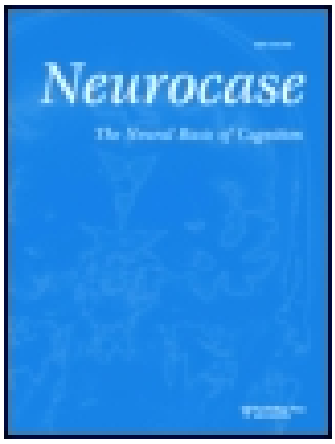

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The Isolation of Numerals at the Semantic Level

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Abstract

In this study, we examine the case of a patient (NM) who could comprehend and produce numerals despite impairment on comprehension tasks and a high degree of anomia for other categories of words. It will be claimed that NM suffered from an impairment to the semantic system affecting all categories except numerals and the series of days and months. The case of a patient presenting with the exact reverse dissociation has been described a few years ago by Cipolotti *et al.* (Brain 1991; 114: 619–37). We conclude that NM's pattern of performance provides evidence that numerals constitute a relevant and perhaps a distinct category at the semantic level.

Introduction

Several authors have proposed a functional architecture of the lexical system in which knowledge of lexical forms is represented in autonomous modality-specific components, separate for input and output processing (see Ellis and Young, 1988; Caramazza and Hillis, 1990). According to this hypothesis, input and output lexicons are connected through a modality-independent semantic component (see Fig. 1). The main evidence for this architecture comes from the observation that brain damage can selectively impair either form of knowledge of words, and that the deficit can be restricted to either word comprehension *or* word production. For example, some patients have been described with a deficit in the access of the phonological form of words for output in the face of spared lexical–semantic processing (Gainotti, 1987; Kay and Ellis, 1987; Caramazza and Hillis, 1990). These patients showed a selective impairment in all the tasks that require spoken word production and only those. On the contrary, it has been shown that a deficit at the semantic level results in impaired performance in *all* lexical tasks (Howard and Orchard-Lisle, 1984; Hillis *et al.*, 1990; Nickels and Howard, 1994).

In addition to this general framework, there is evidence for finer-grained distinctions in the representation of knowledge within the semantic, phonological, and orthographic lexical components. There have been many reports of selective impairment in use of words in the category of living things (plants, animals; Warrington and Shallice, 1984; Hart *et al.*, 1985; Basso *et al.*, 1988; McCarthy and Warrington, 1988; Sartori and Job, 1988; Silveri and Gainotti, 1988; Farah *et al.*, 1989, 1991; Sirigu *et al.*, 1991; Hart and Gordon, 1992; Laiacona *et al.*, 1993; Sheridan and Humphreys, 1993; De Renzi and Lucchelli, 1994; Powell and Davidoff, 1995; Arguin *et al.*, 1996; Cardebat *et al.*, 1996; Damasio *et al.*, 1996; Forde *et al.*, 1997; Caramazza and Shelton, 1998), and the reverse pattern (selective damage of the artefacts category) has also been documented (Warrington and McCarthy, 1983, 1987; Hillis and Caramazza, 1991; Sacchett and Humphreys, 1992; Damasio *et al.*, 1996). These semantic category-specific deficits suggest that the living/non-living dimension represents a fundamental organizing principle of semantic representation. Two different explanations can be proposed for the observed dissociation. One may suggest either that the representation of meanings are processed by discrete brain mechanisms for different semantic categories of words, or that certain semantic properties shared by members of a particular category are processed by separate brain mechanisms or in separate brain regions (Warrington and McCarthy, 1983; Damasio, 1990; Hillis and Caramazza, 1995, p. 396).

Other studies have shown that brain damage can selectively affect specific grammatical categories of words, such as nouns versus verbs (Miceli *et al.*, 1984, 1988; Baxter and Warrington, 1985; McCarthy and Warrington, 1985; Zingeser and Berndt, 1988). Furthermore, such a selective deficit in the processing of a single grammatical category can be restricted to a single modality of output. For instance, patient HW (Caramazza and Hillis, 1991) showed an advantage for nouns over verbs in oral naming but no

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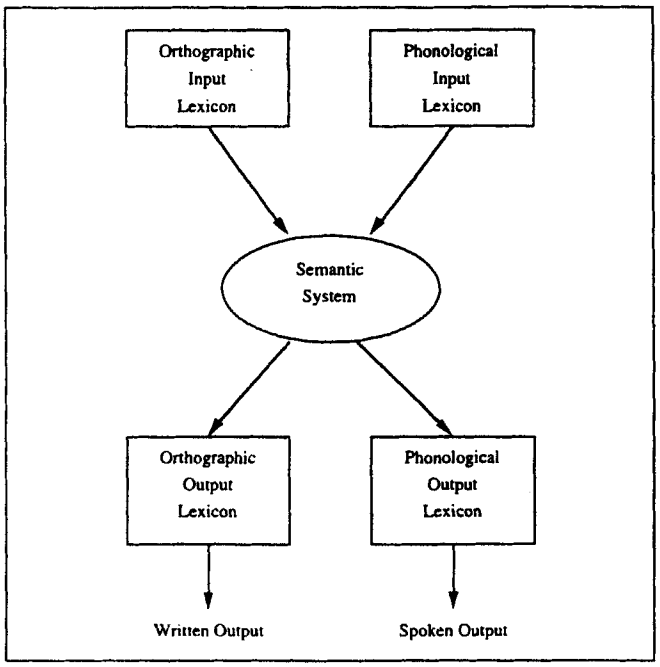

Fig. 1. Organization of lexical knowledge according to Hillis and Caramazza (1990).

such advantage was noticed in written naming. On the other hand, patient EBA (Hillis and Caramazza, 1995) showed the same advantage for nouns in tasks assessing the comprehension of written words although he was flawless for the comprehension of spoken words; at the production level, on the contrary, oral naming showed an advantage for verbs over nouns (the reverse of HW). Thus, there is evidence that knowledge of orthographic and phonological forms is organized by grammatical categorization.

In the same line, one may wonder if patients could be found with a dissociation between the processing of numerals and language processing at large. Goodglass *et al.* (1966) had already noted that the deficit in picture naming found in some patients was in contrast with their preserved ability to read aloud letters and digits. Moreover, preserved counting abilities have been reported in non-fluent aphasic patients (see Barbizet *et al.*, 1967; Deloche and Seron, 1984; Seron *et al.*, 1991; Lum and Ellis, 1994). However, a few studies in neuropsychology have reported data showing the existence of separate subsystems for the processing of numerals and other words at the lexical or at the semantic level (see Seron and Noël, 1992, for review). We have found three exceptions to this statement.

Anderson *et al.* (1990) described a case where the patient suffered from severe alexia and agraphia after a circumscribed surgical lesion in the left premotor cortex (Exner's area). The patient showed preserved oral naming and good comprehension: there was indeed no sign of aphasia. Of particular interest in this case was the finding that the patient could read digits aloud (although she could not read letters nor words), and that she was able to write down digits (although she could not write letters nor words). However, the functional locus of the impairment was difficult to establish in this case.

Secondly, there is a well-documented case of a specific impairment affecting the category of numerals. Cipolotti *et al.* (1991) reported the case of CG, who could neither produce nor understand verbal numerals beyond four. CG was totally unable to read aloud Arabic numerals, to write Arabic numerals to dictation, to discriminate Arabic numerals from meaningless shapes, to discriminate verbal numerals from non-words, to produce orally the numeral that follows or precedes a given auditory numeral, and to judge which of two verbal numerals or which of two dots patterns is the larger. Even counting was impossible beyond 4. As far as non-numerical material was concerned, CG was unable to write, read or recognize even a single letter. Nonetheless, in all other linguistic and non-linguistic tasks CG performed normally. She was able, in 1 min, to produce a normal amount of words from designed semantic categories (fruits, animals, cars), to name pictures from different semantic fields (animals, fruits and vegetables, body parts, musical instruments, vehicles, household objects), to point to the picture corresponding to a spoken name, to define proverbs, to judge whether two words were synonyms; finally, her performance was also flawless in size judgement tasks and size serialization tasks with pictures. The only exception to this pattern occurred in the case of ordered sequences: CG was unable to recite the days of the week, the months of the year, or the alphabet. When she was given an element from the sequence, she was unable to give the following one; and she was unable to serialize a set of three elements from a sequence. In sum, CG was unable to deal with numerals above 4, whatever the task and the modality, although she showed good comprehension of spoken words and a normal performance in a verbal fluency and a naming task probing various semantic categories. On the basis of the consistency of the deficit across tasks, Cipolotti *et al.* concluded that CG suffered from damage to the semantic system, specific to the category of numerals.

Finally, Rossor *et al.* (1995) described a patient with probable Pick's disease, who developed severe non-fluent aphasia following a left temporal atrophy. The patient was impaired in all linguistic tasks (picture naming, word to picture matching, and even repetition) suggesting an impairment at both the semantic and the phonological level. In contrast, he was still able to solve addition, subtraction, and some multiplication problems when he was presented with the items in the Arabic code and was asked to respond in the same code. The authors concluded that the patient was impaired at the level of the semantic system, except for the category of numerals in which he retained some preserved abilities. However, the patient showed some additional impairments with numerals: he was unable to produce or comprehend spoken verbal numerals.

In the present study, we report a case (NM) showing poor performances on comprehension tasks as well as a severe anomia. This patient was able to deal with numerals despite an impairment to the semantic system and a virtually total inability to give a single correct response on tasks such as naming, production of synonyms, verbal fluency, etc. The fact that the patient was able to deal with numerals in various contexts (e.g. naming, verbal fluency, addition, subtraction) leads us to suggest that the semantic representation of these elements has been spared by the deficit. Together with CG, who presented with the reverse dissociation, this case points to the working hypothesis that numerals may constitute a relevant category at the semantic level. Furthermore, in these two patients, the performance with the series of days and months strictly follows the one observed for numerals, suggesting the association of these semantic categories.

Case history

In February 1995, NM, a 60-year-old right-handed male, fell off a horse and was admitted to the hospital in a comatose state (Glasgow Coma Scale 9/20). A GCS score ≤ 8 on admission indicates coma and a severe head injury, while a GCS > 8 is compatible with a less severe head injury which does not produce unequivocal coma. Prior to the trauma, NM was a full professor of law at university with no significant medical history. An X-ray CT scan revealed a cerebral contusion involving the left temporal lobe and the right and left frontal lobes, as well as subdural haematoma in both the left temporal and the right frontal lobe. After 1 month, during which the monitoring of intracranial pressure and the evacuation of a right frontal hygroma took place, NM emerged from his coma and was removed from intensive care. At that time he manifested a motor hyperactivity, a fit of ill humour with opposition behaviour, the refusal to take food and compulsive drinking behaviour. Moreover, he presented with extensive damage to all cognitive functions: a spatio-temporal disorientation, a frontal syndrome with attentional disorder, a severe visual agnosia, a jargonaphasia, a comprehension deficit, a total alexia and agraphia, as well as a complete anosognosia. A control scan revealed a hypodensity at the periphery of the left frontal, temporal, and parietal lobes.

Eight months post-onset, NM was oriented in time and place and the behavioural signs of the trauma had disappeared (except for the motor hyperactivity). At that time, on Raven's Advanced Matrices (PM38), NM scored 35/60, which was significantly lower than expected for his education. On the Wisconsin Card Sorting test (Nelson, 1976), NM was able to classify the cards according to the colour, but not according to the shape or the number. On the Tower of London test (Shallice, 1982, adaptation by F. Coyette and M. Van der Linden, 1993) his performance was accurate whatever the minimum number of movements required to get the correct arrangement. On the D2 test (Hogrefe, 1962), he scored beyond the normal range in quality (> 90th percentile) and in regularity (> 90th percentile). In other words, he virtually never failed to cross a target letter, crossing only the target letters, and showing no sign of fatigue. However, he was very slow in this task (velocity < 10th percentile and efficiency < 10th percentile). NM was also given a test of selective attention. In this task, he had to respond as fast as possible to a white square appearing on the horizontal axis of the screen of a LCII (Macintosh) computer, either at the right or at the left. The white square was preceded by a red arrow indicating accurately in 80% of the cases the side where the square was supposed to appear. NM's response time was within the normal range whether the cues were valid (742 ms; $\mu = 664$, $SD = 163$) or not (844 ms; $\mu = 724$, $SD = 159$) and whether the squares appeared at the right (771 ms; $\mu = 670$, $SD = 163$) or at the left (742 ms; $\mu = 669$, $SD = 165$). NM's working memory was evaluated by the forward digit span test, the Corsi block-taping procedure (Milner, 1971), and a computerized version of the Brown–Peterson task. His digit span was 6 (control 6–7); his Corsi block span was 6 (control 5–6); and he was within the normal range on the Brown–Peterson task, since he was able to recall 100% of the consonants in the immediate recall condition ($\mu = 98.9$, $SD = 3.5$), 94% when he had to invert pairs of digits during a 5 s delay ($\mu = 86.7$, $SD = 17.4$), 89% with the same interference during a 10 s delay ($\mu = 73.9$, $SD = 19.6$), and 72% with a 20 s delay ($\mu = 66.7$, $SD = 19.1$). NM's perceptual skills were investigated using the BORB (Riddoch and Humphreys, 1993). He scored 23/25 on the minimal feature view task ($\mu = 23.3$, $SD = 2.0$) and 25/25 on the foreshortened view task ($\mu = 21.6$, $SD = 2.6$). He was thus able to match pictures of objects from usual and unusual views almost perfectly. He made 108/128 correct judgements on the object/non-object decision task, which is in the lower normal range ($\mu = 114.7$, $SD = 5.7$). Finally, on the item match task for which he was required to match pictures on the basis of functional information, he scored 31/32 correct ($\mu = 30$, $SD = 2.2$).

As far as language processing was concerned, the neuropsychological evaluation revealed a severe anomic aphasia. NM's spontaneous speech was fluent, with no obvious articulatory problem or phonemic paraphasia. However, NM's productions were non-informative and composed of a few very frequent and polysemous verbs and nouns. For instance, he was asked to describe two sets of five pictures from the WAIS, each one representing a short story. One story was about an angler who catches a fish and cooks it; NM's description was as follows:

- /il roule, il a pris çà pour rouler/
  [he drives-rolls-, he got that to drive-roll-]
- /alors là, il s'assied et il met dans l'eau
  [so there he sits and he puts in the water]
- /et ici il tourne/
  [and here he turns]

- /et ici il a un chose/
  [and here he has one thing]
- /et ici il met dans l'eau pour manger/
  [and here he puts in the water to eat]

However, when we presented NM with a mixed set of about eight words which formed a sentence describing one of the pictures, he proved able to arrange the words in order to get a correct sentence (e.g. 'Il attend qu'un poisson morde l'hameçon' [he is waiting for a fish to bite the bait]). As another example of NM's spontaneous speech, the experimenter asked him what he did the day before and he responded:

/Hier, j'ai été travailler ici, j'ai lu, j'ai joué avec les petits enfants, les enfants de chez nous ... on a été ... on a marché ... (expérimentateur: "ils sont venus?") deux sont venus, parce qu'ils vont à l'école, alors on a été dire bonjour et caetera ... (exp: "et puis après, vous êtes revenus ici avec les enfants de l'école?") puis il y a un enfant qui est resté ici, qui a dormi ici, qui est parti ce soir, ce matin, à l'école, et l'autre était rentré./

[Yesterday, I went to work here, I read, I played with the little children, children from our place ... we were ... we walked ... (experimenter: 'did they come?') two came, because they go to school, so we went to say hello et cetera ... (exp: 'and then, you came back here with the children from school?') then there is a child who stayed here, who slept here, who went tonight, this morning, to school and the other one was back home]

NM's performance was evaluated on a picture naming task (Bachy-Langedock, 1988) using 90 black and white line drawings. The items were controlled for length (one, two or three syllables) and frequency [according to Vikis-Freibergs' (1974) count: high frequency $\geq 20/125\,000$; medium frequency $\in$ (2/125 000; 10/125 000) and low frequency = 0/125 000]. NM was unable to name a single picture (0/90). This performance did not improve over the testing period and NM was still 0/90 with the same items 1 year later; it was the most striking deficit that the clinician had ever observed. In order to check whether or not NM had implicit access to some information about the words he was not able to produce, he was presented with a sub-set of the pictures, and he was asked, with a two-alternative forced choice procedure, to evaluate the word length, to guess the first letter of the word, and to say if it was a masculine or feminine French word. NM scored above chance for the three questions [37/60, 39/60, and 45/60 respectively, with $P(X > 36) = 0.0465$]. He was thus able to provide some phonological and grammatical information about the words he could not retrieve in picture naming. Despite his severe anomia, NM was able to recite the days of the week and the months of the year; moreover, he was able to count orally without any difficulty at all. NM was tested on an auditory lexical decision task to assess the integrity of the spoken-word recognition process. In this task, he was presented with a mixed set of 220 words and 220 pseudowords, and was asked to state (under no time constraints) whether or not each stimulus was a French word. The list included nouns and verbs, counterbalanced for word frequency and concreteness. The pseudowords were created by changing one phoneme in words matched for grammatical class, frequency, and concreteness, to the target words in the list. NM correctly accepted 213/216 words ($\mu = 213$, SD = 2.11), and correctly rejected 210/216 pseudowords ($\mu = 213.6$, SD = 2.2). At the comprehension level, NM had recovered somewhat, although not completely, and his performances remained imperfect on tasks that control subjects of the same educational level performed without error. For instance, on a French version of the LUVS (Bishop and Byng, 1984), he scored 35/40 (87.5%). On another occasion, NM was presented with a French version of the 'Pyramids and Palm Trees' test (Howard and Patterson, 1992) in which a written word (e.g. pyramid) has to be matched to one of two pictures that are co-ordinates (e.g. a pine tree and a palm tree). In addition, in order to examine semantic processing without the use of pictures, NM was given another version of the same task in which the stimulus word had to be matched to one of two written words (instead of pictures). His performance was very similar in the two versions of the test: 40/52 and 41/52 respectively. NM's repetition was flawless for letters (8/8), syllables (15/15), words (18/18) and pseudowords (6/6). Interestingly, his reading of words was relatively preserved. On one occasion, he was presented with a list composed of 42 regular words, 12 irregular words and 26 ambiguous words; he read correctly 41/42 regular words (98%), 11/12 irregular words (92%) and 25/26 ambiguous words (96%). On another occasion, he was presented with a list composed of 40 irregular words and 40 pseudowords mixed in random order. He read 35/40 irregular words correctly (87.5%) and 34/40 non-words (85%). The few errors NM made in reading irregular words were regularization errors such as SAOÛL [drunk] read /saul/ instead of /su/ or POULS [pulse] read /pul/ instead of /pu/ (5/6 errors).

NM's performance on processing numerals and words from other semantic categories have been extensively studied between May 1996 and May 1997. Testing was performed at home in 1 h sessions. Normal subjects of the same age and social level named without error all the pictures that were used in the testing.

Experimental investigation

In the first section, evidence was provided that NM was impaired on comprehension tasks for several categories of words and that the measured degree of impairment increased with the increasing complexity of the tasks. Moreover, it was shown that NM was drastically impaired on tasks requiring the oral production of words. Secondly, a dissociation was identified between the production of

numerals and that of words belonging to several other semantic categories, and matched with verbal numerals for frequency. This dissociation was evidenced in oral production as well as in written production. Thirdly, we study NM's performance with numerals and other semantic categories on various tasks such as verbal fluency, verbal association, recitation, etc. We discuss the influence of the size of the semantic category upon NM's performance on tasks requiring the oral production. Fourth, in order to complete the evaluation of NM's ability to deal with numerical information, we report his performance on tasks specific to the numerical domain.

Comprehension and production of spoken words

Two sets of tasks were administered to the patient in order to explore the comprehension and production of spoken words. The results showed that he suffered from a deficit at the semantic level. In particular, it seemed that NM did not activate a complete semantic representation. The strength of the impairment in production tasks must be outlined since it seemed disproportionate compared to the underlying semantic impairment.

Comprehension versus production: set 1

The first set of tasks allowed us to compare NM's performance on picture naming and on several comprehension tasks with the same set of 96 black and white pictures (72 target pictures and 24 fillers). These items belonged to one of four semantic categories (animals, plants, objects, transports), and the items from various categories were matched for word frequency according to Vikis-Freibergs' (1974) count. The 72 target pictures were presented to a group of 15 normal subjects who were asked to rate on a five-point scale how familiar the concept depicted in the picture was to them and to evaluate the visual complexity of the picture. The mean concept familiarity did not differ between living and non-living things [2.65 and 2.96 respectively; $t(70) = 1.26$, $P > 0.2$]. The mean visual complexity of the pictures did not differ between living and non-living things [2.86 and 2.93 respectively; $t(70) = 0.32$, $P > 0.7$]. Seven comprehension tasks were presented to the patient: four classification tasks, a size judgement task, a word/picture matching task and a word/picture verification task. During several sessions, the seven tasks were presented in blocks, using different subsets of the items. The order of the tasks was systematically varied and the same set of items was not tested consecutively in two different tasks.

During one of the classification tasks, NM had in front of him four words, written on separate cards and labelling the four semantic categories: animals, plants, objects, and transport. He was presented with the 96 pictures, and had to classify each of them into one of the four semantic categories (we report only the scores for the 72 target pictures). On this task, as well as on the following comprehension tasks, normal subjects of the same age and social level are supposed to be flawless, since they were perfectly able to name all the pictures. NM made one error on this picture classification task (99% correct). On the same task when he was presented with spoken words instead of pictures, he made two errors (97% correct).

Table 1. NM's performance on four classification tasks

Picture classification (broad semantic categories)	
Correct reponses	71/72 (99%)
animal	18/18
plant	18/18
object	18/18
transport	17/18
Word classification (broad semantic categories)	
Correct reponses	70/72 (97%)
animal	17/18
plant	18/18
object	17/18
transport	18/18
Picture classification (semantic sub-categories)	
Correct reponses	65/72 (90%)
animal	16/18
plant	13/18
object	18/18
transport	18/18
Word classification (semantic sub-categories)	
Correct responses	63/72 (87%)
animal	12/18
plant	15/18
object	18/18
transport	18/18

NM also underwent another two classification tasks with the same set of pictures or words. He was presented separately with each category and was asked to state, for each animal, whether it could be found in Belgium or was supposed to live in a foreign country; for each plant, whether it was a fruit or a vegetable; for each object, whether it was a tool or a household object that could be found in an office; for each transport, whether it was a road (or rail), sea or air transport. On this task, which requires retrieval of relatively precise semantic information, NM made seven errors with pictures (90% correct) and nine errors with words (87.5%). The difference between the performance with pictures and words was not reliable. All the errors occurred in the categories of animals and plants, with no error in the categories of objects and transport.

Thus, NM already made some errors when he was asked to classify the items according to broad semantic categories, and when he had to retrieve more precise semantic information in order to respond, the error rate increased. The increase in error rate, when the access to more precise semantic information was required, was of $\sim$10% for word as well as for picture classification (see Table 1). This suggests that the errors were due to a deficit to a central semantic component.

We also presented NM with a size judgement task on words. For this task, 32 pairs of words have been selected from the list of 96 items, each member of a pair belonging

Table 2. NM's performance on three other comprehension tasks

Size judgement on words	
Correct responses	32/36 (89%)
Error example:	kiwi < fraise [kiwi < strawberry]
Word/picture matching	
Correct responses	60/72 (83%)
animal	14/18
plant	13/18
object	16/18
transport	17/18
Errors:	
8 choices of the close associate	
e.g. 'cerf'—*cerf, biche, castor, raton-laveur*	
['stag'–stag, hind, beaver, racoon]	
4 choices of the weak associate	
e.g. 'tomate'—*tomate, carotte, noix, cacahuètes*	
['tomato'—tomato, carrot, walnut, peanut]	
Word/picture verification	
Correct responses	39/72 (54%) with three correct verifications
animal	9/18
plant	8/18
object	11/18
transport	11/18
Correct picture correctly accepted	63/72 (87.5%)
Close associate correctly rejected	48/72 (67%)
Weak associate correctly rejected	69/72 (96%)
Errors:	
9 rejections of a correct picture	e.g. 'phoque'/*phoque* ['seal'/*seal* (No)]
24 acceptations of a close associate	e.g. 'crayon'/*stylo* ['pencil'/*pen* (Yes)]
3 acceptations of a weak associate	e.g. 'biche'/*koala* ['hind'/*koala* (Yes)]

to the same semantic category (e.g. aubergine—mushroom). NM was presented with each pair of words both orally and visually, and he was asked to point to the word corresponding to the largest item in real size. NM made 32/36 (89%) correct judgements in this task. This performance is similar to the one on the most difficult classification task.

For the word/picture matching task, NM was orally presented with the 72 words (and 24 fillers) and had to choose the picture corresponding to each word among four pictures. The three foils were extracted from the set of 96 pictures and included a close semantic associate and two weak semantic associates of the stimulus word. The close semantic associate was selected in such a way that it had a lot of visual, functional, and semantic features in common with the target word (e.g. 'lion'—*leopard*); on the contrary, the two weak semantic associates shared only a few features with the target word, but they were strongly associated with each other (e.g. 'lion'—*dolphin, seal*). (Throughout this report, a word in *italics* designates a picture stimulus, a word (or a sentence) in quotes designates a spoken stimulus, a word between slashes designates a spoken response, and a word in CAPITAL letters designates a written stimulus or response.) NM correctly matched 60/72 (83%) words with their corresponding picture. Among the 12 errors, he chose the close semantic associate eight times and one of the weak associates four times. Table 2 shows the results on this matching task according to the various categories of words. Most errors occurred in the category of living things (nine errors, against three for the non-living things). However, the low error rate does not allow us to conclude that there was a better comprehension of non-living as compared to living things.

Finally, NM's spoken word comprehension was further assessed with a word/picture verification task using the same set of stimuli. In this task, the 96 words were presented three times on separate occasions, once with the correct picture, once with a close associate, and once with a weak associate of the target picture. The close and weak associates were selected among the set of 96 pictures using the same criterion as for the word/picture matching task. In each session one-third of the words were presented in random order with each of the foil types. NM had to verify or reject the correspondence between the picture and a spoken word. An item was scored as correct if, in response to the word, he accepted the correct picture and correctly rejected both the close and weak associate as referents of the word across the three trials. NM made a lot of errors in this task (see Table 2). He responded correctly to 39/72 stimuli on the three occasions. In fact, he accepted 63/72 of the correct pictures (87.5%), but he only correctly rejected 48/72 closely related pictures (67%), while he correctly rejected 69/72 weakly related pictures (96%).

NM's performance was clearly worse on the word/picture matching and the word/picture verification tasks than in the classification tasks with the same items. In the matching and the verification tasks, the patient was indeed confronted with a semantically related foil, and he showed particular difficulties in discarding this kind of distractor. Exactly two-thirds of the errors made by NM on these

Table 3. NM's performances on naming tasks

Picture naming	
Correct responses	0/72 (0%)
Errors:	
Omission (no response)	1/72
Circumlocutions	71/72
e.g. *tournevis* [*screwdriver*]	/çà c'est pour travailler, avec une chose ici derrière (montre le manche), et avec çà (montre la tête) on travaille/ [/this is to work, with one thing here at the back (shows the handle), and with that (shows the head) one works/]
e.g. *voiture* [*car*]	/rouler, j'aimerais bien avoir çà, je ne l'ai pas pour le moment et on peut mettre une personne ici (montre le siège du passager)/ [/to drive, I would like to have that, I don't have it for the time being, and one can put someone here (shows the front seat)/]
e.g. *clé* [*key*]	/pour travailler avec un chose pour fermer/ [/to work, with one thing to close/]
e.g. *tomate* [*tomato*]	/c'est pour manger, c'est fermé, c'est pas noir, c'est pas bleu/ [/it is to eat, it is closed, it is not black, it is not blue/]
e.g. *éléphant* [*elephant*]	/ici deux comme çà (montre les oreilles), et il roule, il marche, il est grand, il a son sac ici comme çà (montre la trompe)/ [/here, two like that (shows the ears), he drives, he walks, he is tall, he has is bag here, like that (shows the trunk)/]
e.g. *cheval* [*horse*]	/çà j'aime bien/ [/I like that/]
Naming from a definition	
Correct responses	0/16 (0%)

two tasks were due to the incorrect acceptance of the semantically related distractors.

In a subsequent session, NM was required to name the 72 target pictures. He did not give a single correct response (0/72). Among the 72 errors, there was one omission to respond and 71 circumlocutions which consisted mainly in descriptions (see examples on Table 3). These descriptions were of various length (ranging from 4 to 29 words). NM's output was fluent, with no syntactical error (no error in tense agreement, use of correct prepositions, etc.), and no phonemic paraphasia. However, the descriptions were made using a few very frequent verbs and nouns bearing no specific semantic content (e.g. /quelqu'un/ [/someone/]; /dehors/ [/outside/]; /travailler/ [/to work/]). Moreover, NM sometimes made a gesture or pointed to a part of the picture he was describing, in order to replace a word in the sentence that he was producing. Thirty-three out of 71 circumlocutions could be viewed as descriptions of a functional property of the item, most of which (23/33) occurred with non-living things. Twenty-three out of 71 circumlocutions were descriptions of some visual properties of the item, most of which (19/23) occurred with living things. Finally, 13/71 circumlocutions referred to both functional and visual properties of the item. This anecdotal observation is in line with the assumption that, at a semantic level, animals are distinguished on the basis of their visual properties, while objects are firstly defined in terms of their functional properties.

To confirm that the naming deficit was not the consequence of a difficulty to deal with pictures, we asked NM to name 16 words from a definition. All items were selected among the list of 72 living and non-living things, four items in each category. The items were matched for frequency, familiarity and visual complexity across the four categories. The definitions corresponded to verbal descriptions providing information about the category membership of the target, its physical appearance and its functional properties, as well as some encyclopaedic information (e.g. for kangaroo: 'it is a big animal with four legs, his coat is usually reddish-brown, it has hind-legs more developed than the forelegs, and the females have a pouch on their stomach in which their babies grow, it lives in Australia and moves forward by jumping'; for saw: 'it is an object made of a grip and a big long blade with sharp teeth, it is used for cutting wood by pushing the hand backwards and forwards'). In this task NM was still unable to name a single item (0/16).

NM's high degree of anomia was thus observed on two naming tasks with the same items (picture naming and naming from a definition). In these tasks, he never produced a correct response.

Comprehension versus production: set 2

The second set of tasks was designed in order to confirm the preceding results on tasks that do not require the visual processing of pictures and that allow us to test items from different grammatical categories and concreteness. The comprehension of words was assessed in a judgement of synonymy. To evaluate word production, we asked NM to produce the synonyms of auditory-presented words.

In the synonymy judgement, NM was presented with 240 spoken words; for each of them, he was given a card with two written words and he had to point to the word that was a synonym of the spoken word. All three words in a trial (the spoken word, the synonym, and the foil) shared the same grammatical class (verbs or nouns), the same concreteness (abstract or concrete), and the same frequency

Table 4. NM's performance on tasks of recognition and production of synonyms

Recognition of synonyms
Correct responses 211/240 (88%)
no frequency effect:
high frequency (11 errors/80), medium frequency (7 errors/80), low frequency (11 errors/80)
no grammatical class effect:
verbs (15 errors/120), nouns (14 errors/120)
no concreteness effect:
concrete (11 errors/120), abstract (18 errors/120)
21 errors on trials with a distractor semantically related
e.g. 'charité'—BIENFAISANCE, HOSPITALITÉ ['charity'—KINDNESS, HOSPITALITY]—low frequency abstract nouns
e.g. 'terminer'—FINIR, ÉVITER ['to complete'—TO FINISH, TO AVOID]—high frequency abstract verbs
8 errors on trials with an unrelated distractor
e.g. 'clapet'—VALVE, BLOUSON ['rectifier'—VALVE, WINDJAMMER]—low frequency concrete nouns
Production of synonyms
Correct responses 10/120 (8%)
Errors:
7 productions of an appropriate definition
e.g. 'habit'—/ce que je mets sur moi/ ['clothes'—/what I put on me/]
e.g. 'souhaiter'—/essayer d'obtenir/ ['to which'—/to try to get/]
6 semantic associates
e.g. 'enlacer'—/prendre/ ['to embrace'—/to take/]
e.g. 'gazon'—/arbre/ ['lawn'—/tree/]
3 approximate answers
e.g. 'excuser'—/admettre/ ['to excuse'—/to admit/]
4 non-responses
90 productions of an unrelated word
e.g. 'empiler'—/exécuter/ ['to pile'—/to execute/]
e.g. 'pancarte'—/prendre/ ['sign'—/to take/]
e.g. 'enfler'—/prendre ou donner/ ['to swell'—/to take or to give/]
e.g. 'canapé'—/un cartable/ ['sofa'—/a satchel/]
e.g. 'bénéfice'—/les points/ ['profit'—/the points/]

range (high, medium, or low, with frequencies estimated according to the TLF; Imbs, 1971). The concreteness and the frequency of the items was counterbalanced across verbs and nouns. The foil was either semantically related or unrelated to the spoken word (e.g. 'félicitations'—REMERCIEMENTS, COMPLIMENTS ['congratulations'—THANKS, COMPLIMENTS]; versus 'herbe'—GAZON, LIQUEUR ['grass'—LAWN, LIQUEUR]). The other word was a synonym of the spoken word according to three different French dictionaries. NM correctly pointed to the synonym in 211/240 trials (88%). There was no effect of frequency on the rate of errors, nor any effect of grammatical class or concreteness (see Table 4). Most of the errors occurred in items with a distractor semantically related to the spoken word (21 errors against eight for unrelated distractor).

In order to test the production level, we selected a subset of 120 words among the 240 spoken words used for the synonymy judgement task, preserving the distribution across grammatical class, concreteness, and frequency. NM was required to produce a synonym for each spoken word (examples of errors are shown on Table 4). In this task, NM gave a response in most of the cases (he made only four non-responses) but the large majority of his productions (90/116) were totally unrelated to the stimuli (e.g. to the verb 'empiler' ['to pile'], he answered /exécuter/ [/to execute/]). Moreover, there was no diversity in NM's productions (e.g. the answers /donner/ [/to give/] or /prendre/ [/to take/] were given on 27 items), and most of his productions were high frequency words. Overall, NM gave an acceptable synonym for only 10 of the 120 words (e.g. 'admettre'—/accepter/ ['to admit'—/to accept/]); he gave seven correct definitions (e.g. 'souhaiter'—/essayer d'obtenir/ ['to which'—/to try to get/]), six semantic associates (e.g. 'gazon'—/arbre/ ['lawn'—/tree/]), and three approximate answers (e.g. 'excuser'—/admettre/ ['to excuse'—/to admit/]). The number of semantically related words did not differ significantly from the baseline 'chance level' for obtaining semantic errors in this experiment ($P = 0.1093$). In order to estimate the baseline 'chance level', we took the entire body of whole-word errors (99 responses), and, 20 times, we randomly re-allocated them to the stimulus list [see Ellis and Marshall, 1978).

NM made a substantial amount of errors on the synonymy judgement task. As expected, most of the errors were for semantically related distractors. On the other hand, there were very few correct responses on production of synonyms (8%) and virtually no semantically related answers.

Comment

The study of NM's performance on several comprehension tasks revealed the presence of a semantic impairment. NM made some errors on the easiest classification tasks. When he was asked to classify the same items according to semantic sub-categories, the error rate increased. This increase was similar for words and pictures indicating a central locus of impairment. Yet, the error rate was higher in two other tasks using the same set of stimuli: word/picture matching and word/picture verification. On these tasks, NM scored 83 and 54% correct and most of the errors were due to the choice of a semantically related distractor. The same kind of errors were observed on the synonymy judgement task. This suggests that he was unable to access a full semantic representation.

The production of spoken words was evaluated on three tasks. On a picture naming task, NM never correctly named a single picture (0%). For most of the pictures, he produced a circumlocution composed of very frequent words and of little informative value. Furthermore, NM never produced semantically related words, or phonological paraphasia. On naming from a definition, he showed the same degree of impairment. Likewise, in a task in which he was required to produce the synonym of a spoken word, NM gave the correct synonym to only eight percent of the stimuli, most of his productions being unrelated words.

It is difficult to give an interpretation to the discrepancy between the performance in tasks of word comprehension

and of word production. Given NM's semantic impairment, one could expect a better performance on comprehension tasks than on tasks of spoken production—which probably require the activation a full semantic information of the target word. However, one may also suggest that one part of the observed discrepancy was the consequence of an additional post-semantic impairment. Two arguments may be advanced in favour of the latter proposal. Firstly, if NM's performance on production tasks was the reflection of the underlying semantic impairment, one would have expected to observe semantically related errors. Secondly, NM's performance was far beyond the chance level on a task in which he was asked to guess the gender of words that he was not able to retrieve in the context of a naming task (see Case history). This performance could probably not be achieved without the individuation of the semantic representation of the target items. Thus, if we are right, the presence of an additional deficit located beyond the semantic system, was responsible for the disproportion in error rate between the comprehension and the production tasks, and for the absence of semantically related errors in the latter. Considering the absence of phonological paraphasia in NM's production and the perfect repetition of words (see Case history), one may assume that this additional deficit, if any, prevented the access to the phonological form corresponding to a given meaning.

About numerals and other high frequency words

We are now coming to the main point which is the dissociation between the production of numerals on the one hand and the production of words from other semantic fields on the other hand. In this section, we show that, in contrast with his severe anomia, NM was able to produce any numeral when he was given its Arabic form. However, numerals are very frequent words and one could thus argue that the observed dissociation is an artefact due to the lower frequency of the items used to test the other semantic categories. To avoid this bias, we compared the production of numerals with that of words matched for frequency according to the TLF. NM was first tested for oral naming, and then tested for written naming with a subset of the same items.

Oral naming

NM was presented with 168 items printed on cards for oral naming. Half of the items were Arabic numerals corresponding to one-word verbal numerals ($n = 84$), the other half were letters ($n = 9$), colours ($n = 8$), or black and white pictures from different semantic categories: animals ($n = 8$), body parts ($n = 20$), pieces of furniture ($n = 7$), humans ($n = 7$), buildings ($n = 4$), geometrical figures ($n = 3$), transport ($n = 5$), household objects ($n = 9$), seasons ($n = 4$). There are 25 one-word numerals in French (except 'million', 'billion', etc.). Some numerals have thus been presented several times in order to increase the number of items in this category which seemed to be preserved. Moreover, we disregarded the number-words un (1) and neuf (9), since they are polysemious in French. Items from all semantic categories were mixed in random order, except the four seasons which were presented consecutively but in the wrong order.

Results are summarized on Table 5. NM gave a correct and immediate response to 82 of the 84 numerals. For the two remaining items (7 and 60), initially, he seemed to show difficulty in categorizing the Arabic forms as numerals, and started to recite the months of the year, the days of the week, and the letters, but was unhappy with his production. Then the examiner gave the semantic category ('it's a numeral!'), and NM produced the correct answer without hesitation. NM also gave a correct and immediate response to six of the nine letters. For the remaining three letters (p, t, f), he initially manifested some difficulty in recognizing the items as letters, but he responded immediately after he was given the upper case letters (P, T, F) instead of the lower case letters. Finally, NM also correctly named five of the eight colours (black, white, yellow, green, blue). One more colour (red) was correctly named after NM was explicitly asked to 'give the colour', and he responded to the two remaining items (grey and brown) with a description such as: *brown*—/not blue, not green, not red, not yellow/. NM did not give any other correct responses across the nine other semantic categories (0/67). A lot of errors (33/67) consisted in short descriptions (see examples on Table 5). On 13 other occasions, NM did not respond (omissions), and among those 13 items, there were 10 body parts that he correctly pointed to on his own body. Six responses were semantically related to the target word (e.g. *voiture*—/rouler/ [*car*—/to run/]). Twelve other productions were unrelated to the target word (e.g. *soldat*—/lui/ [*soldier*—/him/]). Finally, on three occasions NM produced a phonemic paraphasia.

Comment and complementary results

NM was perfectly able orally to produce numerals, as well as letters and some colours. However, he was not able to produce a single word in nine other semantic categories although the words to be named were matched with verbal numerals for frequency.

For the 69 items that he was not able to name, NM was given a phonological cueing. The phonemes were given one at a time till the end of the word, unless NM produced a correct response before. There were 46 words that NM correctly completed and 23 words (one-third) that NM did not complete before the last phoneme. The frequency of the words that were not completed did not differ from the frequency of those that were correctly completed [$\mu = 19\,032$, $SD = 26\,870$ and $\mu = 9659$, $SD = 11\,438$ respectively, $t(26;\ 0.05) = -1.706$, NS]. Words from all categories were equally likely to be correctly completed.

Table 5. NM's performance on naming numerals and other words

Oral naming			
Semantic category	*Mean frequency (SD)—% of correct responses*		
Numerals	12 535 (19 850)	84/84	(100%) with 2 hesitations
Letters	10 551 (17 909)	9/9	(100%) with 3 hesitations
Colours	14 046 (9661)	6/8	(75%) with 1 hesitation
Other semantic categories		0/67	(0%)
animals	6524 (5101)	0/8	(0%)
body parts	18 125 (22 470)	0/20	(0%)
buildings	18 969 (22 121)	0/4	(0%)
figures	3274 (2383)	0/3	(0%)
furniture	7501 (8412)	0/7	(0%)
humans	27 213 (33 097)	0/7	(0%)
objects	7139 (11 314)	0/9	(0%)
transport	6842 (5703)	0/5	(0%)
seasons	7183 (3336)	0/4	(0%)
Errors:			
Omissions (no response)		13 (19% of errors)	
Phonemic paraphasia		3 (4% of errors)	
Semantically related words		6 (9% of errors)	
e.g. *voiture*—/rouler/ [*car*—/to run/]			
balle—/rouler/ [*ball*—/to run/]			
Unrelated words		12 (18% of errors)	
e.g. *oiseau*—/un petit/ [*bird*—/a little/]			
chien—/un petit/ [*dog*—/a little/]			
train—/un chose/ [*train*—/some stuff/]			
soldat—/lui/ [*soldier*—/him/]			
Descriptions		33 (49% of errors)	
e.g. *chaise*—/pour s'asseoir/ [*chair*—/to sit down/]			
tapis—/par terre/ [*carpet*—/on the floor/]			
singe—/un petit garçon, . . . pas un petit garçon/ [*monkey*—/a little boy, . . . not a little boy/]			
main — /un, deux, trois, quatre, cinq, mettre/ [*hand*—/one, two, three, four, five, to put/]			

Phonological cueing

Relative and cumulative frequencies of correct completion as a function of the proportion of phonemes provided

Proportion of phonemes provided as cue	Relative frequency of correct completion	Cumulative frequency of correct completion	Count of correct completions	Mean lexical frequencies
[0; 1/4]	0.072	0.072	5	16 223
[1/4; 1/3]	0.072	0.145	5	7181
[1/3; 1/2]	0.217	0.362	15	7426
[1/2; 2/3]	0.174	0.536	12	10 941
[2/3; 3/4]	0.103	0.638	7	10 019
[3/4; 1]	0.029	0.667	2	7240

Table 5 shows the relative and cumulative frequencies of correct completion as a function of the proportion of phonemes provided as a cue. In fact, the frequency of correct completion was still very low when NM had been presented with the first third of the phonemes of the words (0.145). The frequency of correct completion only reached 0.536 when two-thirds of the phonemes had been presented.

On the other hand, NM's performance did not improve when he was given the semantic category of the item that he had to name. He had indeed been presented with another naming task using a subset of the items composed of 46 numerals, six letters, three colours, and 37 black and white pictures belonging to one of the nine other semantic categories (numerals were matched with other words for frequency), and this time, NM was given the semantic category as a cue before each item. In this version of the task, NM correctly named the 46 numerals, the six letters, and the three colours. However he correctly named only two other pictures from the 37 (5%). Thus NM did not seem to get any benefit from the semantic cueing.

In short, NM proved to be able to produce numerals, letters and some colours, although he presented a striking naming deficit in any other semantic category with virtually no benefit from semantic cueing and little benefit from phonological cueing.

Written naming

So far, we have documented the presence of a deficit which resulted in a virtually total inability to access the phonological representation of words for output. Interestingly enough, the deficit did not affect all semantic categories, since NM showed preserved abilities to name digits, letters, and, to a lesser extent, colours. We now turn to written naming, and we show that the dissociation was not specific to the oral production but also appeared in written production.

Table 6. NM's performance on written naming

Written naming
Numerals
Correct responses 31/37 (84%)
Errors: Spelling errors (6/6)
Colours
Correct responses 6/8 (75%)
Errors: Omissions (2/2)
Other semantic categories
Correct responses 2/29 (7%)
Errors:
Omissions (18/27 errors)
Semantically related words (6/27 errors)
e.g. *crayon*—ÉCRIRE (*pencil*—TO WRITE)
e.g. *pouce*—MAIN (*thumb*—HAND)
Unrelated words (3/27 errors)
e.g. *carré*—OUVERT (*square*—OPEN)

Seventy-four items were selected from the set described in the previous experiment, half of which were pictures (eight colours, four animals, seven body parts, two buildings, two geometrical figures, three pieces of furniture, two humans, four household objects, three seasons, and two transports), and the other half, Arabic numerals matched for frequency. NM was asked to write down the name corresponding to each stimulus.

In this task NM tried spontaneously to produce a response orally before writing it down and any attempt to discourage him proved useless. He gave a correct response to 31/37 numerals and the remaining six errors were spelling errors which differed from the correct response by a single letter (e.g. '60' was spelled SOISANTE instead of soixante). NM also wrote down correctly the name of six of the eight colours, while no response was given to the two remaining colours (grey and brown). On the other hand, NM gave only 2/29 correct responses across the nine other semantic categories. Among the 27 errors, there were 18 omissions (no response), six semantically related words, and three unrelated words (see examples in Table 6). Apart from the 20 omissions, NM thus produced 17 words other than numerals (six colours, two other correct responses, and nine errors). Among those words, there were 13 orthographically ambiguous or irregular words (e.g. MAIN [hand], MONSIEUR [mister], BANC [bench]); nonetheless, NM made only one spelling error.

Comment

One could think that NM's performance in written naming as compared to oral naming is not surprising. NM tried to produce orally the word before writing it down; thus, he should not achieve a better performance in written naming. Following this hypothesis, NM used a non-lexical route to write (relying on phoneme-to-grapheme conversion rules). However, it does not fit with the fact that all but two verbal numerals are orthographically ambiguous or even irregular in French (UN and NEUF, which have a regular spelling, were not included in the list). Thus for this category, NM retrieved the correct orthographic form in 84% of cases. Moreover, the six errors in written naming of numerals do not correspond to regularization errors. In the same way, among the 17 responses recorded in the other categories, there was only one spelling error—though there were 13 orthographically ambiguous or irregular words. Thus NM seemed to be able to retrieve the correct form of some orthographically ambiguous words, a process which is currently attributed to the route connecting the semantic system to the orthographic output lexicon (see Fig. 1). If this is so, then we can conclude that the written naming of numerals (and some colours) was relatively spared, while the written naming of words from other semantic categories was severely impaired—a pattern of performance which is very similar to the one observed in oral naming, suggesting that a common deficit should account for the performance in both oral and written naming.

Further investigations on the production of numerals and other words

Up to now, we have shown that NM was able to produce a spoken or written verbal numeral when he was given the corresponding Arabic numeral. However, some authors in the literature on numerical processing have suggested the existence of a non-semantic pathway dedicated to the transcoding of Arabic numerals into verbal numerals (see Seron and Noël, 1995, for a review). If such a non-semantic pathway exists, then the dissociation we have observed could reflect the preservation of this pathway beside a total inability to access the phonological representation of words (even numerals) from the semantic system. In the present section, we show that the dissociation between numerals and other words was observed on several tasks that do not involve reading of Arabic numerals. Furthermore, we explore NM's performance in some categories that are difficult to introduce in a naming task (e.g. days, months, etc.).

Verbal fluency

NM was asked to produce as many different words as possible in 2 min belonging to a specified semantic category. NM's performance was recorded for 14 different semantic categories: tools, transport, body parts, colours, weapons, clothes, music instruments, military ranks, jobs, sports, cities, countries, letters and numerals. For the categories of letters and numerals, NM was required to avoid producing the elements in the conventional order.

NM was not able to produce a single item from the categories of tools, jobs, weapons, clothes, and military ranks; he gave only one transport, one body part, one sport, two music instruments, and three countries. He was able to give five colours, nine Belgian cities, and 15 letters. However, this performance is clearly pathological and numerous errors were noted in each of these categories:

Table 7. NM's performance on tasks of verbal fluency

Verbal fluency		
Target semantic categories (Number of correct productions in two minutes)		
Tools (0)	Transport (1)	Colours (5)
Jobs (0)	Body parts (1)	Cities (9)
Weapons (0)	Sports (1)	Letters (15)
Clothes (0)	Musical instruments (2)	Numerals (28)
Military ranks (0)	Countries (3)	
Examples		
Transport:	/. . . taxi . . ./	
	[/. . . cab . . ./]	
Musical instruments:	/. . . flûte, violon . . ./	
	[/. . . flute, violin . . ./]	
Countries:	/Belgique, France, Italie, le grand derrière nous . . . . . le petit . . ./	
	[/Belgium, France, Italy, the big one behind us . . . . . the small one . . ./]	
Colours:	/vert, bleu, rouge, jaune, noir, plus petit noir, vert, bleu, rouge, jaune, noir, ce que j'ai içi, moi-même, . . . vert, rouge, bleu, noir, jaune, (il montre sa main) rouge vif ou pas rouge . . ./	
	[/green, blue, red, yellow, black, smaller black, green, blue, red, yellow, black, what I have got here, myself, . . . green, red, blue, black, yellow, (shows his hand) vivid red or not red . . ./]	
Letters:	/b, c, d, zéro, l, v, m, p, j, k, t, 1.2, 1, 250, i, a, m, , l, t, g, a, e, v, k, w, grand v, zéro, 1, 3, 51, 1, 2, 3, 4, 5/	
	[/b, c, d, zero, l, v, m, p, j, k, t, 1.2, 1, 250, i, a, m, , l, t, g, a, e, v, k, w, upper v, zero, 1, 3, 51, 1, 2, 3, 4, 5/]	
Numerals:	/10 000, 2000, 3000, 25 000, 30 000, 46 000, 2, 0, 4, 22, 12, 81, 23, 250, 376, 428, 28, 8 moins 2 (8 minus 2), . . . 82, 5000, 1 000 000, 10 000 000, 8, 3, 0, 25, 28, 43, 38, 51, 10/	

intrusion of non-words among the Belgian cities, intrusion of numerals during the fluency for letters, and many repetitions in the three categories (see examples in Table 7). On the contrary, NM gave 28 different numerals in 2 min and this task was performed easily.

Verbal associations

In this task, NM was given a word orally and had to produce any related word that came to his mind, the only constraint being to respond as fast as possible. NM received three different lists; the first one was composed of 55 abstract and concrete nouns and had been presented twice on separate sessions; the second list was composed of the first 20 numerals and had been presented three times on separate sessions; the third list was composed of the days of the week, the 'notes' (in the tonic sol-fa series: 'do, ré, mi, fa, sol, la, si' [doh, ray, mi, fa, soh, lah, si]), and some months of the year (seven items in each category).

For all the items, NM gave his responses within 1 or 2 s. As can be seen from Table 8, for nouns on the first list only a few responses were semantically related to the stimulus (12/110; e.g. 'évangile'—/quatre/ ['gospel'—/four/], 'route'—/vite/ ['road'—/fast/]). On seven other occasions, NM just repeated the stimulus word, sometimes preceded by an article, on five occasions, he produced a morphological derivation of the stimulus, and he produced four non-words. Most of NM's productions were correct French words unrelated to the stimulus noun (82/110). Among those 82 unrelated responses, the words 'petit' [little] and 'grand' [big] were produced 31 times (38%) and 21 responses (26%) were very frequent unrelated verbs (e.g. 'religion'—/essayer/ ['religion'—/to try/], 'canard'—/être/ ['duck'—/to be/]). In this task, the number of semantically related responses was nonetheless greater than that expected by chance ($P < 0.05$, on the basis of 20 random distributions of the 106 whole-word responses). In response to numerals on the second list, NM always produced a numeral which was, most of the time, the given numeral plus or minus one (28/60 and 20/60 respectively, i.e. 80% of responses). Finally, with the elements from other ordered series, NM also always produced elements within the same

Table 8. NM's performance on tasks of verbal associations

Verbal associations	
List 1: 110 abstract and concrete nouns	
semantically related responses	12/110
e.g. 'évangile'—/quatre/ ['gospel'—/four/], 'route'—/vite/ ['road'—/fast/], 'kilomètre'—/quinze/ ['kilometer'—/fifteen/], 'pardon'—/mal/ ['pardon'—/evil/]	
unrelated responses	82/110
/petit/ [/little/] and /grand/ [/big/] were recurrent productions (31 responses)	
e.g. 'rivière'—/petite/ ['stream'—/little/], 'lion'—/grand/ ['lion'—/big/], 'sport'—/grand sport/ ['sport'—/great sport/]	
very frequent unrelated verbs were often produced (21 responses)	
e.g. 'flamme'—/je prend/ ['flame'—/I take/], 'canard'—/être/ ['duck'—/to be/], 'religion'—/essayer/ ['religion'—/to try/]	
other responses	
repetition of the stimulus	7/110
morphological derivations	5/110
non-words	4/110
List 2: 60 numerals	
prevalent semantic relationships (80% of responses)	
+ 1	28/60 responses
− 1	20/60 responses
other semantic relationships (20% of responses)	
{+ 2, − 2, + 5, ÷ 5, + 10, × 10, × 2}	12/60 responses
List 3: 21 elements from ordered series	
100% of the stimuli and responses were within the same series	
the following one	16/21 responses
the preceding one	2/21 responses

Table 9. NM's performance on recitation and what comes next/before questions

Recitation		
Letters: /A, B, C, D, É, F, G, K, L, . . . I, J, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z/		
Notes: /A, do, 10, do, L, F, M, do, ré, S/		
Production of the following and preceding elements		
	'What comes next?'	'What comes before?'
Numerals	10/10	10/10
Days	10/10	10/10
Months	10/10	10/10
Letters	6/10	9/10
Notes	4/10	5/10

series, and most of the time it was the following one (16/21).

Recitation and 'what comes next/before' questions

We have already mentioned NM's preserved ability to count as well as to recite the series of days and weeks. He was also asked to recite the letters of the alphabet, the 'notes' in the tonic sol-fa series, and the signs of the zodiac ('Bélier, Lion, Sagittaire, . . .' [Ram, Lion, Archer, . . .]). He omitted the letter H and erred on the order of the following letters when he recited the alphabet (see Table 9). He proved totally unable to recite the notes, and some letters as well as one numeral were intruded in the answer (see Table 9). Prior to the trauma, NM knew the musical notation and he was able to read the notes on a staff. We thus presented a picture of each note on a staff and we asked him to name or to sing the notes in the conventional order. He was still unable to give a correct response (0/7). Finally, for the signs of the zodiac he was also primed with a picture of each sign, but he was once again unable to respond (0/12).

In order to assess further NM's ability to deal with elements from ordered series, he was orally presented with 20 numerals, 20 letters, 20 days of the week, 20 months of the year, and 20 notes and he was asked to produce the following or preceding element. NM was presented with a same set of 10 elements from each ordered series on two separate sessions. During the first session he was asked to give the following element in the list, while during the second session, he had to give the preceding one.

Results are presented in Table 9, the following and preceding elements were correctly produced in response to a given numeral (20/20), day (20/20) or month (20/20). When he was presented with letters, NM could give the following one on six occasions and the preceding one on nine occasions (15/20). Finally, he was able to produce the following note on four occasions and the preceding one on five occasions (9/20).

These results showed that NM's performance was not preserved for all the ordered series. He was indeed impaired on very simple tasks for the alphabet, the notes and the signs of the zodiac. On the contrary, NM showed good performances on the same tasks with numerals, days and months.

Table 10. NM's performance when responding to propositional questions

Responses to propositional questions	
Set 1: Questions about numerals	
Questions with an evident answer	15/15
Other questions	25/40
e.g. 'How many weeks are there in one year?'	
-resp- /Twelve, no fifty-four/	
'How many days are there in one year?'	
-resp- /Three hundred sixty, three hundred sixty-one, about that/	
'How many letters are there in the alphabet?'	
-resp- /Thirty-two no, a bit less, . . . twelve/	
'Which is the number that brings misfortune?'	
-resp- /Sixty/ (NB: NM was sixty years old when he was injured)	
'How many teeth has an adult got?'	
-resp- /Twenty/	
'How many players are there in a rugby team?'	
-resp- /Five/	
Set 2: Questions about days and months:	20/22
About days:	6/6
About months:	14/16
Set 3: Questions about seasons:	0/10
e.g. 'In which season is the start of the new school year?'	
-resp- /September, . . . third season /	

Responses to propositional questions

As another test of NM's ability to deal with numerals and with other elements from ordered series, he was presented with several sets of questions whose answers corresponded to such elements. The first set was composed of 55 questions requiring the retrieval of numerical information from long term memory. For 15 of the 55 questions the answers were evident since one could get the correct solution through the inspection of a stored visual image and control subjects always responded accurately to these questions (e.g. 'How many wheels has a car got?', 'How many colours are there on the Belgian flag?'). The remaining 40 questions required the retrieval of numerical knowledge presumably stored in a propositional form within the semantic system (e.g. 'How many degrees are there in a right angle?', 'How many footballers are there in a team?', 'How many states are there in the USA?'). The second set of questions presented to the patient concerned the series of days and months. NM was presented with six questions that required the production of a day (e.g. 'Which is the last day of the week?'), and 16 questions requiring the production of a month (e.g. 'Which is the shortest month of the year?'). Finally, a third set of 10 questions was presented to investigate the name of the seasons (e.g. 'Which is the last season?'). Questions about days, months and seasons were all responded to correctly by control subjects.

Results are summarized on Table 10. For the first set of questions tapping on numerical knowledge, NM gave 40/55 correct responses. All the correct responses were given within one or two s. He was flawless for the questions with an evident answer (15/15). He responded

correctly to 25/40 of the remaining questions that required the retrieval of verbal semantic information in the form of numerals. This performance was significantly worse than the one of control subjects between 45 and 55 years old and with a high degree of education ($\mu = 33.73$, $SD = 3.826$). In fact, NM was sometimes able to respond accurately to questions that required the retrieval of very precise semantic information from memory (e.g. 'How old was Jesus when he was crucified?', 'How long is a pregnancy?', 'How many days are there in December?'). However, as can be seen from Table 10, NM also erred on relatively easy questions for which he should have known the answer before the accident. On the second set of questions, for which the answer was a day or a month, NM gave 20/22 correct responses, the two errors concerned a question about a month. Finally, NM was totally unable to respond to the questions bearing upon the four seasons (0/10). As can be seen from the example of Table 10, NM sometimes demonstrated a good comprehension of the question though being unable to retrieve the target name for the season.

Thus, NM was perfectly able to produce numerals in response to propositional questions when these questions had an evident answer. However, NM scored below the normal range when he had to respond to questions requiring the retrieval of a propositional knowledge about the world. On the other hand, NM's performance with days and months, though not preserved was relatively good, but he could not respond to a single question about seasons.

Comment

In this section, we report NM's performance on tasks that allowed us to compare the oral production of numerals and of words from other semantic categories. We were able to demonstrate that the dissociation between numerals and other categories was observed in tasks that do not involve naming Arabic numerals. In particular, numerals were adequately produced in tasks of verbal fluency and of verbal associations, as well as in the context of 'what comes next/before' questions and of propositional questions which have an evident answer. In contrast, NM showed an impaired performance in lots of other categories. We paid special attention to the processing of elements from ordered series which are similar to numerals in some respects. In fact, numerals, days and months were the only elements that were adequately produced, whatever the task in which they were involved. One factor that could explain NM's performance across the different categories of words would be the size of the category. Given NM's semantic impairment and his difficulty in activating a full semantic representation, one may assume that the selection of concepts from larger sets was more difficult because of the greater competition among category members. According to this hypothesis, numerals should be preserved because they are members of a small category. Moreover, NM's performance should decrease as a function of the size of the category. In order to check this hypothesis, we collected NM's performance on picture naming and verbal fluency tasks, separately for all categories (see Table 11). The size of each category was determined either according to Dubois (1983) or using complementary data that we recorded following exactly the same procedure in the missing categories (except for closed categories for which we simply counted the number of elements). A first inspection of Table 11 shows that there exist several small categories in which NM showed problems on naming and verbal fluency, namely, seasons, notes, signs of the zodiac, military ranks and geometrical figures. Among these impaired categories, some are ordered (seasons, notes) and some have been tested on items matched with verbal numerals for frequency (seasons, geometrical figures, signs of the zodiac for five of the items). Moreover, there were some other tasks in which the patient showed evidence of impairment on small categories. For instance, he was not able to respond to questions about seasons, nor to give the letter or the note that comes after or before a given letter or a given note, even the recitation of the alphabet contained some errors. On the opposite side, the categories in which NM seemed able to retrieve some elements during the verbal fluency task were not necessarily the smallest ones (e.g. Belgian cities, colours, countries). We computed Pearson's coefficients on ranks to evaluate the correlation

Table 11. NM's performance on oral naming and verbal fluency tasks as a function of the size of the category

Semantic category	Size of the category	Performance on oral naming (proportion correct)	Performance on verbal fluency (number of words)
Seasons	4	0.00	—
Notes (tonic sol-fa)	7	0.00	—
Signs of the zodiac	12	0.00	—
Letters	26	1.00	15
Numerals	28 (*)	1.00	28
Military ranks	28 (a)	—	0
Geometrical figures	37 (a)	0.00	—
Vegetables	60 (d)	0.00	—
Fruits	63 (d)	0.00	—
Musical instruments	87 (d)	—	2
Colours	98 (a)	0.75	5
Sports	102 (d)	—	1
Pieces of furniture	102 (d)	0.00	—
Weapons	112 (d)	—	0
Clothes	112 (d)	—	0
Transport	124 (d)	0.00	1
Body parts	137 (a)	0.00	1
Countries	147 (a)	—	3
Tools	148 (d)	0.00	0
Belgian cities	157 (a)	—	9
Animals	223 (d)	0.00	—
Jobs	232 (d)	—	0

The size of the different categories was (d) taken from Dubois (1983) or (a) evaluated according to the same procedure. (*) For the category of numerals, we took into account the words 'million', 'billion' and 'milliard'. All results were extracted from the tasks of oral naming and verbal fluency that have been presented before.

between the size of the categories and the performances on naming or on verbal fluency. The correlation between the proportion of correct naming and the size of the category was $r_s = -0.221$. The correlation between the number of items produced in verbal fluency and the size of the category was $r_s = -0.323$. These two coefficients fall to -0.131 and -0.216 respectively when numerals are not entered into the analysis. In summary, the pattern of performance evidenced in NM does not seem to sustain the hypothesis that numerals were spared because of the small size of this category. However, this does not mean that this factor played no role in the relative preservation of numerals. It could be, for instance, that the size of the category interacts with other factors such as the presence of a conventional order and the familiarity of the series. However, the present case will probably not be enough to give a definitive conclusion on that point.

NM's performance on tasks specific to the numerical domain

So far, we noted that NM could adequately produce numerals in the context of very simple tasks in which he proved unable to produce words from other categories (excepted days and months). Interestingly enough, we also noted a large number of errors in response to propositional questions tapping very precise numerical knowledge about the world. In this section we investigate NM's performance on tasks that do not have a non-numerical equivalent in order to determine the extent of NM's preservation in the numerical domain.

Naming patterns of dots

In order to test NM on a task that requires the processing of quantities at a semantic level, he was asked to name canonical dot patterns (like on dice). Some authors (see e.g. Mandler and Shebo, 1982) have indeed demonstrated that such patterns are 'subitized', giving a direct access to the quantity, at least for patterns of three dots or less. Thirty-two patterns composed of one to nine dots were flashed on the screen of a computer and NM's naming response time was recorded with a vocal key connected to the computer. The stimuli disappeared when NM gave his response. During the same session, NM was also presented with the 32 corresponding verbal numerals and the 32 corresponding Arabic numerals using the same technique.

NM never made a single error in this task (0/96). For patterns composed of less than five dots his mean response time was < 700 ms, but response time for patterns of six dots or more increased linearly up to 2 s. This showed that NM was able to subitize patterns up to five dots. With written verbal numerals and Arabic numerals NM's mean response time was below 600 ms for all numerals from 1 to 9.

Reading the time on an analogue clock

In another task, NM was asked to read the time on 24 clocks printed on separate cards. On each clock, the positions corresponding to 3, 6, 9, and 12 o'clock were indicated with a digit (3, 6, 9, 12), and the hour and minute hands were pointing towards a complex hour (e.g. 4 h 06, 10 h 46, etc.).

NM produced a correct answer to 21 of the 24 items and the remaining three errors were good estimates of the correct responses (e.g. 5 h 48 instead of 5 h 52).

Reading aloud complex numerals

In order to explore NM's performance with numerals that do not have a single-word name, he was presented with a set of 106 Arabic numerals corresponding to numerals composed of two to seven words. The length of the Arabic numerals varied from two to six digits. NM was presented with the Arabic numerals on cards and he had to read them aloud.

He gave 98/106 correct responses. Reading was fluent even for the longest numerals. Since all responses in this task were composed of several words, one can conclude that NM had retained relatively spared ability to process numerals at a syntactical level.

Calculation

NM performed four calculation tasks. In all four tasks, he was required to give his response orally. He was given a list of 100 addition problems composed of all problems from 0 + 0 to 9 + 9. The list was presented on two occasions, the first time NM was given the items orally, while the second time the same list of problems was presented in the Arabic notation. NM was also orally presented with a list of 100 subtraction problems composed of all problems from 18–9 to 0–0. Finally, he also responded to a list composed of all multiplication problems from 0 × 0 to 9 × 9 (100 items). The items were orally presented.

NM responded correctly to a large number of problems. He gave 99/100 correct responses for addition problems presented orally and 99/100 correct responses when presented in the Arabic notation. He also gave 99/100 correct responses for subtraction problems. On these tasks, NM's response time was mostly of 1 or 2 s (and never exceeded 3 or 4 s). Finally, NM's performance was less preserved for multiplication since he gave only 87/100 correct responses. However, NM's main difficulty was for problems involving 9 as operand, but for smaller problems he was fast and accurate.

Comment

In this last section, we investigated NM's performance on tasks specific to the numerical domain. NM was flawless on

naming patterns of dots and he showed the expected 'subitizing effect' for patterns of less than five dots. This result showed that he was able to process small quantities at a semantic level and to retrieve the name for those quantities without counting. In the same line, NM was able to read the time on an analogue clock. This task requires the understanding of quantities and the production of somewhat more complex numerals [e.g. cinq heures quarante-six (5 h 46)]. NM also showed a relatively spared ability to read aloud Arabic numerals representing large quantities (92% correct). He was thus able to process numerals at a syntactical level. Finally, NM proved to be able to solve simple addition and subtraction problems almost perfectly. He showed some difficulties with multiplication problems (87% correct), but mostly for problems with large operands.

On the basis of the observed results, we can conclude that NM had retained a relatively preserved ability to process numerals through the levels of comprehension and production.

Discussion

In this study, we have examined the case of a patient who could comprehend and produce numerals despite an impairment on comprehension tasks and a high degree of anomia for other categories of words.

NM scored between 0 and 10% correct on tasks of picture naming, naming from a definition and production of synonyms. He produced very few semantically related words and phonological paraphasia. Moreover, his performance on picture naming was unchanged for the impaired categories when he was primed with the semantic category of the item. The use of a phonological cue helped him to retrieve the correct name of two-thirds of the pictures; however, the probability of correct completion only reached 0.5 when NM was given two-thirds of the phonemes of the words. In other words, NM got relatively little benefit from phonological cueing.

NM's performance was also impaired in very easy comprehension tasks. He performed quite well on tasks that can be realized on the basis of the access to a part of the semantic information concerning a concept (e.g. classification in broad semantic categories), but on tasks requiring the activation of somewhat more complete semantic information, NM's accuracy decreased (e.g. classification in sub-categories). The decrease in performance was similar for the comprehension of words and pictures. Furthermore, NM's performance was very poor in word/picture matching and word/picture verification tasks. In these tasks most of NM's errors (two-thirds) were made on a semantically related foil. These results suggest that NM was unable to activate a full semantic representation of the items.

Despite the presence of this semantic deficit and the high degree of anomia, NM retained preserved ability to comprehend and to produce numerals after the cerebral trauma. Although he was virtually unable to name a single picture, he indeed showed a very good performance on naming Arabic numerals. The same dissociation was observed in oral naming, in written naming, and in several tasks that do not require the processing of Arabic numerals. For instance, NM was drastically impaired on verbal fluency tasks for all categories except numerals. In fact, numerals, as well as days and months, were the only elements to be adequately produced whatever the task: verbal association, recitation, 'what comes next/before' questions and propositional questions with an 'evident' answer.

One potential explanation of the preservation of numerals was the relatively high frequency of these elements. However, we showed that the dissociation between numerals and words from other categories remained even when the items were matched for frequency. Another potential account of the preservation of numerals was the relatively small size of this category. However, there was no evidence of a strong correlation between the size of the category and NM's performance on tasks of naming or verbal fluency. Moreover, NM's performance was inaccurate in several very small categories (letters, notes, seasons, signs of the zodiac, military ranks, and geometrical figures), among which some are composed of very frequent elements and some are ordered series. Thus, one may conclude that the size of the category was unlikely to be the main factor to account for NM's pattern of performance.

In fact, the finding that NM had retained preserved performances on tasks specific to the numerical domain may allow us to go a step further. NM could process syntactically complex numerals and thus he was potentially able to produce an infinite number of elements in this category. Moreover, NM could compute or retrieve the solution of simple arithmetical problems (addition, subtraction, and multiplication to a lesser extent). NM was thus able to deal with very precise semantic information supposed to be retrieved from a large network of arithmetical knowledge, in which the excitatory and inhibitory mechanisms play an important role (see e.g. Campbell, 1995). These supplementary results add some evidence in support of a category-specific preservation of the semantic representation of numerals in the face of impaired semantic processing in other categories (except days and months). Together with CG (Cipolotti *et al.*, 1991), who presented with the reverse dissociation, the case of NM suggests that numerals may constitute a relevant category at the semantic level. A straightforward explanation for the double dissociation between numerals and other words may be that the semantic of numerals is processed in separable brain regions.

One can speculate on the reason why numerals constitute a relevant category at the semantic level. One potential explanation would be that numerals emerge as a category in the semantic system because they share particular properties that may be implemented in distinct brain regions.

One such property could be that numerals are organized in an ordered sequence (Seron *et al.*, 1992). At the semantic level, this means that each numeral must be linked to the following one by a 'plus-one' link, and to the preceding one by a 'minus-one' link. The observation that, in NM, the categories of numerals, days and months were conjointly spared by the deficit fits with the hypothesis that the concepts sharing this property are grouped together in particular brain regions (that have been relatively spared in NM). Furthermore, this hypothesis is strengthened by the fact that, in contrast with NM, in CG (Cipolotti *et al.*, 1991), the categories of numerals, days and months were conjointly impaired.

Nonetheless, the observation that numerals form a relevant category at the semantic level may receive another explanation. One may propose that numerals are processed in a specific semantic sub-system stored in separable brain regions. Numerals indeed often refer to quantities, and they are subject to specific semantic manipulations such as calculation, parity judgement, etc. Moreover some preverbal counting abilities have been described in young infants (Gallistel and Gelman, 1992; Wynn, 1992). Thus it may be that a particular processing component in the brain is devoted to numerical processing (Dehaene and Changeux, 1993; Dehaene and Cohen, 1995).

So far, we do not have empirical ground to distinguish between these two hypotheses. However, whichever one proves correct, they both assume that NM's preserved production of numerals was tied to the preservation of this category at the semantic level.

In conclusion, NM's pattern of performance provides compelling evidence that numerals constitute a relevant category at the semantic level. The processing of numerals may rely on a separable neuronal network that was spared in NM although the brain region supporting the semantic representation of other words has been damaged.

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The isolation of numerals at the semantic level

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Abstract

In this study, we examine the case of a patient (NM) who could comprehend and produce numerals despite impairment on comprehension tasks and a high degree of anomia for other categories of words. It will be claimed that NM suffered from an impairment to the semantic system affecting all categories except numerals and the series of days and months. The case of a patient presenting with the exact reverse dissociation has been described a few years ago by Cipolotti *et al.* (Brain 1991; 114: 619–37). We conclude that NM's pattern of performance provides evidence that numerals constitute a relevant and perhaps a distinct category at the semantic level.

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Primary diagnosis of interest

Semantic impairment

Author's designation of the case

NM

Key theoretical issue

- Category-specific preservation for the processing of numerals at the semantic level

Key words: semantic system; anomia; numerals

Scan, EEG and related measures

CT-scan 1, CT-scan 2

Standardized assessment

Raven's Advanced Matrices (PM38); Wisconsin Card Sorting Test (Nelson, 1976); Tower of London (adaptation from Shallice, 1982); D2 Test (Hogrefe, 1962); Lateralized response time; Block-Tapping Test (Milner, 1971); Digit Span; Brown–Peterson task; BORB (Riddoch and Humphreys, 1993); LUVS (Bishop and Byng, 1984; French version); Palm Tree (Howard and Patterson, 1992; French version); Picture Naming (Bachy-Langedock, 1988); Auditory Lexical decision task

Other assessment

Reading aloud and repetition of words and non-words; picture and word classification tasks; word/picture matching task; word/picture verification task; size judgement task; oral and written picture naming tasks; naming from a definition; judgement of synonymy; production of synonyms; naming patterns of dots; reading the time; reading aloud Arabic numerals; calculation tasks; etc.

Lesion location

- Extended lesions to the left frontal, temporal and parietal lobes

Lesion type

Trauma

Language

French