly common" but did not check for the existence of word frequency differences between the nouns and the verbs. This lack of control for lexical frequency in Day's studies may well account for the lack of any imageability effect with verbs presented to the RH. Finally, if the Nieto results are taken into consideration as a baseline for the normal RH effect with verbs, the RH superiority with high-imageability verbs observed in HJ is likely to reflect his premorbid RH capacities.

The RT with Lvf-RH targets at T1 and T2 (2 and 6 months postonset, respectively) suggest an RH superiority at the beginning of the experiment, which increased at T2. It should be pointed out that, at T1 and T2, there was no difference between RT with RH presentations and RT with Cv presentations. This suggests that, at those test sessions, lexical processing in central vision mainly depended on the RH. In that same period, language comprehension improved while language expression remained severely impaired. The recovery of language comprehension in the subacute state of the recovery from aphasia has been related to RH activity in metabolic (Demeurisse & Capon, 1987; Heiss et al., 1993) and clinical studies (Gainotti, 1993). More specifically, Cappa et al. (1997) found a positive correlation between the recovery of comprehension and the increase in metabolic activity in the RH in a group of aphasics followed up between 2 weeks and 6 months after stroke. Interestingly, HJ showed an Lvf-RH advantage on the LDT and a recovery of comprehension roughly within the same time window as that explored by Cappa et al. (1997).

The fact that our patient showed no improvement in expression tasks within the same period (i.e., T1 and T2) suggests no recovery of the LH. The literature shows that there is a close relation between recovery of the LH and improvement in oral expression tasks (Heiss et al., 1993). Furthermore, the production of semantic paralexias observed at T2 seems congruent with the assumption of RH superiority in lexical processing between 2 and 6 months after aphasia onset. Hence, it is considered that in cases of extensive LH lesions, the production of semantic paralexias during the recovery from aphasia reflects RH reading (Landis & Regard, 1983). Specifically, it is argued that the RH provides a lexical address that is unconstrained by phonology, and thus semantic paralexias are likely to occur (Landis & Regard, 1983). HJ had an extensive LH lesion and presented semantic paralexias, an Lvf-RH advantage on the LDT, and selective improvement on comprehension tasks. This pattern may be interpreted as an indication that the language recovery observed in HJ between 2 and 6 months after onset was sustained by the RH.

Schweiger and Zaidel (1989) described a similar pattern of recovery in the case of RW, an aphasic subject who showed an Lvf-RH advantage in a LDT and semantic paralexias in reading tasks. The authors concluded that RW showed a shift to RH dominance for lexical decisions. However, Schweiger and Zaidel's patient was a bilingual woman. The literature shows that bilingual subjects and women may have less marked LH lateralization for language processing (Hiscock, Israelian, Inch, Jacek, & Hiscock-Kalil, 1995). Therefore, in the case reported by Schweiger and Zaidel, the RH superiority may have been largely a function of an atypical premorbid language lateralization. In the case reported here, the RH dominanceobserved cannot be attributed to the premorbid factors of gender or bilingualism, since HJ is a unilingual male.

At T3, HJ's pattern of lateralization on the LDT changed. There was a reduction in RT with LH displays relative to T2, while RT with RH displays remained stable in the same interval. There was no presentation site effect, given that the difference between RT with lateralized and Cv presentations was no longer significant. Concurrently, an improvement was observed in oral naming at T3, while the scores on comprehension tasks remained stable relative to T2. Although semantic paralexias were still frequent, oral language gained in fluency, specifically at the word level. As discussed in the previous paragraph, an improvement in oral expression has consistently been related to the recovery of LH function during the recovery from aphasia (Demeurisse & Capon, 1987; Gainotti, 1993; Heiss et al., 1993). In line with these findings, the improvement in RT with LH presentations in the LDT, together with the improvement of oral expression observed in HJ, points to a recovery of the LH at T3.

Overall, the results of the LDT indicate a change in the pattern of hemispheric lateralization with time elapsed after aphasia. There was an RH superiority on RT at T1 and T2 and a more equivalent participation of both cerebral hemispheres in lexical processing at T3. Changes in the lateralization pattern during the recovery from aphasia have been reported in activation studies using cortical potentials (Thomas, Altenmüler, Marckmann, Kahrs, & Dichgans, 1997), regional cerebral blood flow (Demeurisse & Capon, 1987; Karbe et al., 1997), and PET (Cappa et al., 1997; Karbe et al., 1998). These studies describe changes in the pattern of lateralization over time which are consistent with the observations of the present study. Thomas et al. (1997) reported that Broca's aphasics subjected to a silent search for synonyms showed an increased activation in the RH at 1 month postaphasia onset, and a shift back to LH lateralization 1 year after aphasia onset. The fact that HJ presented with Broca's aphasia and an initial RH dominance in the LDT is in line with these findings. Moreover, the recovery of the LH observed 10 months after aphasia in HJ (i.e., T3) could indicate the beginning of greater LH participation in HJ's language recovery. Unfortunately, this study was not pursued long enough after HJ's aphasia onset to examine this possibility. Finally, HJ showed faster RTs with nouns than with verbs at T3. These results are in line with previous reports by Micelli, Silveri, Nocentini, and Carramaza (1988), who found that subjects with Broca's aphasia are more impaired in processing verbs than in processing nouns.

6. Conclusion

The results of this experiment show that both cerebral hemispheres participated in HJ's recovery from aphasia. However, the pattern of lateralization with the LDT indicates that the relative contribution of the two cerebral hemispheres varied during the course of recovery. The RH appeared to dominate language processing between

2 and 6 months after aphasia, and this coincided with an improvement in language comprehension, but not in language expression. Furthermore, the RH was particularly sensitive to high-imageability words, regardless of their grammatical class. These results suggest that, in cases of severe aphasia due to extensive LH lesions, high-imageability words may be more likely to recover and thus should be particularly considered when planning language therapy. Ten months after aphasia onset, however, there was a recovery of the LH, but the contribution of the RH did not decline, and both hemispheres were at that point equivalent in terms of speed of response. However, the RH was still more efficient in terms of accuracy. At the same time, language comprehension remained stable by reference to previous test sessions, whereas there was also an improvement in oral expression. The impact of language therapy on the evolution of the lateralization pattern over time is difficult to evaluate. It is interesting to notice that HJ continued to show language recovery throughout the 2 years during which he received therapy and that his communication abilities, particularly with regards to language expression, have continued to improve showing that recovery from aphasia is a long-term process.

To conclude, the present findings suggest that even when both cerebral hemispheres participate in the recovery from aphasia, either one may contribute to the recovery of specific language abilities. The RH seems capable of sustaining the recovery of language comprehension and the processing of high-imageability nouns and verbs. Hence, the recovery of comprehension may start early after stroke and attain a functional level even in cases of severe aphasia following extensive lesions in the main LH language areas. Conversely, severe damage to the LH will seriously compromise the recovery of language expression, which may take longer to begin, since it seems to depend on the recovery of LH function. The process of recovery from severe aphasia is long and thus opens a wide window for language rehabilitation.

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