

Right Hemisphere Semantic Performance and Competence in a Case of Partial Interhemispheric Disconnection

SYLVANE FAURE

Groupe ment de recherche en neuropsychologie (GDR-978 CNRS), Marseille, France

AND

JEANINE BLANC-GARIN

*Groupe ment de recherche en neuropsychologie (GDR-978 CNRS), Marseille, France;
and URA-1166 CNRS "Cognition & Mouvement," Marseille, France*

Various forms of right hemisphere (RH)—spontaneous or provoked—performance changes were observed in a partial split-brain patient. Variations in hemispheric activation levels and their interhemispheric balance were retained as the most plausible mechanisms for accounting for these facts. This article presents our attempts to obtain higher RH lexical semantic performance than that observed in a preliminary study where RH performance was at chance level: two forms of the dual-task paradigm were used in order to improve the expression of an assumed RH potential for lexical semantics. Experiment 1 was aimed at activating the RH with a visuo-spatial task as a prior activity before each semantic decision trial. Experiment 2 was intended to overload LH processing systems with a concurrent verbal memory task and induce RH release from LH inhibition. As expected, better RH lexical semantic performance was obtained in these two conditions. Using pictures as stimuli, the aim of Experiment 3 was to observe the spontaneous temporal course of RH implementation in a semantic decision task devoid of written words. These results are discussed along with the issues of performance/competence and the dynamics of neurocognitive function. © 1994 Academic Press, Inc.

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The neuropsychological approach to higher cognitive functions often assumes, at least implicitly, that neurocognitive functioning is rather stable and mechanistic. Hence, time-dependent changes are disregarded. Hemispheric performance has only recently been considered as prone to develop with practice and to change according to various parameters supposed to influence the attentional set (Mondor & Bryden, 1991) and/or hemispheric activation level (Kinsbourne & Byrd, 1985; Kinsbourne & Bruce, 1987; Kittler, Turkewitz & Goldberg, 1989; Mathieson, Sainsbury & Fitzgerald, 1990; Sullivan & McKeever, 1985; Turkewitz & Ross, 1983; VanStrien & Bouma, 1990).

Similarly, in a previous study (Blanc-Garin, Faure & Sabio, 1993), we observed dramatic changes in right hemisphere (RH) performance in image generation tasks performed by a partial split-brain patient (FDG). The various modifications in FDG's RH performance, mostly improvements that were observed with the sole practice of the tasks and without any experimental parameter alterations, were interpreted as reflecting the implementation of an RH competence not initially mobilized because of the verbal form of the tasks. That is to say that an "activation" hypothesis was retained rather than an interpretation in terms of learning: the learning account was rejected because the pattern of changes was repeated at each session (i.e., sharp improvement occurred within blocks of trials for letters presented in the left visual field, while right visual field performance remained high and quite stable).

In order to investigate such data, one needs a working model of hemispheric function that incorporates the structural implications of Kimura's model (1961) and the activation component of Kinsbourne's dynamic model (1970, 1982), as advocated by more and more authors (see Levy & Trevarthen, 1976; Guiard, 1980; Mondor, & Bryden, 1991). The main theoretical claims of the "dynamic model" can be summarized as follows.

The human brain is a highly interconnected neural network.

Both the nature of the cognitive task itself and the subject's expectations regarding the stimuli and/or the task induce the activation of the corresponding specialized neural systems. This results in an asymmetrical state of hemispheric activation.

This activation is not limited to the specialized area but can spread to other areas in the same hemisphere that are not directly involved.

Furthermore, each cerebral hemisphere can exert facilitating or inhibitory influence upon the contralateral hemisphere through the cerebral commissures. One hypothesis is that the specialized area exerts an inhibitory influence on the homologous contralateral areas which might be competent for carrying out the same process.

Expression of hemispheric differences, according to this schema, is assumed not only to be due to hemispheric ability specialization, but also

to a particular state of inter-hemispheric activation balance, itself linked to various subject-task parameters (type of strategy*type of material*type of processing; see Levy & Trevarthen, 1976, for a review).

Although many studies have concluded that the range of linguistic competence the RH can subtend is limited, these conclusions are subject to debate (e.g. Rastatter, Dell, McGuire, & Loren, 1987). Mondor and Bryden (1991) raised the question of whether dichotic listening investigations in normals lead to overestimations in the frequently observed LH advantage by neglecting the interactions between attentional bias and hemispheric specialization. This suggests that the RH lexical semantic potential may have been underestimated for germane reasons. Indeed, the question of the linguistic performance of the RH, although controversial, has not yet been investigated in a theoretical background like the "hemispheric specific activation model." Experimental tests should therefore be conducted to determine whether previous studies on split-brain or normal subjects did actually tap the upper limits of RH linguistic competence.

RH lexical semantic capacities were explored in our patient, FDG. FDG's RH performance in a preliminary test, using a simple semantic categorization task for words presented tachistoscopically with a divided visual field paradigm, proved to be at chance level; left visual field-RH (lvf-RH) performance did not improve with time and practice and contrasted with good performance of the right visual field-left hemisphere (rvf-LH). Did these preliminary results reflect actual lexical semantic incompetence in FDG's RH? The issue deserved to be addressed since some abilities in the lvf-RH could be expected, for several reasons. First, lexical decision has been shown to be possible in the lvf-RH in this patient and RH performance followed the classical results, that is, better scores for concrete and frequent words than for abstract ones (Touze, Habib, Blanc-Garin, & Poncet, 1990). Second, it is now largely accepted that the RH has access to some lexical semantic information (see Hannequin, Goulet, & Joannette, 1987; Joannette, Goulet, & Hannequin, 1990): although split-brain patients cannot be considered as constituting a "population" (see Sergent, 1990), certain lexical semantic capacities have been observed in some of them (Gazzaniga & Sperry, 1965, 1967; Gazzaniga, 1983; Sidtis & Gazzaniga, 1983). Moreover, a right hemispheric lexical semantic potential has been inferred from the neuropsychological study of normal right-handed adults (Chiarello, 1988). Finally and above all, the puzzling characteristics of FDG's lvf-RH performance quoted above suggest that we cannot take the preliminary findings for granted and that the conditions of RH functioning should be questioned. The present article attempts to determine whether the absence of semantic discrimination reflects an intrinsic limitation in the abilities of FDG's lvf-RH system. Rather, is this lack the result of an asymmetrical arousal reflecting exclu-

sive activation of the LH, which is dominant in the verbal task used (i.e., semantic judgement of written words)? The hypothesis of exclusive LH activation and control was considered for this verbal task: it was assumed that the observed level of performance did not express the full potential of the RH, but rather an activation imbalance. We thus hypothesized that the RH's semantic performance could be improved in conditions of enhanced right hemispheric activation. This was attempted using two forms of the dual-task paradigm. Its general principle, stated by Kinsbourne (1970, 1982), posits that the brain areas are connected to each other and that the activation induced by the processing of a given cognitive task can spread from the specialized systems to other areas in the same hemisphere which are not functionally involved in the task. Various studies with normal subjects have indeed supported the view that a prior task can prime a specific processing system, enhancing the activation level of the whole hemisphere: the main task, carried out soon after the prior task, benefits from this increased activation and improved sensitivity is obtained (Kinsbourne & Byrd, 1985). On the other hand, when the secondary task is difficult enough and concurrent to the main task, specialized processing systems can be overloaded: interference between the two tasks occurs (Kinsbourne & Bruce, 1987), and the other hemisphere, less specialized, can take control. However, these hypothetical mechanisms are not to be taken for granted: for example, even a heavy verbal memory load has been shown to prime LH functioning and improve its performance (VanStrien & Bouma, 1990).

The hemispheric performance of FDG on cognitive tasks was investigated in line with these assumptions concerning some of the dynamics of brain-mind functioning. In order to obtain independent and convergent evidence for the RH underactivation hypothesis in FDG, two distinct experiments were designed to enhance RH activation, using two forms of the dual-task paradigm (Kinsbourne & Byrd, 1985). They were based on the view that dual-task priming can increase hemispheric activation and that dual-task hemispheric overloading can eventually shift control to the other hemisphere. In the first form of the paradigm used here, the objective was to "directly" increase the RH activation level by preceding the standard semantic decision (SD) trial with a visuo-spatial analysis activity, assumed to require RH-system functioning. In the second form, the objective was to more indirectly obtain a higher RH commitment by creating the conditions for RH release from the supposed LH inhibitory influence (because of the verbal form of the SD task): a concurrent verbal memory task was required during the SD trial.

In brief, in the first experiment (Experiment 1), a prior spatial activity was required before the semantic decision trial was presented. In the second experiment (Experiment 2), a concurrent verbal mental activity was required during the SD trial. The hypothesis is that both of these

conditions will induce a state of interhemispheric balance which could be less unfavorable to the RH than when the SD task is performed alone. In these conditions of enhanced RH activation, better RH semantic decision performance than in the other experimental conditions was expected. Finally, in the third experiment (Experiment 3), pictures were used rather than words in order to test semantic decision making without reading.

CASE HISTORY

In April, 1987, FDG, a 49-year-old, previously healthy, right-handed man suffered a CVA (thrombosis of the left internal carotid artery), resulting in a right hemiplegia. Several months later, he was referred for neuropsychological evaluation because of obvious difficulties in his daily activities, experienced as "inner conflict." The right hemiplegia had regressed to moderate motor impairment of the right upper limb. Neuropsychological assessment revealed the following pattern.

Cognitive Function

Acutely, the language deficit which severely impaired the patient's speech comprehension and production was estimated as "severe global aphasia." The aphasic disturbances regressed very fast; indeed, 1 month after their onset, FDG was administered the Boston Diagnostic Aphasia Examination (HDAE-F) and aphasia was rated as "mild global aphasia," slightly impairing both production and comprehension. Five months post-onset, the B.D.A.E. was repeated and nearly all aphasic disturbances had totally regressed, except for slight difficulties in reading. The W.A.I.S. test revealed that FDG's IQ was above the mean (PIQ, 104; VIQ, 112), probably very near his former level.

Callosal Syndrome

Testing disclosed typical features of the callosal syndrome (Sperry, 1968): left-hand agraphia, left tactile dysnomia, left unilateral ideomotor apraxia, right-hand constructional difficulties, and left-ear extinction on dichotic listening. Naming and recognition of tachistoscopically presented pictures or words were similar to those found in classical split-brain studies. Bilateral and divided visual field tasks with object naming and recognition disclosed features of the posterior disconnection: left visual field anomia for pictures of objects, but accurate multiple choice.

Left Hemisphere Brain Damage

An MRI brain scan showed that the cortex was spared and that the lesion was restricted to white matter from the frontal to the occipital

lobe; LH paraventricular lucency damaged the callosal outflow of the entire posterior half of the callosum, and destroyed the splenium (see Fig. 1). Fibers from the anterior half of the body and the genu were totally spared (see Habib, Ceccaldi, & Poncet, 1990, for neuropsychological and anatomical reports).

FDG can be considered as an opportune case for investigating RH lexical semantic competence, for several reasons, the major one being that the partial interhemispheric disconnection had spontaneous lesional origins and occurred in adulthood. So, contrary to the majority of split-brain patients (Gazzaniga, 1984), FDG's RH can be considered free of both pathology and pre-morbid anatomo-functional reorganization. Furthermore, FDG is right-handed and, before the left cerebral vascular accident, had been highly skilled in language-related activities (he read extensively and wrote poems). At the time of the present study, he had recovered from the aphasic disorders and LH cognitive performance in several tasks had become consistently accurate. These characteristics provided the unique opportunity for studying a supposedly "representative" and healthy disconnected RH.

GENERAL METHOD

Main task: Semantic decision. The same main task was used in Experiments 1, 2, and 3. It is a divided visual-field tachistoscopic semantic decision task (SD) in which the patient was to decide whether a stimulus presented briefly in the left or right visual hemifield belonged to the "animal category." The experimenter insisted that FDG respond as quickly and accurately as possible and remain silent during the 32 trial block.

After the display of a central fixation point, stimuli were briefly presented in the left or right visual half-field in random order. The visual stimuli were words from four to seven

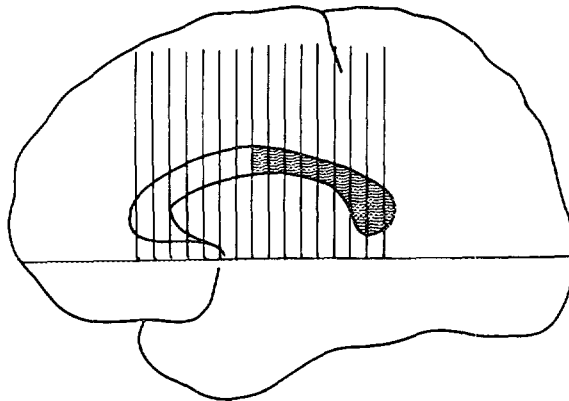


FIG. 1. Diagram of the antero-posterior extent of callosal fibers damaged by the paracallosal lesion (from Habib, Ceccaldi, & Poncet, Syndrome de déconnexion calleuse par infarctus jonctionnel hémisphère gauche, *Revue Neurologique*, 1990, © Masson S. A., Paris).

letters in Experiments 1 and 2, vertically (Experiment 1) or horizontally (Experiment 2) presented, and pictures in Experiment 3. The center of the stimuli was located at 3.4 degrees to the left or right of the fixation point.

No oral responding was required. The patient answered with the left hand¹ by pressing one of two keys (yes/no) and pointing on an 8-point confidence scale. No feedback was given.

Accuracy was measured from "yes" and "no" responses: using hit [H] and false-alarm [FA] rates, a non-parametric measure, $P(A)$, was calculated as proposed by MacNicol (1972) according to the Signal Detection Theory model. $P(A)$ varies between .00 and 1.00, with a score of .50 indicating chance level performance and a score of 1.00 reflecting the highest level of discrimination. In addition, Receiver Operating Characteristics (ROC) curves were plotted from H% and FA%, scored with successive criteria according to the confidence ratings given by the patient (MacNicol, 1972).

Response times of the key pressing (yes/no) were recorded in Experiments 2 and 3.

Apparatus and procedure. FDG was seated in front of a video monitor, with his eyes sixty centimeters from the screen. In Experiment 1, the task was driven by an AppleIIe computer with a special program to monitor stimulus presentation. Experiments 2 and 3 were run on PsychLab.VO 85 (Gum & Bub, 1988) on a MacintoshII computer. Stimuli were presented to the right or left of the fixation point for 150 msec in Experiment 1 and for 100 msec in Experiments 2 and 3. This brief exposure was necessary to be certain that the subject did not deviate his gaze and bring the stimulus into view in the fovea. Stimulation of a single hemisphere was further controlled by the random presentation of stimuli in either field. Finally, FDG was told that centering his gaze was the safest strategy. A control condition was repeated several times during the testing period: FDG proved consistently unable to name aloud the left visual field stimulus words presented in the same condition as in the experimental condition.

EXPERIMENT 1

Three experimental conditions were contrasted, two involving hemisphere-specific activation using a dual-task procedure and one without hemisphere specific activation (i.e., SD alone was required) for base line performance assessment. The spatial condition was intended to increase RH activation and improve RH semantic decision performance.

Spatial Condition

Prior task. Visuo-spatial analysis was required before the patient performed each main SD trial. FDG had to solve a maze (printed on a sheet of paper and presented centrally in free vision) by pointing to the maze exit with the left hand, without talking. Performance of this task is assumed to rely mainly on processing by RH systems: in a pilot experiment,

¹ The response hand variable in FDG was controlled in Blanc-Garin et al. (1993). There was no compatibility effect; the left hand was neither more rapid nor more accurate with lvf stimuli than with rvf stimuli. These data can be explained by the fact that the patient's disconnection is partial and only posterior: inter-hemispheric transfer was possible for simple manual pressing. In the present experiments, given these previous data and the usual spontaneous LH implementation in FDG, the right hand was not used so as to avoid possible LH priming.

FDG's copy of Rey's Figure proved to be better when performed with the left hand than with the right hand. Improvement was also greater with the left hand. Thus, the maze problem was assumed to mainly induce RH activation.

Expectations. We attempted to enhance RH activation by requiring a visuo-spatial analysis trial before each SD trial. This was expected to allow for better RH lexical semantic performance than in the other two conditions.

Verbal Condition

Prior task. Phonologic analysis was required before the patient could perform each SD trial. A rhyme problem had to be solved. A word such as "rose" was printed on a sheet of paper and presented centrally in free vision, and FDG had to say aloud a word "that rhymes" with the stimulus word. This prior verbal processing (rhyming) was assumed to mainly induce LH activation, since the LH has proved to be clearly dominant for verbal expression in FDG.

Expectations. The pattern of hemispheric commitment for the prior verbal task was assumed to be congruent with the main SD task pattern, so performance was not expected to exhibit great changes in either field. If changes did occur, they would consist of lvf-RH deteriorations, since LH activation would increase and perhaps RH underactivation would be magnified.

Base Condition

No prior task. As in preliminary testing, the main SD task was performed alone in order to compare with the other two conditions and check for spontaneous changes. In the Base condition then, each trial involved the presentation of a lateralized word, and responding.

Main Task

Stimulus words were vertically presented for 150 msec, either in the left or right visual field. In the Spatial and Vertical conditions, a SD trial was performed immediately after FDG has responded to a trial of the prior task.

Procedure

Each block of 32 trials was devoted to one of the three experimental conditions which were alternated in a session. The order of presentation was counterbalanced across sessions; there were 10 blocks of trials for each condition, presented in eight sessions spread over a 2-month period.

Results

Rvf-LH semantic decision performance. The three ROC curves, shown in Fig. 2a, are very close to each other and far from the indiscriminatory diagonal (where H rate = FA rate), indicating good semantic discrimination in all three conditions (Base, Spatial, and Verbal). The P(A) scores for these three conditions range from .89 to .91. The apparently superior

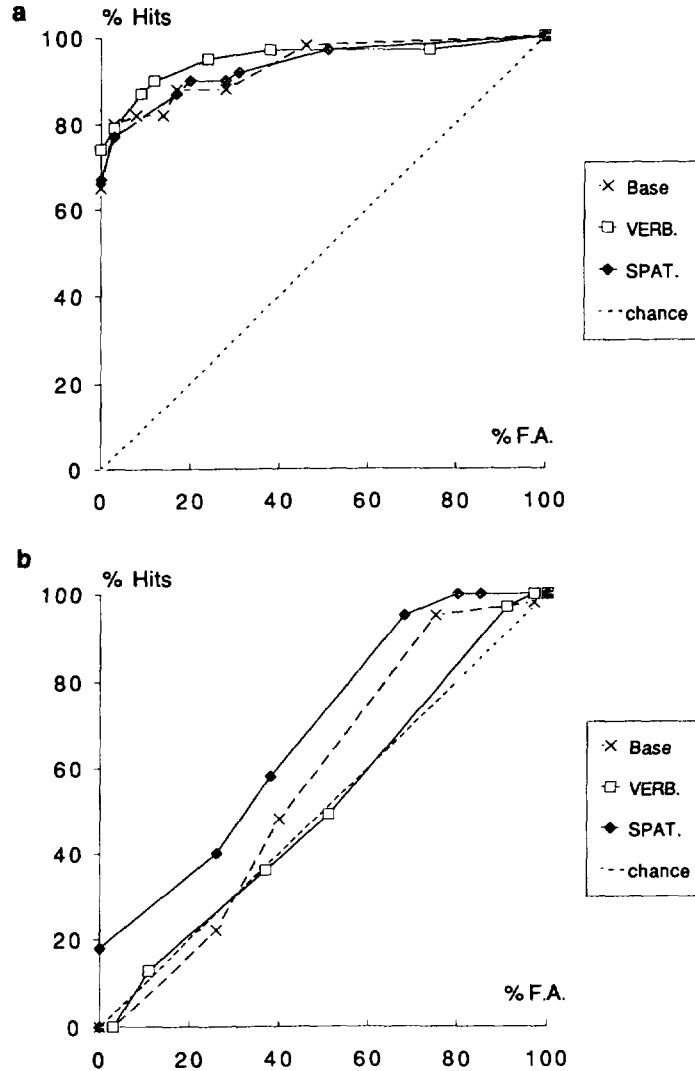


FIG. 2. ROC curves for each visual hemifield [(a) rvf-LH, (b) lvf-RH] and the three experimental conditions of Experiment 1.

performance seen on the Verbal-condition curve is not significantly different from the other two (Sign Test). This is the expected result, to the extent that one can assume that the activation linked to the added prior verbal task is just the same as that linked to the SD task.

Lvf-RH semantic decision performance. In contrast, the three ROC curves that express RH semantic decision accuracy are clearly distinct (see Fig. 2b).

The Base condition curve (without prior task) deviates from the indiscriminability diagonal only for the laxest criterion, where hits include responses with a very low confidence rating (i.e., animal, "not sure at all"). The P(A) score is .58.

The Verbal-condition curve closely follows the indiscriminability diagonal, reflecting chance level performance (for each H-FA pair, the H rate equals the FA rate). PA(A) is .47, which is equal to the indiscriminability level.

The Spatial-condition curve is clearly different and reflects a higher level of SD performance compared to the previous two: this superiority is statistically significant, at $p < .02$ (Sign Test). Performance is low, with a P(A) score of .65, but deviates clearly from the chance level. This condition offers an especially sharp contrast with the Verbal condition, where the performance level is null. The expected superiority of the Spatial condition over the Verbal condition is observed in 67% of the blocks, whereas the opposite pattern—Verbal condition superior to Spatial condition—was never observed. This performance nevertheless remained very inferior to that obtained for the rvf-LH.

Discussion

As hypothesized, above chance level accuracy for lexical semantic decision on words presented in the left visual field appeared only when the SD trials were preceded by a visuo-spatial activity: SD performance of the lvf-RH system was higher in the right hemispheric activation condition (prior visual task) than in the Base condition. Moreover, the left hemispheric activation condition (prior verbal task) was the worst for the RH, giving rise to SD performance at chance level. SD accuracy was high in the rvf-LH in all conditions, expressing prevalence of the FDG's LH for verbal processes.

So some discrimination capacities can be said to be subtended by the RH in FDG. However, lvf-RH performance remains very inferior to rvf-LH performance, in all conditions. These findings support our hypothesis of a facilitating effect of RH selective activation through prior visuo-spatial analysis, and thus corroborate the underactivation hypothesis stated in our interpretation of the preliminary results.

EXPERIMENT 2

RH system release was attempted by imposing a verbal memory load during the semantic decision task. The concurrent memory task was intended to overload the left hemispheric processing systems, and consequently, to induce RH release from an assumed LH inhibitory influence. In addition to the Base condition (without memory load), three experimental conditions were proposed involving the memorization of verbal stimuli (ranging from one letter to four words). Each condition was assumed to involve a different LH memory load. RH performance was expected to improve as a verbal memory load increased. The heaviest load condition for the LH (four words to hold in working memory), resulting in LH overloading, was expected to allow for the release of the inhibitory influence LH systems exert on RH systems.

Verbal Memory Loading Conditions

Before each SD trial, the verbal memory stimulus was presented centrally on the screen. FDG's task was to memorize the stimulus and recall it orally once the SD trial had been completed. The procedure was identical in all dual-task conditions (VM1 to VM3: see below).

Verbal memory load-1 (VM1). A letter (presented for 600 msec) was to be recalled.

Verbal memory load-2 (VM2). A word (600 msec) was to be recalled. The memory material was a set of person's first names, excluding those to which FDG attached an emotional value, either positive or negative.

Verbal memory load-3 (VM3). Four concrete words (inanimate object names) were to be recalled. They were listed vertically and presented for 4 sec.

Base condition (VM \emptyset). Only the main SD task was required, as in Experiment 1.

Main SD Task

For each trial, a word was presented horizontally for 100 msec, either in the left or in the right visual field. In the three VM conditions FDG performed a SD trial immediately after a verbal memory stimulus has been presented. He responded to the SD trial first by pressing a key on the keyboard (yes/no) and pointing to the confidence scale. Then he recalled the items in the memory task.

Dependent Variables

For the main task (lexical semantic decision):

Accuracy: mean P(A) was obtained from H% and FA% (yes/no responses on the keyboard).

ROC accuracy curves were drawn from H% and FA%, scored with successive criteria according to the confidence ratings given by the patient (see MacNicol, 1972).

Confidence level was evaluated for each condition by the percentage of "totally sure" responses (yes and no).

Response times of the key pressing, for yes/no responses.

In addition, the number of correct items recalled was noted for the verbal memory tasks.

Procedure

Each session was devoted to one experimental condition; the order of presentation was VM1 (first session), VM2 (2nd), VMØ (3rd), and VM3 (4th), and the four sessions were spread over a 1-month period. Four blocks of 32 trials were presented per session.

Predictions

Interference between the concurrent verbal memory load and rvf-LH semantic decision processing was expected, while no interference was expected for the lvf-RH SD trials. In contrast, the semantic decision performance level of the lvf-RH was expected to improve as LH loading increase.

Results

Semantic decision: Accuracy. Semantic decision responses to words presented in the rvf-LH were accurate in all four conditions. The P(A) scores were always at their maximum (i.e. 1.00), and responses were given a high confidence rating (see Table 1). This makes the use of ROC curves irrelevant, so they are not shown here.

In the lvf-RH the following were found:

—Base condition [VMØ]: P(A) was .68. The ROC curve indicated low

TABLE 1
Performance for Each Visual Hemifield (Experiment 2)

	Base (VM0)	Letter (VM1)	Word (VM2)	4 words (VM3)
(a) lvf-RH				
Mean RT (msec)	3269	2795	2785	1758
Accuracy: P(A)	.68	.60	.66	.76
"Sure response" rate	25%	48%	42%	60%
(b) rvf-LH				
Mean RT (msec)	919	1184	1162	1061
Accuracy: P(A)	1.00	1.00	1.00	1.00
"Sure response" rate	100%	100%	100%	98%

but above chance level performance (see Fig. 3). This curve looks like the Base condition curve in Experiment 1 (see Fig. 2b), but performance was slightly superior to that obtained several months earlier.

—VM1 (one letter) and VM2 (1 word): P(A)s were .60 and .66, respectively, which is not very different from the score obtained in VM \emptyset . ROC curves were nearly confounded and close to the indiscriminability diagonal.

—VM3 (four words): P(A) was higher (.76) than in the other two conditions. The ROC curve clearly deviated from the chance level. This curve was significantly different from those obtained in the other two conditions (VM1 and VM2) with $p < .01$ (Sign Test).

Response times. The three-way ANOVA (with visual field (2), verbal memory load (4), and blocks (4)) on RTs yielded a significant main effect of visual field ($F(1, 120) = 782.8, p < .001$); a significant main effect of verbal memory load ($F(3, 120) = 30.2, p < .001$); and a significant two-way interaction between visual field and verbal memory load ($F(3, 120) = 37.1, p < .001$). The interaction is shown in Fig. 4 (given the large differences in RT between the two hemifields, a log₁₀ transformation was used to plot the data). No significant effect of block was found, nor any interactions with the other factors.

Simple effect analysis indicated that lvf-RH RTs were significantly slower than the rvf-LH RTs in all conditions of verbal memory load ($p < .001$). Verbal memory load had the expected significant effect on lvf-RH RTs ($p < .001$) with a sharp decrease as verbal memory load in-

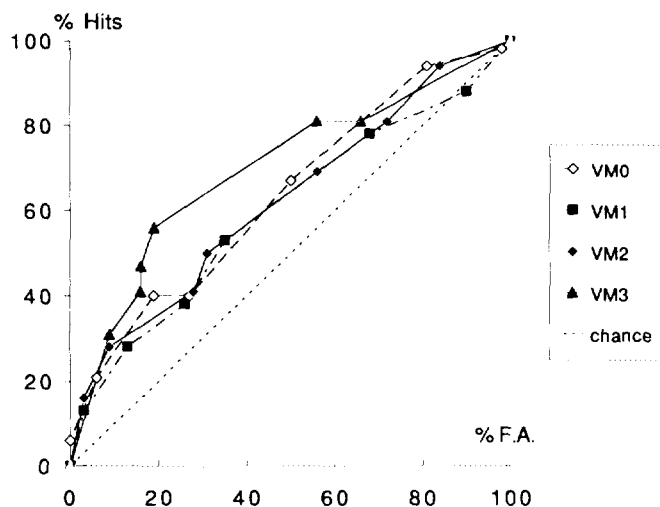


FIG. 3. ROC curves for the lvf-RH performance in the four experimental conditions of Experiment 2.

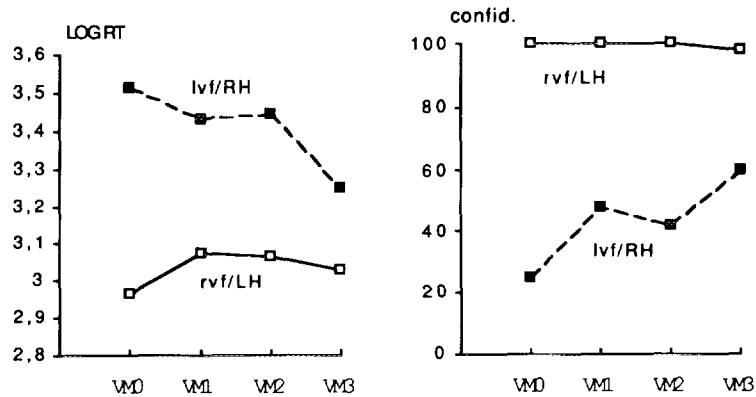


FIG. 4. Semantic decision in Experiment 2 (words) for each visual hemifield. Response times (left graph) and percent of "sure" responses (right graph).

creased. Verbal memory load had a marginal effect on rvf-LH RTs ($p = .068$).

Semantic decision: Confidence ratings. The confidence rating given by FDG to his rvf-LH responses, expressed by the "sure" response rate, was always very high. His confidence ratings for the lvf-RH responses were lower than for the rvf-LH, but increased as a function of verbal memory load. The confidence ratings were higher in condition VM3 (60% "sure" responses) than in the other two conditions (VM1: 48% and VM2: 42%). See Fig. 4.

Semantic decision: Temporal course of performance. The temporal dynamics of performance between successive blocks and between sessions was carefully checked. No sharp improvement or deterioration with time was observed (see Fig. 5). It is nonetheless striking to observe the consistency of lvf-RH performance in condition VM3 (four words) compared to its variability in conditions VM1 and VM2. Was there attentional and/or activation balance lability in these two conditions, and could it be related to the light but existent LH cognitive load?

Memory performance. In the VM1 (one letter load) and VM2 (one word load) conditions, memory performance was nearly perfect. In the VM3 condition (four word load), the proportion of totally successful (i.e. all four words recalled) memory trials concurrent to an rvf-LH SD trial was only 16%; with an lvf-RH SD trial, 27% were successful. This difference was marginally significant (χ^2 near .10). The most frequent score was two words recalled in the former case and four words recalled in the latter case, although the average number of words recalled did not reach significance (Mann-Whitney U test).

In addition to the interaction effect on RTs evidenced by the ANOVA (see Fig. 4), this pattern of mnemonic performance on the added task can

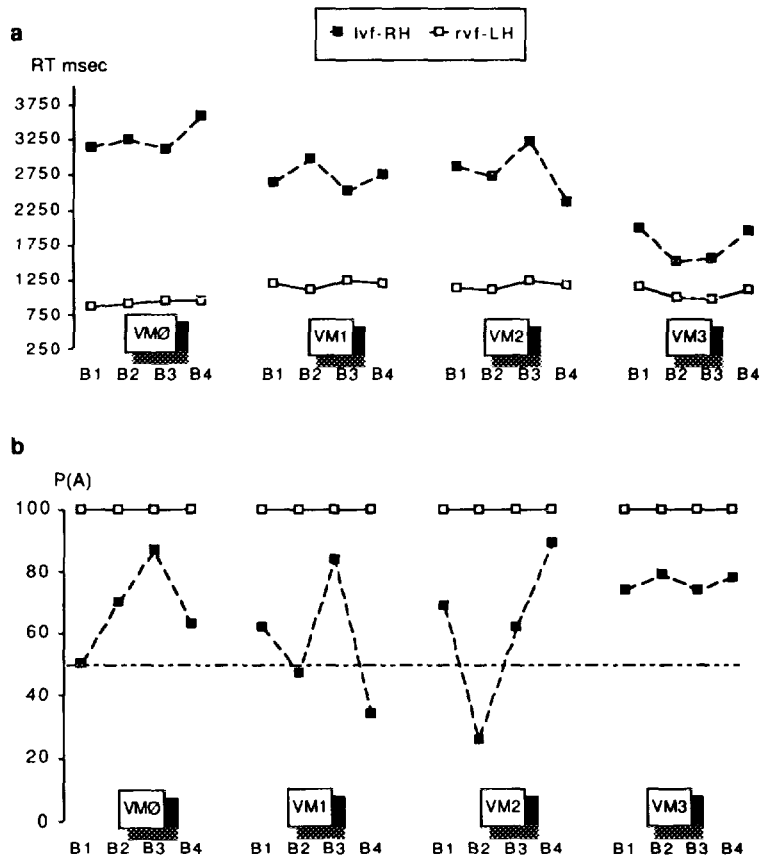


FIG. 5. Semantic decision performance in Experiment 2 for each visual hemifield as a function of successive blocks (B1 to B4) for the four experimental conditions: (a) Response times and (b) accuracy (P(A)).

be interpreted as reflecting actual interference between the VM3 and SD tasks when the LH had both tasks to perform. This pattern provides evidence that this condition is a left hemispheric dual processing condition. When SD stimulation was addressed to the RH, the two tasks could be processed in parallel: the LH performed the memory task, and performed it better.

Discussion

Spontaneous improvement in RH baseline. Taking the results of Experiments 1 and 2 as a whole and considering P(A) measures, we can see that RH performance seemed to improve slightly in the long term. In the Base condition used in preliminary experiments, the RH's SD perfor-

mance was at chance level at first ($P(A) = .50$). Then $P(A)$ increased to .59 in Experiment 1 and to .68 in Experiment 2 (a year later). It can be proposed that both the technical improvements made to the experimental device between Experiments 1 and 2 (a MacintoshII computer was used in Experiment 2 instead of an Apple IIE, with better visual display) and FDG's recovery and practice of the SD task may have contributed to the slightly better baseline performance of the RH between the two experiments.

Facilitation effect in the RH. Semantic decision performance for words presented to the lvf-RH improved when FDG performed a verbal memory task at the same time. However, this result was only clear in the extreme condition where the memory load was the heaviest. This improvement was observed whatever the dependent variable: the effect was expressed through improved accuracy, faster response times and higher confidence in SD responses (see Table 1 and Fig. 4). The clear superiority of RH performance under condition VM3 compared to the other three conditions is the expected pattern of results. Whereas LH accuracy was otherwise always optimum, slight deteriorations in the confidence ratings and response times (see Table 1) of the rvf-LH SD were observed in this condition. Assuming that one cannot invoke an activating-facilitating effect of the conditions of verbal memory load directly on the RH, this is supporting evidence of interference processes in the LH and data which argue for the hypothesized release of an inhibitory influence exerted from the LH on the RH.

Was a gradient of improvement observed in RH performance as a function of verbal-memory task difficulty, as expected? VM2 (one word to be remembered) was expected to have a greater effect than VM1 (one letter). It turns out that both tasks had similar, small effects. One can suppose that the verbal load in those two conditions was light, did not induce overloading of left hemispheric resources, and hence did not allow for the hypothesized release of LH inhibitory control over the RH. The two conditions seem to correspond to a one-item load, the effect of which appears more clearly in RH response times than in accuracy.

Improved semantic decision performance of the RH was obtained when the LH was in charge of a verbal memory task. In agreement with our hypothesis, this was interpreted as the result of the release of RH abilities when the overloaded LH could not exert its inhibitory influence.

EXPERIMENT 3

Experiment 3 was carried out a week after the completion of Experiment 2, in one session. Its aim was to test semantic decision making without reading. Black and white drawings were used as stimuli. They subtended a visual angle of about 3 degrees horizontal and 4 degrees

vertical and were centered 3 degrees from the central fixation point. Stimulus duration was 100 milliseconds, followed by a 50-msec mask (a large X). As in the previous two experiments, responses were given with the left hand by pressing one of two keys (YES, animal; NO, not an animal) and then by rating the confidence level on an 8-point scale. Four blocks of 32 trials were given in the same session. Three indices were considered: accuracy (measured by $P(A)$), confidence rating, and response time.

Results

Accuracy of semantic decision. SD accuracy was almost perfect in the two visual fields, with only one omission in each field out of 128 trials and no false alarms.

Response time. A two-way ANOVA of SD response time showed no significant main visual field effect or block effect. No interactions were found. The only significant simple effect was rvf-LH superiority during the first block of trials ($p = .01$). The decrement in lvf-RH RTs across the 4 blocks failed to reach significance ($p = .14$).

Confidence rating. FDG's confidence in his SD responses, initially weaker with stimuli in the lvf-RH, increased from the second block on, and remained higher than rvf-LH confidence (see Fig. 6).

Temporal course of performance. Although accuracy was maximal throughout the session for both hemifields, performance alterations can be inferred from the other two indices. Figure 6 shows jigsaw rvf-LH curves which are highly contrasted to the regular slope of the lvf-RH curves. The initial rvf-LH advantage was great (in block 1), both for RT and confidence rating. Then a temporary imbalance occurred in block 2, with a small lvf-RH improvement and a sharp deterioration in the rvf-LH

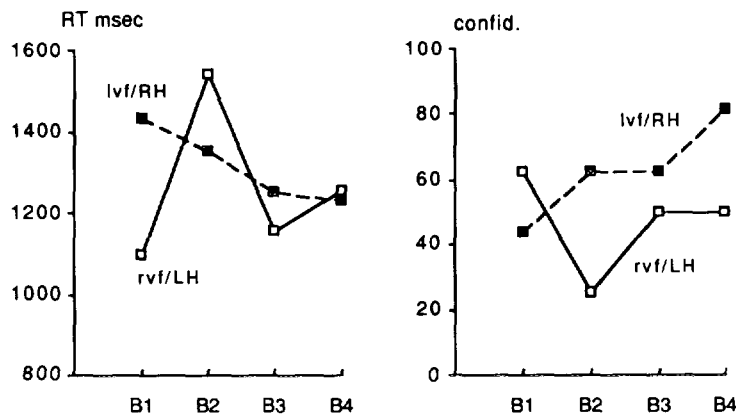


FIG. 6. Semantic decision in Exp. 3 (pictures) for each visual field. Response times (left graph) and percentage of "sure" responses (right graph).

responses on RT and confidence rating. A balance then set in for the two last blocks, with RTs not differing from each other (i.e. for block 4: mean lvf-RH RT = 1229 msec; mean rvf-LH RT = 1254 msec) and a clear lvf-RH advantage for confidence ratings only.

Discussion

In this experiment where no lexical processing was required, RH competence was not initially used at its maximum level, replicating the previous observation of this patient when visual imagery was requested (Blanc-Garin et al., 1993). It is not possible to determine whether this was due to the pathology or whether it was a premorbid "individual characteristic in perceptual asymmetry" (Levy, Heller, Banich, & Burton, 1983; Kim & Levine, 1991), i.e. a stable individual particularity corresponding to a "characteristic arousal asymmetry" (Kim & Levine, 1992; Green, Morris, Epstein, West, & Engler, 1992). However, this individual characteristic proved flexible since RH resources were mobilized at a higher level when FDG became more familiar with the task. Thus, in the same category membership decision as in Experiments 1 and 2, but with pictorial material, lvf-RH performance sometimes equaled that of the rvf-LH.

GENERAL DISCUSSION

The FDG case provides an excellent opportunity for investigating the cognitive capacities of healthy but relatively isolated RH functioning. Although FDG presents all the signs of partial interhemispheric disconnection, affecting the transfer of visual information in particular (see Habib et al., 1990), he is nevertheless an exceptional split-brain case. First of all, there was no previous neurological damage and the RH remained intact after the left lesion that provoked the syndrome. In addition, the damage was recent, had occurred in adulthood (at the age of 49), and was of abrupt onset. These facts allow us to assume that anatomic-functional reorganizations regarding language could not take place, or in any case, would be very limited. Therefore, unlike in most split-brain cases, the RH in this patient is intact and probably rather typical of a normal RH.

However, the "normalness" of FDG's RH must not lead us to excessive generalization. Some of our findings are limited in scope. On the one hand, insofar as only one semantic category was tested in Experiments 1, 2, and 3 (the animal category), the results cannot be generalized to other semantic categories. On the other hand, we cannot infer "the" normal RH lexical semantic ability from findings obtained in FDG: levels of RH abilities are probably highly variable across normals and the mental set and strategies may be used in a variety of ways. Nevertheless, the

temporal course of process implementation may have some relevance to normal functioning, since it reflects attention allocation and regulation, and fundamental mechanisms of interhemispheric activation balance. If FDG's neurocognitive function is more sensitive than normals to balance fluctuations, their pattern can nevertheless teach us something about their laws.

First, lexical semantic processes of which FDG's RH appears capable will be briefly reviewed. Then, two questions concerning the dynamic aspects of these processes and the competence/performance issue will be discussed.

RH Lexical Semantics

In FDG, lexical semantic capacities have been approached through several tasks, including the semantic decision paradigm with word or picture stimuli presented here, and the processing of generated images (Blanc-Garin et al., 1993). In the lexical semantic categorization task (Experiments 1 and 2), these capacities were optimal in the rvf-LH, whereas those subtended by the RH appeared weak. When pictures were used in Experiment 3 to elicit the same decision of category membership as in Experiments 1 and 2, lvf-RH performance equaled that of the rvf-LH. The two tasks involving size decision making from visuo-imaged representations used by Blanc-Garin et al. (1993) called for the extraction of figural semantic features from semantic memory: whether from words or from pictures, the RH appears to have access to this semantic information (the size of the object) and to be able to make the comparative decision. In summary, in FDG, lexical semantic competence subtended by the RH does exist, but his RH performance always remains highly inferior to LH performance (always proficient), reflecting the expected left hemispheric functional specialization. FDG's LH appears better equipped than his RH, and "takes the lead" most of the time. But RH performance turned out to be eminently prone to variations. It emerged from our study that the lexical semantic competence subtended by the RH in FDG cannot be analyzed without considering its conditions of implementation, as postulated in the initial steps of this study in our hypothesis that the patient's right hemispheric capacities are latent and non-actualized.

Among surgical split-brain patients, only 5 of 44 (Sidtis & Gazzaniga, 1983; Hannequin et al., 1987) were considered to access lexical semantic information and process semantic relations from both the LH and the RH (Gazzaniga, 1983, 1984). Reports on image generation and lexical semantics reveal both great variability across patients (Sidtis & Gazzaniga, 1983) and time-dependent changes within individuals (Gazzaniga et al., 1984; Farah, Gazzaniga, Holtzman, & Kosslyn, 1985). Several factors

have been invoked to explain inter-individual variability, including pre-morbid history (lesion site and severity, age, education). Some intra-individual variability, on the other hand, can be considered as random fluctuations, although part of it appears to make sense. The authors stress that the variance of RH performance is much higher than that of the LH. The fact that FDG's competence is expressed to varying degrees depending on experimental characteristics—practice, RH selective activation, LH overloading—illustrates that this variability is not just noise; it can inform us about the particularities of RH functioning, in this case, about RH flexibility.

Performance Changes

It seems conclusive that an improvement in lvf-RH performance was obtained in very different paradigms. FDG's semantic judgment capacities for words presented in the left visual field were elicited in conditions hypothesized to induce a state of inter-hemispheric activation balance which is less unfavorable to the RH. This appears to occur when the semantic decision trial was preceded by a visuo-spatial activity, i.e., according to our working hypothesis, in an RH selective activation condition (Experiment 1). The view that the patient's initial inability to categorize words by meaning does not express a genuine lack of RH competence is also corroborated by the results of Experiment 2. As hypothesized, when the cognitive working load of the LH increased, better RH SD performance was observed. This data obtained in the verbal overloading situation allow us to continue the interpretation of the selective RH activation data of Experiment 1. As a tentative "scenario" it can be proposed that in FDG, a verbal situation induces exclusive LH activation, and the LH takes the lead while the RH remains "inactive". This again suggests that the expression of the lexical semantic potential of the RH in FDG depends, beyond functional dominance, on the state of the cerebral activation balance: when FDG is to read words and to access lexicon on the basis of meaning, balance would be established exclusively in favor of the LH, and the lvf-RH system capacities appear null. When, by means of specific hemispheric activation (visuo-spatial activation, i.e. direct RH priming) or increased functional independence between the two hemispheres (verbal cognitive overloading, i.e., LH indirect release of the RH), the balance is modified in favor of the RH, and the observed lexical semantic performance of the RH is decidedly better than chance. Several types of RH commitment were thus obtained in our experimental series on FDG, with different experimental settings, but we know little about why in a given task, spontaneous implementation occurs while it does not in another task. An interesting hypothesis is that the more abstract the criteria for categorization (i.e., hypothetically, the weaker the RH

competence), the greater the difficulty obtaining spontaneous changes. Further work could be conducted to investigate the idea that the greater the LH proficiency, the more robust the imbalance.

The facilitating effect linked either to selective activation of the RH or to its relative release from LH control constitutes a convincing illustration of the mechanisms Levy and Trevarthen (1976) proposed. These authors state that "in the commissurotomed patient the inactive hemisphere can be maintained in its inactive state either by deficient arousal or by this in combination with actually inhibitory inputs from the brain stem regions" (p. 300).

For split-brain patients, there is experimental evidence of underactivation of the poorly competent hemisphere and activation imbalance (Cf. Levy & Trevarthen, 1977; Levy, 1985), and the corpus callosum is considered as a means for regulating the balance of the arousal levels of the two hemispheres (Lassonde, 1986; Levy & Trevarthen, 1976; Zaidel, 1986). Mayer, Koenig and Panchoaud's (1988) work has revealed sensitivity to external stimulations that modify this imbalance: in the somesthetic modality (form discrimination in a dichaptic situation) these authors obtained an improvement in performance of the left hand when the trial was preceded by fingering of other objects with a memory load.

In normals, for whom this balance is more regulated, fluctuations are certainly less substantial, but they do exist and are reflected by variations in lateral differences for numerous tasks. According to Chiarello (1988), when an rvf-LH advantage is observed for semantic categorization judgments, "this asymmetry only emerges after subjects have had considerable experience with the same semantic categories" (p. 64). Variations have also been observed in object and word naming by Sullivan and McKeever (1985), and in dichotic listening by Mondor and Bryden (1991).

Expression of Competence

Our analysis of FDG's data contributes to our understanding of some passably neglected factors of neurocognitive functioning. The present experiments have enabled us to specify the conditions under which a potential which is not implemented spontaneously might be expressed. Contrary to the data obtained for the letter-image generation task (Blanc-Garin et al., 1993), FDG's RH capacities were not expressed spontaneously here. It is possible to account for the lack of spontaneous improvement by the existence of differing RH competence for letter-image generation on the one hand and semantic decision on the other, a competence that could be weaker in the latter case. For semantic decision on written words (Experiments 1 and 2), the LH in FDG is admittedly superior to the RH, and this preponderancy cannot be challenged spontaneously: the verbal task generates a mental set and left hemispheric control

that cannot be counterbalanced solely with practice. This prevents the expression of RH capacities. Experimentally driven modifications in RH activation were required to observe some, albeit minimal, lexical semantic abilities. Alterations in the state of hemispheric activation and in the inter-hemispheric "balance of power" thus appear as important factors of variation in the lateral differences in perception. An analysis neglecting the dynamic aspects would have led to the underestimation of the "equipment" that the RH proved to have. These factors should be taken into account with other more usual factors such as material and task nature.

In most of the situations in our study, the rvf-LH system exhibited performance that was sharply superior to that of the lvf-RH, and remained quite stable. But the spontaneous and progressive implementation of the lvf-RH system observed in a previous study (Blanc-Garin et al., 1993) and the provoked change in the RH performance pattern obtained in the present data suggest that a performance level at a given moment should not be considered as a "straightforward" measure of the cognitive competence of the cerebral machinery. In FDG defective performance (at chance level) does not signify lack of competence: a cognitive capacity apparently lacking can be brought into play, depending on enhanced hemispheric activation and/or practice. In normal subjects, selective hemispheric activation experiments generally concern the LH, with verbal priming tasks (Kinsbourne & Byrd, 1985). RH activation is rarely attempted, although it has been obtained by Larmande, Elghozi, Bigot, Sintès and Autret (1983) through voluntary gaze eccentrication. Regard, Landis, and Cook (1992) obtained it in epileptic patients. Chiarello (1988) noted the relativity and lability of lateral advantages in semantic categorization tasks and stressed the fact that the LH advantage seems to depend on extensive practice. A working framework that incorporates the specialization of each hemisphere and the interhemispheric balance of activation is necessary for accounting for our results as well as recent data in the literature.

CONCLUSIONS

Are the various changes observed here in the performance of the lvf-RH functional system relevant at a more general level? Although they call for further investigation, these changes strongly suggest extreme cautiousness in the interpretation of performance in terms of neurocognitive "equipment": hemispheric activation mechanisms and their inter-hemispheric balance must also be taken into account in this inference process. Our results also suggest that the study of spontaneous alterations and attempts to modify processing modes may constitute powerful analysis tools for neuropsychology (with fundamental and practical issues). Research into the conditions under which an apparently lacking or im-

paired cognitive capacity can effectively be brought into play is of undeniable interest. One potential contribution could be made by the "activation paradigm" for reconsidering the RH linguistic competence/performance problem, as stressed above. It is quite evident that the data obtained for FDG cannot be considered as a manifestation of normal functioning. It is also certain, however, that activation and inhibition processes constitute very general phenomena, and that the rules they follow in case of callosal disconnection are part of their general laws of functioning. The consistent patterns of change in FDG's RH performance illustrate dynamic aspects of neurocognitive functioning that are often neglected, particularly its flexibility. These characteristics are to be taken into consideration in cognitive neuropsychology; they provide the incentive for the continued analysis of the optimal conditions for RH functioning.

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