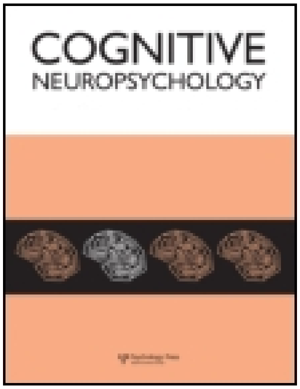

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Knowing where but not what: Impaired thematic roles and spatial language

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Knowing where but not what: Impaired thematic roles and spatial language

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We describe case J.P. who, following a left inferior frontal lesion, made frequent role confusions in comprehension and production (e.g., saying "The boy kicks the girl" for a picture showing a girl kicking a boy). J.P.'s preserved ability to judge the grammaticality of sentences rules out a syntactic deficit as the primary cause of the role confusions. Thematic role assignment is also required with spatial prepositions such as *in* or *above*, and J.P.'s thematic role assignment was also severely impaired with spatial prepositions. We capitalized on prior linguistic analyses and behavioural studies to design accurate tests of the semantics of spatial terms, spatial relations, and critical features of objects. Fine-grain semantic tests revealed that the semantics of spatial terms and objects was intact. We hypothesize that J.P.'s role confusions reflected a failure to integrate objects within semantic representations that define the thematic roles. Our data suggest that properties of objects and thematic roles are specified by distinct semantic processes, which have different brain localizations. J.P.'s lesion further suggests that left inferior frontal regions are critical in thematic role assignment, thus contributing to the understanding of the linguistic functions of these regions.

Keywords: Spatial language; Thematic roles; Semantics; Semantic impairment.

Evidence that semantic deficits can selectively affect knowledge about animals, actions, or people has recently received ample attention (for a review see Caramazza & Mahon, 2003). Such a widespread interest stems from the recognition that semantic deficits provide a rare opportunity to unveil the organization of semantic knowledge and its neural underpinnings. Another type of semantic deficit, which has received comparatively less attention, concerns so-called thematic roles—that

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is, a component of word meaning critical for determining what concepts can be related to a given word. For example, in the case of verbs, thematic roles define what concepts can undertake the actions or states described by individual verbs. Thus, the semantics of the verb *eat* licenses *dog* as a possible agent but bans inanimate concepts like *table* or *car* from taking this role. Problems in assigning thematic roles have been observed in brain-damaged individuals who seemed to retain the ability to access core aspects of word meaning (e.g., Saffran & Schwartz, 1994; Saffran, Schwartz, & Linebarger, 1998; see Berndt, 2001, for review). The opposite pattern was described in brain-damaged individuals who could assign thematic roles fairly well despite their failures in retrieving other aspects of word meaning (e.g., Breedin & Saffran, 1999; Hodges, Patterson, & Tyler, 1994). Similar to category-specific deficits, the impairments involving thematic roles are also of critical importance for understanding the functional and neural organization of semantic processing. The investigation of thematic roles in neuropsychology has focused primarily on verbs. The complexity of verb semantics and the fact that individual verbs have meanings that can differ markedly from each other are certainly factors that challenge research on the processing of thematic role assignment in verbs. Although theories of verb meaning being developed in formal semantics have become increasingly detailed in the last two decades, their impact on the neuropsychological investigation of thematic roles has been, for the most part, minimal. Our report extends the investigation of thematic roles to spatial prepositions: terms such as *in*, *between*, or *next to* that refer to spatial relations, a choice that was motivated by the availability of detailed analyses of the semantics of spatial terms both in linguistics and cognitive science. Such analyses would secure a thorough assessment of how different components of the semantics of spatial terms are affected by brain damage.

Current linguistic theories generally agree that the messages speakers want to communicate are not directly mapped onto the syntactic structures that define the linear order and hierarchical relations of the words within the sentences. There is instead an intermediate level within which thematic roles are assigned and where the relations among the concepts forming the message are specified (e.g., Bresnan, 2001; Grimshaw, 1990; Jackendoff, 1990; Van Valin & LaPolla, 1997). Thematic roles refer to abstract semantic categories that define the functions played by the individual concepts in the event. It is the network of thematic roles that is linked to the arguments forming the syntactic structure. Thus, the linear order of the words comprising the sentence “Tom gives a present to Carl” is reconstructed from a representation that assigns *Tom* the role of actor (the initiator of the event), *Carl* the role of recipient (the beneficiary of the event), and *present* the role of patient (the entity undergoing the event). Current psycholinguistic models also subscribe to this view. For example, if we consider the models of speech production, the models proposed by Garrett (1988) or Levelt (1989) embody a repartition along these lines. One of the principal arguments for postulating an additional level of processing devoted to thematic roles lies in the fact that a message can be superficially realized in multiple ways. To return to our example, the sentences “Tom gives Carl a present”, “A present is given to Carl by Tom”, and “Carl receives the present from Tom” are among the possible ways of expressing the same event. The existence of an identical thematic role structure underlying these sentences is a way of securing an equivalence of meaning despite a variability of form.

The hypothesis of an impairment selectively affecting thematic role assignment was first proposed by Schwartz, Saffran, and their collaborators in the context of agrammatism (for a review, see Saffran, 2001). A hallmark of agrammatism is the occurrence of errors characterized by thematic role confusions, as when *Tom* is incorrectly attributed the role of kisser in the sentence “Tom is kissed by Susan” (Howard, 1985; Kean, 1985). Role reversal errors, along with various sorts of difficulties in processing sentences with even moderately elaborate grammatical structures, were believed to reflect syntactic deficits. Contrary to this interpretation, it was demonstrated that at least a few agrammatic patients could detect grammatical anomalies (Linebarger, Schwartz, & Saffran, 1983; Saffran, 2001; Saffran & Schwartz, 1994). For example, it was observed that while agrammatic patients could recognize the sentence* *John kissed by Susan* as ungrammatical, they failed to understand the sentence *Tom is kissed by Susan*, incorrectly construing *Tom* as the actor. If preserved grammatical judgements suggested intact syntactic processes, they also ruled out a syntactic deficit as the primary cause of the sentence impairment observed in agrammatic patients. A second result of relevance here is that the patients who show a (relative) preservation of syntactic knowledge would not confuse one verb for the other in a word–picture matching task. For example, given the word "kiss", they would point to the target picture rather than the foil picture depicting hugging. This latter result would rule out a semantic impairment. By logic of exclusion, a deficit in thematic role assignment was proposed as the most likely cause of patients' failures with sentences. Note that if this conclusion is warranted, data from agrammatism provide a first type of evidence suggesting that there are partially different mechanisms devoted to the core meanings and the thematic roles (of verbs).

While several studies have replicated this pattern of results, conclusions about the (relative) intactness of semantic processing in agrammatism relied on the observation that verb confusions occurred rarely in picture–word matching tasks. A noticeable exception was Breedin and Martin's (1996) attempt to systematically vary the semantic characteristics of verbs. Their critical stimuli were role reversal verbs, which involved the same objects but swapped their thematic roles. An example is provided by the verbs *buy/sell*, which engage the same participants (*a buyer*, *a seller*, *money*) but with role inversions. Unfortunately, role reversal verbs tend also to have similar meanings. To rule out a contribution of semantic similarity, Breedin and Martin (1996) also tested control verbs that were matched to the role reversal verbs in terms of semantic similarity and thematic role structure. Verbs with opposite meanings (e.g., *push/pull*) were among the stimuli used to control for semantic similarity. The performance of one of the patients tested by Breedin and Martin (1996)—the agrammatic patient L.K.—is of particular relevance in the present context. L.K.'s errors were far more frequent with role reversal verbs in tasks ranging from picture naming to sentence production and sentence comprehension. L.K.'s specific difficulties with role reversal verbs suggested a problem with thematic roles rather than other aspects of verb semantics, which remained more available and could support discriminations—for example, between verbs of opposite meanings but with identical role arrangements (for converging results see also Byng, 1988).

Breedin and Martin's (1996) approach illustrates the nontrivial difficulties one encounters in determining the relative intactness of verb semantics. Not only must different groups of verbs be painstakingly matched on several variables, but, lacking a theory about verb semantics on which there is widespread agreement, one has to rely almost completely on raters' subjective intuitions. The approach taken in other studies of agrammatism—that is, the discrimination of related verbs in sentence–picture matching tasks—was certainly simpler, but probably insufficiently sensitive to reveal subtle semantic deficits.

Also of concern are the results suggesting the intactness of thematic roles in the context of semantic impairment. The progressive deterioration of semantic knowledge observed in semantic dementia offered an opportunity to examine whether semantic and syntactic deficits dissociate. A few reports have documented the persistence of syntactic abilities even during relatively advanced stages of deterioration, when semantic processing has already declined considerably. One such report was presented by Breedin and Saffran (1999). Their case D.M. performed flawlessly in a sentence–picture matching task consistently avoiding the choice of pictures showing role reversals. This result contrasted sharply with D.M.'s poor performance in tasks tapping other aspects of semantic knowledge, for example deciding whether two words were synonyms or two objects were associated. One can explain results such as those reported from D.M. by assuming partially distinct mechanisms for the meanings and the thematic roles of verbs. Unfortunately, this is not the only possible way of accounting for these findings, as pointed out by Breedin and Saffran (1999) who offered the alternative explanation that thematic role assignment could rely on basic semantic properties, such as animacy or stationary/mobile contrast, which patients could retrieve even if more specific features ceased to be available. Thus, albeit considerably impoverished, semantic knowledge was sufficient to support thematic role assignment but not finer grain semantic discriminations.

To the extent that the complexity of verb semantics is a serious challenge for an investigation of verbs, one might seek other classes of words that are not vexed by similar problems. Locatives—that is, terms denoting spatial relations—might represent a suitable alternative. Locatives such as the English prepositions *in*, *on*, or *between* also entail the assignment of semantic roles (Talmy, 1983). For example, the proper understanding of the sentence *The coffee is in the cup* requires correctly determining which of the two names take the roles of container and contained. The assignment of the thematic roles of locatives depends on the specification of the semantic features that objects must have in order to participate in certain spatial relations (Carlson & van der Zee, 2005; Coventry & Garrod, 2004; Herskovits, 1986; Landau & Jackendoff, 1993; Levinson, 2003; Levinson & Wilkins, 2006; Svorou, 1994). Together, linguistic analyses and behavioural experiments provide a fairly accurate picture of the semantics supporting locative use, thus offering a convenient framework for assessing semantic processing in neuropsychology. Another reason for directing our attention to locatives is that compared to nouns and verbs their semantics is generally coarser (Landau & Jackendoff, 1993). *In* offers an illustrative example. In its most prototypical spatial sense, the meaning of *in* reduces to a single semantic feature—containment—and entails a class of objects with some sorts of cavities that allow at least the partial inclusion of other objects (Garrod, Ferrier, & Campbell, 1999).[1] Obviously, we are better off with a simpler semantics that allows a tight experimental control. These considerations motivated our choice of locatives in our study of the agrammatic patient J.P.

Locatives were tested in a few of the prior studies of agrammatism, although sentence–picture matching has typically been the task used for assessing the semantics of locatives (Byng, 1988; Kolk & van Grunsven, 1985; Schwartz, Saffran, & Marin, 1980a, 1980b). Such a matching task required choosing the picture that corresponded to a sentence presented in either a written or an auditory format. Foil pictures were of two types; they showed either a role reversal or a different spatial relation. To illustrate, let us suppose that the target sentence was *The circle is above the square*; the role reversal foil showed a square above the circle, whereas the different locative foil depicted a circle *inside* a square. Patients frequently chose role reversal foils, less often the different location foils, although the incidence of these errors was still noticeable in many of the patients (about 15% or higher). This asymmetry in foil choice suggests a relative intactness of locative knowledge and a relative impairment of thematic roles. However, the greater accuracy for location foils may also have reflected differences in task demands. In this respect, it is instructive to have a closer look at the sentence–picture matching task used by Byng (1988) and Schwartz et al. (1980a). In each trial, patients saw three pictures showing geometrical shapes: (a) the target (e.g., *square above circle*), (b) role reversal foil (*circle above square*), and (c) different locative foil (*square on circle*). Note that while

[1] This is not to say that the meaning of *in* (or other locatives) does not exhibit a certain degree of complexity. The variety of spatial relations to which *in* applies or its extension to nonspatial domains—for example, in temporal expressions such as "in time" or "in an hour"—probably requires a meaning that entails more than cavities and partial inclusions (Hawkins, 1988). The point we want to make, however, is that the prototypical spatial meaning of *in*, as in sentences like "the milk is in the bowl" or "the flower is in the vase", is semantically simpler than the meaning of most verbs.

two pictures showed the target spatial relation described in the sentence, only one picture showed an incorrect spatial relation. Repeating the target spatial relation could have biased patients' choices. Maybe it even provided a cue that patients could use consciously to gauge their responses.

The possibility that spatial knowledge could be impaired in patients with agrammatism gains weight when we consider that lesions of the left inferior prefrontal cortex have been reported in both agrammatism and in patients showing spatial knowledge deficits. A few studies documented that patients with lesions in this area who showed grammatical deficits also had problems in choosing which prepositions correctly described the spatial relations between objects (Friederici, Schönle, & Garrett, 1982; Parisi & Pizzamiglio, 1970; Seron & Deloche, 1981). A more recent study by Tranel and Kemmerer (2004) pinpointed left inferior prefrontal cortex as one of the areas consistently associated with problems concerning the meaning of spatial terms. Moreover, the same area was also activated in a positron emission tomography (PET) study in which participants named spatial relationships using locatives (Damasio, Grabowsky, Tranel, Ponto, Hichwa, & Damasio, 2001). In brief, the implications seem to be quite clear: While current results would prevent us from drawing strong conclusions about the status of spatial knowledge in agrammatism, they also demand that we carefully examine the intactness of spatial processing in individuals with left inferior prefrontal lesions.

The role reversal errors that we recorded from patient J.P. with locatives have given us the occasion to further explore the processing of locatives in agrammatism. Like other patients with agrammatism, J.P. could detect syntactic anomalies, a result that we took to indicate a preservation of syntactic processing. The tests of spatial relations that we report here were directed at determining whether J.P.'s deficit affected thematic role assignment or the semantics of locatives. We should emphasize right at the beginning that J.P.'s role reversal errors were not confined to locatives—in fact, the patient made role reversal errors in a variety of contexts, including sentences involving verbs and adjectives. We focused our investigation on locatives for reasons that were purely pragmatic. The relative simplicity of the semantics and syntax of locatives, together with the availability of detailed linguistic analyses of locative meanings, turn locatives into model test cases for examining the structure of semantics, particularly whether distinct mechanisms are devoted to thematic role assignments.

CASE DESCRIPTION

J.P. was a 76-year-old English-speaking male with 16 years of education at the time of the present investigation. His first vocation was in graphic design but for most of his career he ran the audio-visual presentation departments of educational institutions. In 2004 he suffered a stroke affecting the superior division of the middle cerebral artery. He received thrombolytic therapy shortly after the onset of the stroke but was left with marked residual aphasia though without clear motor deficits other than moderately severe apraxia. There was no evidence of spatial neglect, finger agnosia, or right−left confusion. A computed tomography (CT) scan made shortly after the stroke revealed encephalomalacia consistent with infarct affecting parts of the inferior frontal and precentral gyri (and underlying subcortical white matter) in the left hemisphere. We conducted our first language neuropsychological assessment 4 months after his stroke. Participation in the experiments presented below started 2 months later and continued for about 6 months. J.P.'s neurological conditions remained stable during the investigation, and the result of a CT scan following its conclusion showed no change from before.

The results of our initial neuropsychological assessment indicated preserved oral naming with nouns. For example, J.P. scored within normal range in the Boston Naming Task (correct responses: 56/60, 93%; $z = +0.2$; Goodglass & Kaplan, 1972). Oral naming was, however, impaired with verbs, as demonstrated by his score with the action pictures from Zingeser and Berndt (1990; accuracy 21/30; $z = -9.44$). His errors in action naming consisted of omissions, verb substitutions (e.g., "drawing" for *writing*), and circumlocutions (e.g., "sun . . . snowman" for *melting*). Similar problems arose with verbs in a written naming task. Various lines of evidence suggested that J.P.'s difficulties with verbs did not reflect a semantic deficit. For example, required to recognize which of two verbs was closer in meaning to a probe verb, J.P. performed very well (124/127; 98%) despite the close semantic proximity of the choices (e.g., *hit* and *contact* for the probe *beat*). Spontaneous speech was severely reduced showing the distinctive pattern of agrammatism: marked reduction in the number of produced words, predominance of nouns, and frequent omissions of inflections and function words. These characteristics were quantified in an analysis of J.P.'s narration of the cookie thief picture (from Goodglass & Kaplan, 1972), which consisted of 24 words produced after several laborious attempts; 58% of the words were nouns, 21% verbs, and 21% function words. Verbal short-term memory also appeared to be impaired. J.P.'s digit span was abnormal with lists repeated forward (correct repetitions never exceeded 3 or 4 digits). He correctly repeated 17/20 high-imageability, high-frequency words, making single phoneme substitutions (e.g., /ɛkt/ for /ɛks/) for all of his errors. He read 220 of 239 words correctly (92%), showing no effects of regularity, length, concreteness, or frequency. His errors consisted of phoneme substitutions (e.g., "grit" for *grid*), or deletions and additions of single or multiple phonemes. Written spelling was also impaired; he correctly spelled 62/78 words (79%). He showed no effect of regularity, and his spelling errors consisted of letter deletions (e.g., DISTESS for *distress*), transpositions (e.g., STIPUD for *stupid*), additions (e.g., BURROUGH for *borough*), and substitutions (e.g., PROTEAN for *protein*) as well as errors that were a combination of these types (e.g., CHANTLE for *castle*).

Sentence processing

The comprehension of active and passive sentences was tested with the materials from Psycholinguistic Assessments of Language Processing in Aphasia (PALPA; Kay, Lesser, & Coltheart, 1992). On each trial, J.P. saw a sentence that was read aloud by the experimenter (e.g., "The boy kisses the girl") along with three pictures—the target, which depicted the sentence, and two foils. The foils could differ from the target in one of three ways: They could depict (a) a role reversal (the *girl* kissing the *boy*), (b) a different concept (*hugging* instead of kissing) or (c) different participants (a *man* and a *woman* kissing). Overall, J.P. chose the correct picture on 48 out of 60 trials. His performance was poorer when the target sentence was passive than when it was active (8/12 vs. 11/12 correct). On 20 trials, one of the two picture foils depicted a role reversal of the target sentence. J.P. made many mistakes on these trials (13/20 correct; 65%), and his errors mainly consisted of selecting the role-reversed picture foil (6/7). He was much better on the remaining 40 trials where both of the foils depicted incorrect concepts or participants (35/40 correct; 89%).

The comprehension of active sentences was further examined in a task that we constructed. Two pictures were made for each of 50 transitive verbs. Each picture pair involved the same actors exchanging their roles. A pair of pictures was shown to J.P. while he heard an active sentence with a subject–verb–object (SVO) structure (e.g., "The chef scolds the doctor"). J.P. chose the correct picture 76/100 times. Another task we designed was aimed at testing J.P.'s comprehension of adjective comparative constructions like *the tree is taller than the house*. Following the auditory presentation of a sentence, J.P. chose between two alternatives showing the same objects with role exchange (e.g., a taller *tree* vs. a taller *house*). In 68/70 cases, the adjective had the inflected comparative form (stem + er). J.P. responded correctly 49/70 times (70%). The results from these comprehension tasks revealed the severity and the breadth of J.P.'s sentence-processing deficit.

The retrieval of syntactic structures was tested with a grammaticality judgement task modelled after Linebarger et al. (1983). The task required deciding about the grammaticality of sentences spoken by the experimenter. Half of the 78 tested sentences were grammatically incorrect, violating 1 of the 10 grammatical rules considered by Linebarger et al. (1983). Violations involved a variety of grammatical features, including subcategorization, particle movement, and agreement (see Linebarger et al. for details about the grammatical structures and their violations). For example, in the sentence* "She went the stairs up in a hurry", the preposition *up* moved incorrectly to the right of its noun phrase object, while the sentence* "I helped themselves to the birthday cake" is characterized by a violation in the agreement between the subject and the reflexive. Each incorrect sentence was paired with a correct sentence having an identical grammatical structure—for example, the incorrect sentence* "I helped themselves to the birthday cake" was matched with the sentence "I introduced myself to the family friends". Between 7 and 8 sentences were constructed for each of the 10 grammatical structures examined in this task. J.P. correctly judged 74/78 (95%) sentences, in essence exhibiting the same accuracy level as that of three normal controls closely matched for age and education (control range = 75−77). These results provide strong evidence that J.P.'s access to grammatical structures is fairly intact, allowing us to rule out a grammatical deficit as the primary cause of his impaired sentence processing.

Locative thematic roles

Thematic role assignment in speaking

Even if the individual locatives call for roles that satisfy specific spatial relations—for example, containment for *in* and contact for *on*—their roles seem to conform to a more general distinction between figure and ground. The figure is the thing to be located, whereas the ground is the thing that serves as point of reference. Locatives typically describe the position of the figure with reference to the ground. Cross-linguistic studies have consistently confirmed this characterization, which thus appears to be universal (Levinson, 1996). Figure and ground can be unequivocally differentiated in English as they fill distinct arguments within syntactic frames. Specifically, the figure corresponds to the subject noun, so that in the sentence *The coffee is in the cup*, *coffee* takes the role of figure.

The elicitation task was designed to induce the production of figures and grounds with different locatives. J.P. was presented with pictures showing two objects in a particular spatial relation (e.g., containment); beneath each picture there was a written preposition (e.g., *in*), along with two spaces corresponding to the preposition arguments. J.P. named (orally) which object took the role of figure and ground in each picture. Different objects were tested in three variants of the task. In a first task variant, we showed two-dimensional geometrical shapes, which were chosen because they could instantiate a multiplicity of spatial relations and allow figure/ground reversals. The second task variant involved familiar objects with structural properties that only allowed certain figure/ground arrangements but prevented role reversal. Examples of the spatial relations tested in this task included "*the spoon in the cup*", and "*the bird on the branch*". The third variant of the task involved familiar objects and the preposition *next to*, which in certain conditions yields preferential figure/ground arrangements. A description of the semantics of *next* is presented below (see "Method"); here it suffices to say that its role assignment is based on subtle constraints that have been unveiled by linguistic analyses (Herskovits, 1986; Talmy, 1983). To the extent that *next to* is not based on explicit knowledge, it provides a more direct assessment of locative processing.

Several reasons motivated our choice of the elicitation task and its variants. A first reason was to determine whether the reverse errors observed with verbs and adjectives (see section "Sentence processing") would also occur with locatives. Geometrical shapes offered an ideal opportunity to address this question since their structural properties allowed figure/ground reversals. A second reason was to establish whether reverse errors also occurred when objects severely constrained spatial relations. This question has implications for understanding the nature of J.P.'s sentence-processing impairment. The absence of role reversal errors with these objects would provide a first type of evidence suggesting the (relative) intactness of locative meaning. A final reason for choosing the elicitation task was its lack of demands on verbal short-term memory. Given J.P.'s reduced verbal short-term memory (see the "Case description" section), we had to control whether this deficit would affect locative processing. Unlike the matching tasks widely used in the past for examining agrammatism, our elicitation task did not require any comparisons or decisions between stimuli. Thus, by further minimizing task demands, we reduced the likelihood that failures in this task would reflect limited resources, one of the causes proposed for agrammatics' failures (e.g., Caplan & Hildebrandt, 1988; Linebarger et al., 1983; Vallar & Baddely, 1984).

Method. Three geometrical shapes (*circles*, *diamonds*, and *squares*) were arranged in such a way as to obtain nine spatial relations (*above*, *around*, *behind*, *below*, *between*, *in*, *in front of*, *on*, and *under*). The same spatial relations (with the exception of *below*) were tested with pairs of familiar objects that (typically) take fixed figure/ground roles (see Table 1 for examples). Each spatial relation was tested an equal number of times (12 with geometrical shapes, 8 with familiar objects).

In many cases, the preposition *next to* does not prescribe a fixed noun order. It is, in fact, equally acceptable to say "the chair is next to the table" or "the table is next to the chair". Even leaving aside cases where discourse emphasis yields a preferred order, linguists have catalogued numerous instances in which certain orders occur with noticeable consistency, determining a seemingly fixed role assignment (Herskovits, 1986; Talmy, 1983). Mobility and relative size appear to be among the factors underlying this order preference. Specifically, objects that are mobile and of smaller size tend to receive the role of figure. Thus, the sentence "the bicycle is next to the garage" sounds more acceptable than the sentence "the garage is next to the bicycle", since the *bike* can be moved and is of smaller size than the *garage*. The materials for the preposition *next to* were selected on the basis of the responses obtained from a group of 10 neurologically intact native English speakers with college education. We utilized 33 photographs that elicited identical figure/ground distinctions in at least 8/10 control participants (mean identical responses: 30.8/33 pictures). Figure and ground objects occurred on the left and right sides of the photographs with comparable frequencies so that object position would not provide a reliable cue for role assignment.

The pictures for the preposition *next to* were intermingled with those of irreversible objects. Geometrical pictures were tested in a separate testing session. A preposition was shown beneath each picture. The experimenter read the locatives out loud to J.P., in order to avoid any incorrect word recognition. J.P. was instructed to name the two critical objects in the order that correctly described the spatial relation indicated by the preposition. A response was scored as correct if J.P.

Table 1. *Examples of materials tested with irreversible objects*

Pictures shown in the elicitation task	*Queries tested in the placement task*
The stamp is *above* the address	Put the bird *above* the house
The hula-hoop is *around* the girl	Put the fence *around* the windmill
The man is *behind* the camera	Put the boy *behind* the car
The spoon is *in* the cup	Put the penny *in* the cup
The flowers are *on* the table	Put the sheep *on* the box
The hammock is *between* the trees	Put the bird *below* the greenhouse
The teacher is *in front of* the backboard	Put the penny *outside* of the cup
The dolphin is *under* the water	

Table 2. *Summary of J.P.'s correct responses in tasks assessing thematic role assignment with locatives*

	Tasks	*Roles constrained by object semantics*	*J.P.: Correct responses* *N*	*%*	*z*-score
A.	Elicitation tasks[a]				
	1. Two-dimensional geometrical shapes	No	71/108	65	
	2. Familiar objects	Yes	62/64	97	
	3. Next to	Yes	32/33	97	0.46[b]
B.	Sentence comprehension tasks[c]				
	1. Reversible sentences	No	47/80	59	
	2. Irreversible sentences	Yes	24/24	100	

[a]In the elicitation tasks, we presented pictures that showed objects arranged according to different spatial relations (e.g., a dog in front of a tree). Underneath each picture, there were two blank spaces and a locative (__in front of_). The tasks required naming the objects that would fill each blank position. While several locatives were tested in Elicitation Tasks 1 and 2, only the locative *next to* was tested in Elicitation Task 3. [b]The *z*-score was based on controls' responses; see text for details. [c]In the sentence comprehension task, J.P. was given two objects (e.g., *sheep* and *farm*) and was asked to arrange them according to the experimenter's instructions ("Put the sheep in front of the farm").

named the figure and the ground in the expected order. The procedure followed in all of the tasks we reported here involved scoring the patient's first response and introducing the task with practice trials.

Results. J.P.'s responses differed markedly in the three variants of the task (see Table 2 for result summary). He was severely impaired with geometrical shapes (71/108 correct responses; 65%); invariably, his mistakes here were role reversal errors, wherein he produced the correct nouns, but in the inverted order. By contrast, with irreversible objects, J.P. named the figures and the grounds with ease, and his accuracy was particularly high (62/64; 97%). Even with the preposition *next to*, which required more subtle and less intuitive figure/ground distinctions, J.P. performed well; his responses mirrored those of the control participants 32/33 times ($z = +0.46$). The first conclusion we are able to draw from these data is that J.P.'s problems with role assignment extended to locatives. The second conclusion relates to the stark discrepancy between objects that allowed reversible versus irreversible spatial relations. Such a discrepancy offers a first indication that J.P. could access the meanings of the spatial terms.

J.P.'s responses with geometrical shapes deserve further comment. Accuracy was uneven across the different locatives, being almost at ceiling with *on*, *above*, *under*, and *below* (44/48, 92%), but at chance with *in*, *around*, *in front of*, *in back of*, and *between* (27/60, 45%). A comparison between these locatives yielded significant results, $\chi^2(1) = 25.7$, $p < .001$. This stark discrepancy was likely to reflect the different characteristics of the pictorial stimuli. In the four conditions that led to successful responses, geometrical shapes were arranged along a vertical axis, and their locations could be determined on the basis of absolute reference points. For example, the shape that was *above* or *on* occupied the uppermost position, a location that could be determined with reference to spatial cues such as page edges. Once the shapes had been anchored to their upper or lower locations, J.P. could identify that, for these prepositions, the uppermost shapes should be named first, whereas the lower shapes should be named last. In this way, J.P. could avoid having to determine the thematic roles from the relational properties of the individual shapes. When reference points for anchoring spatial locations were absent (or less noticeable), as with the prepositions *around* or *between*, J.P. could not circumvent his language impairment. More generally, the variability in J.P.'s responses to geometrical shapes represented yet another example of the constant search for cues undertaken by agrammatic patients to overcome their difficulties with sentence processing.

J.P.'s results contrast with those that Kolk and van Grunsven (1985) and Schwartz et al. (1980b) reported with agrammatic patients in a similar production task. With rare exceptions, these researchers tested spatial relations that either involved irreversible objects (*the cat is in the suitcase*) or were pragmatically constrained (*the dog is on the pillow*). Unlike J.P., patients often inverted figure/ground order in the sentences that they produced with these materials. Our results are more in line with the findings reported by Seron and Deloche (1981) with a group of patients with left-anterior cortical lesions, whose error rates were reduced as an effect of contextual biases. This disparity highlights a diversity in the types of failure possible with locative processing—specifically, the reduced responsiveness to semantic constraints could reflect the difficulties that some of the patients experience in retrieving locative meaning and/or in the interface between semantic and syntactic mechanisms.

Thematic role assignment in sentence comprehension

In order to provide a comprehensive assessment of J.P.'s locative processing, we tested his ability to understand orally presented sentences that included locatives. As in the previous task, we assessed whether objects with structural features that constrained the spatial relations would affect J.P.'s accuracy. Therefore, we showed familiar objects with which figure/ground exchanges were permissible (reversible objects) or disallowed (irreversible objects). Examples of reversible objects were *sheep* and *cow*, which could exchange the figure/ground roles with spatial relations such as *behind*. Such a reversal could not occur, for example, with the objects *car* and *boy* and the locative *in*. The design of the comprehension task was in part motivated by two of the findings from the elicitation task. First, role reversal errors were virtually absent when familiar objects were tested in the elicitation task, a finding we attributed to the semantic characteristics of the objects rather than to their familiarity. The use of familiar objects with semantic characteristics that ban thematic role exchanges would clarify the role of familiarity on J.P.'s errors. Second, J.P.'s role reversal errors were unequally distributed across the different locatives, a finding we attributed to J.P.'s use of contextual cues such as page edges, which provided critical reference frames for positioning the objects and thus determining their thematic roles. Such cues were removed in the comprehension task, and we then expect role reversal errors to be equally distributed across the different locatives we tested.

In order to minimize task demands, we did not include foils, asking the subject instead to arrange two objects as indicated by a sentence. Most of the objects used in the experiments were toy replicas of familiar objects (e.g., *car*, *sheep*, *farm*). At the beginning of each trial, the experimenter placed two objects in front of J.P., who then heard a locative sentence and arranged the objects so as to reproduce the sentence content. Sentences started with the verb *put*, followed by the figure, the locative, and the ground, as in the sentence "Put the sheep behind the cow". Eight spatial relations (*above*, *around*, *behind*, *below*, *between*, *in*, *in front of*, and *on*) were tested an equal number of times (10) with reversible objects. The preposition *between* required multiple tokens of the same object. Two figures and two grounds were given for *between* and also for a random assortment of other trials. A pair of reversible objects was tested twice with the same preposition, each time with a different figure–ground arrangement. This design proved the reversibility of the spatial relations that we queried in this task. Object pairs were presented in different testing sessions following an ABBA design. Seven spatial relations (*above*, *around*, *behind*, *below*, *in*, *on*, *outside*) were tested with irreversible objects. Each relation was tested between 2 and 5 times, for a total of 24 trials. We showed the same kind of toys (e.g., of *animals* and *buildings*) and familiar objects (*bowls*, *coins*) as those that we used in the other variant of the task. Examples are shown in Table 1. Objects of different sizes (e.g., *boy* and *car*) were showed in the two queries of *behind*, consistent with the bias that bigger objects would serve as grounds (Landau & Jackendoff, 1993). Reversible and irreversible objects were tested in different blocks. The experimenter repeated a sentence upon request, an event that occurred rarely. The accuracy of control participants was at ceiling (99%) in a similar task carried out by Seron and Deloche (1981).

J.P.'s accuracy was flawless with irreversible objects (24/24), but declined dramatically with reversible objects (47/80, 59%), $\chi^2(1) = 14.5$, $p < .001$. His incorrect responses with reversible objects consisted for the most part of reverse errors (29/33, 88%); location confusions occurred only three times (9% of the errors) and always with the preposition *below*, which was substituted once by *in front* and twice by the phonologically similar preposition *behind*. The fact that J.P. performed identically in the elicitations tasks that imposed no demands on verbal short-term memory makes it unlikely that his failures in the comprehension task stemmed from a verbal short-term memory deficit. There was a noticeable difference between the distribution of J.P.'s errors with reversible objects in the elicitation and comprehension tasks. To allow for a direct comparison, we analysed the locatives that were used in both tasks. J.P.'s errors occurred in the elicitation task with *in*, *around*, *in front of*, and *between* (15/48; 31%) but almost never with *on*, *above*, and *below* (32/36, 89%), $\chi^2(1) = 25.44$, $p < .0001$; however, J.P. performed equally poorly in the comprehension task with these two sets of locatives (26/40, 65% vs. 15/30, 50%), $\chi^2(1) = 1.03$, $p > .2$. We argued that J.P. performed well with certain locatives in the elicitation task because of cues in the materials that allowed J.P. to bypass his problems with thematic role assignment. Crucially, as soon as these contextual cues were removed in the comprehension tasks, J.P.'s accuracy dropped. These results strengthen the hypothesis that J.P. failed when responses depended solely on the identification of thematic roles.

Locative semantics

The testing of locative semantics was limited in previous studies of agrammatism to choosing between pictures representing different spatial relations (e.g., *in* vs. *around*). This task fell short of providing a thorough assessment of the intricate semantics underlying locative use. Here we used a wider range of tests to assess J.P.'s locative semantics. In particular, we attempted to determine whether J.P. could identify the regions of space and portions of objects that are critical in certain spatial relations and whether his semantic representation of space exhibited the same organization found with neurologically intact individuals. The results of the various tasks that we employed to test the locative semantics are shown in Table 3.

Locative judgement task

Discerning which preposition (e.g., *on* or *above*) better describes a certain event (e.g., *a cat snoozing on a sofa*) requires intact access to locative meanings. These types of judgements were employed to assess the availability of locative meanings. J.P. saw a picture and heard two spatial prepositions. One preposition (the target) appropriately described the spatial relation portrayed in the picture, whereas the other preposition (the foil) did not. Foils were chosen to be as close as possible semantically to targets. Thus, for example, *in* was foil for *under* with the picture of a woman *under* an umbrella. J.P.'s accuracy was high (45/47; 96%) and comparable to the one recorded from a control group of 10 native college-educated English speakers (mean: 46.1; $z = -0.75$).

The distinction between the English prepositions *on* and *above* is purely topological and

Table 3. *Summary of J.P.'s correct responses in tasks assessing the semantics of locatives and their corresponding spatial regions*

		J.P.: Correct responses	
	Tasks	*N*	*%*
A.	Locative judgement task		
	1. Picture-locative matching	45/47	96
	2. On/above discrimination	20/20	100
B.	Recognition of spatial regions		
	1. Object-centred regions	237/240	99
	2. Viewer-centred regions	40/40	100
C.	Along vs. across	19/20	95

entails whether contact occurs within a certain region of space (approximately defined as the uppermost region in reference to a certain object). The decision of whether *on* or *above* would apply in a given context does not depend on figure/ground distinctions, but on the appreciation of a topological relation. We tested whether the topological knowledge needed to distinguish *on* from *above* was available to J.P. in a decision task in which he saw a picture and indicated which locative was more appropriate for the spatial relation shown in the picture. Each locative was tested an equal number of times ($N = 20$). J.P.'s responses were invariably correct.

Location recognition task

The locations indicated by spatial terms can be ambiguous, a point illustrated by the sentence "The boy is in front of the car", which allows two interpretations. For one, it can express the idea that the boy stays anterior to the forward part of the car. The speaker's intention here is to refer to a region of space centred on the object and invariant to the speaker's position. In fact, the expression remains true even if the car and the boy lay behind the speaker. The same sentence, however, can have another connotation, one that is defined with reference to the speaker's position. It would be correct to say "The boy is in front of the car" even if the boy is near the back part of the car were it the case that the boy is closer to the speaker than the car. This interpretation depends crucially on the positions the car and the boy take relative to the speaker. The orientation of the car is irrelevant in this case, so that the expression is equally valid when the boy is close to the front versus the back of the car. What these alternative interpretations illustrate is that the proper use of locative terms implies identifying certain regions of space with reference to specific frames—that is, those centred on the objects or the speakers. Conditions preventing this would inexorably lead to failures in the understanding and production of locatives.

J.P.'s ability to identify object-centred regions of space was examined using a recognition task that demanded him to mark the *front*, the *back*, the *top*, and the *bottom* of objects. Objects were presented with a noncanonical orientation, so that object- and viewer-centred frames were not aligned. To illustrate one such case, an upside-down car had its top part facing towards the bottom. The presentation of objects with noncanonical orientations enabled an assessment of whether J.P. could identify object regions with reference to object-centred frames. We used 3-D, high-resolution computer renditions of familiar objects ($N = 80$) that in Laeng, Carlesimo, Caltagirone, Capasso, and Miceli (2002) had been judged as viewed from unusual perspectives. Stimuli were shown one at a time by the experimenter, who named the object part that J.P. was expected to mark with a pen. The four object parts were queried randomly. We prepared a second set of photographs and pictures ($N = 40$) to test the recognition of the inside and outside of objects with visible cavities, such as *bowls*, *drawers*, and *bags*. The goal of this second list was to determine whether J.P. could recognize the inner regions of objects that are relevant for using the locative *in*. The same pictures were shown to test three binary-term pairs (i.e., *front–back*, *top–bottom*, and *inside–outside*) using an ABBA design. J.P. performed remarkably well in this task: 237/240 correct (99%).

J.P.'s accuracy remained high in a task we created to assess the recognition of viewer-centred locations. Here, an object drawing was shown in the four following positions on a page: *front*, *bottom*, *right*, and *left*. The experimenter indicated the object that J.P. was expected to point to ("Point to the *left* kite"; "Point to the *top* kite"). We selected 10 object drawings to prepare 10 quadruplets. Quadruplets were repeated in four blocks, for a total of 40 trials. Within each block, an individual object appeared only once, and the four locations were tested an equal number of times. J.P. always responded correctly in this task.

Along and across

Along and *across* differed from the locatives we have tested in the other semantic tasks in that they often do not require a fixed figure/ground distinction (Herskovits, 1986; Landau & Jackendoff, 1993).

Given two series of movable objects—for example, *marbles* and *candies*—the sentences *put the marbles along the candies* and *put the candies along the marbles* appear to be equally acceptable. What counts with these locatives is whether the objects can be arranged in a certain way—in parallel or intersecting. In other words, the use of these prepositions depends on an object's structural properties. If the meanings of the locatives *along* and *across* were available to J.P., he would correctly lay the objects to reproduce the spatial relations corresponding to these locatives. This prediction was tested in 20 trials of the location task we presented above. *Along* and *across* were randomly tested together with other locatives. J.P. correctly positioned the objects 9/10 times with *along* and 10/10 times with *across*.

Locative production task

As anticipated by the linguistic analyses of Talmy (1983) and Herskovits (1986), and later confirmed empirically by Hayward and Tarr (1995), the space described by English spatial prepositions such as *above*, *to the left of*, and *beside* is uneven, showing a "core" region in which there is a strong terminological preference and peripheral regions where multiple terms can coexist. Predominant regions of use seem to fall along salient axes that originate from reference objects. Thus, it is more probable to hear the sentence "x is *above* y" when x is close to the vertical axis of y, whereas, as we move from this region, the terms "left of" or "right of" would appear with rising frequency as the distance from the axis increases. We set out to examine whether J.P.'s use of spatial terms revealed the same graded structure with fuzzy boundaries that had been observed with unimpaired speakers. To this end, we reproduced the experiment of Munnich, Landau, and Dosher (2001), which in turn was modelled after Hayward and Tarr (1995).

J.P. viewed a reference object (a square) appearing at the centre of the computer screen and a figure object (a dot) displayed in another position. An example of the display is shown in Figure 1A. The figure object appeared in one of 72 locations surrounding the reference object. Each location corresponded to one of the cells in an undisplayed

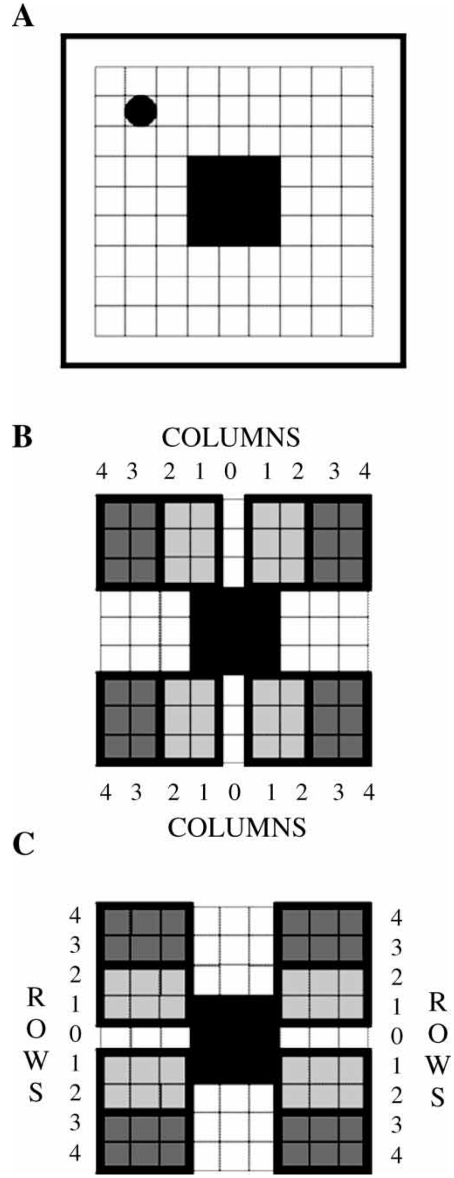

Figure 1. *Panel A shows the display used to induce the production of spatial prepositions (adapted from Hayward & Tarr, 1995). The target (a dot) appeared in one of the 72 locations around the central square. The grid was not displayed in the experiment and is included to illustrate target locations. The space was repartitioned into columns (Panel B) and rows (Panel C) to determine the incidence of locative terms referring to vertical versus horizontal planes (e.g., above, below vs. left, right). In both panels, light grey cells mark positions closer to the axes, whereas dark grey cells correspond to positions more distant from the axes.*

9×9 grid, in which the reference object occupied the nine middle cells. The grid covered an area of 11.43 cm^2. In each administration of the task, the circle randomly appeared in all of the 72 cells. The task was repeated five times in separate testing sessions. J.P. was instructed to describe the figure location using a "simple word or phrase, such as on, above, to the left or on the top of", and was told to avoid using "compass, clock face, or degree angle answers".

Responses were analysed as in Munnich et al. (2001), apart from a single exception indicated below. Participants in previous studies occasionally would respond with more than one preposition, and J.P. was no exception. In line with previous studies, we scored the first preposition produced, since participants seemed to regard the first spatial term as the "primary" descriptor. Responses were then divided into three categories depending on the locatives chosen as descriptor: (a) vertical locatives (e.g., *above*, *below*, and *over*), (b) horizontal locatives (e.g., *left*, *right*, and *beside*); (c) contact locatives (e.g., *on*). Separate analyses were then carried out for vertical and horizontal locatives, to determine whether their relative incidence varied as a function of distance from orthogonal axes. For vertical terms, we considered the 27 cells above and the 27 cells below the reference object. These cells were contained in 9 columns, which were numbered according to their distance from the middle column (designated as "0"). Specifically, the columns adjacent to the column 0 were numbered 1, the columns next to them were numbered 2, and so forth (see Figure 1B). Note that as we move from columns 1 to 4, the distance from the vertical axis increases. An arrangement in rows was utilized for the horizontal terms (see Figure 1C). The rows were numbered relative to the horizontal axis (row 0). Again, distance from the orthogonal axis increases as we move from row 1 to row 4. Because the task was repeated five times, we had five responses per position.

Results are summarized in Figure 2. To determine whether the frequency of vertical terms varied across columns, we used analyses of variance (ANOVAs) to compare the number of vertical terms elicited in the individual cells of columns

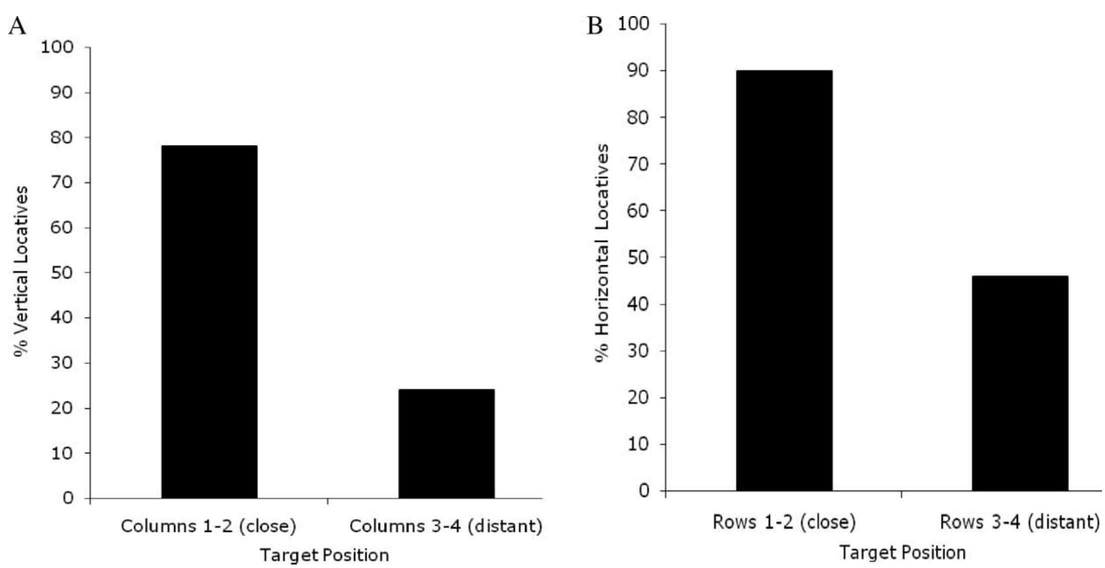

Figure 2. *Panel A: Percentage of responses in locations that were close to the reference object (columns 1 + 2) or more distant from it (columns 3 + 4) and in which J.P. used vertical terms. Panel B: Comparison concerning the responses containing horizontal terms used in reference to targets that were close to the reference object (rows 1 + 2) or distant to it (rows 3 + 4).*

1 + 2 versus columns 3 + 4. Responses were not grouped in previous studies, a procedural change we introduced in order to compensate for our smaller response set. Vertical terms were elicited more frequently by targets in cells closer to the vertical axis, $F(1,\ 23) = 65.24$, $MSE = 1.79$, $p < .0001$. An analogous analysis was carried out with the horizontal terms. The incidence of horizontal terms was also greater within the two rows of cells closer to the horizontal axis, $F(1,\ 23) = 33.64$, $MSE = 2.08$, $p < .0001$. Each of these results confirmed a graded distribution of vertical and horizontal terms that paralleled the one found with normal speakers. A final result concerns contact locatives such as *on*. These latter terms occurred only in positions adjacent to the reference objects (see Figure 3). The same tendency was reported in normal speakers by Munnich et al. (2001). This further indicated that the space carved out by different locatives is preserved in patient J.P. Note that the key of J.P.'s success in the present task hinged on the specific figure/ground distinctions demanded here. Because roles were fixed and correlated with physical cues (e.g., mobility, size), there were no uncertainties as to whether objects were figures or grounds.

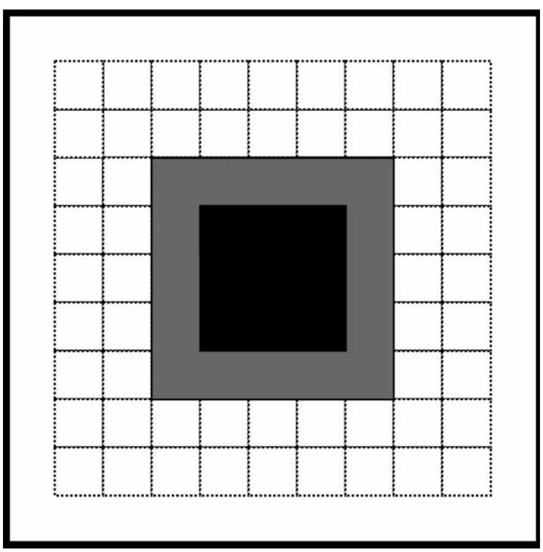

Figure 3. *The locations in which J.P. used contact locatives (e.g.,* on*) are highlighted in grey (note that these locations are only in positions adjacent to the reference object).*

Even when we adopted very subtle measurements of the spatial representations corresponding to locatives, we failed to find signs of impairment in J.P. The hypothesis that J.P.'s locative reverse errors stemmed from a lack of appreciation of their meaning received no support whatsoever in the series of tests presented in this section.

GENERAL DISCUSSION

J.P.'s acquired language impairment exhibited the classical clinical profile of agrammatism, which follows a lesion predominantly affecting the left inferior frontal areas. Errors denoting confusion in the assignment of thematic roles, one of the characteristic features of agrammatism, were frequently produced by J.P. in comprehension and production tasks requiring the identification of the thematic roles of verbs and adjectives. Of relevance here, thematic role confusions were also recorded with locatives.

Like a few other cases of agrammatism described in the literature, J.P. retained the ability to detect syntactic anomalies. Thus, it seems that J.P. can correctly represent the syntactic structures of sentences that embody spatial terms such as "the dog is behind the tree", identifying the critical phrasal elements (noun phrases, NPs, and prepositional phrase, PP) and deriving the proper order of the phrases. More generally, J.P.'s ability to detect syntactic anomalies suggests a relative intactness of syntactic processes and rules out the level of syntactic processing as a plausible locus of his thematic role confusions. On the other hand, profiting from the detailed descriptions of locative semantics provided by linguistic and psycholinguistic analyses, we could accurately chart J.P.'s knowledge concerning spatial relations and spatial terms. A series of results come together in demonstrating that J.P. could identify the regions of space and the features of objects critical for determining all sorts of spatial relations and spatial terms (see result summary in Table 3). Even subtle features, like the ones implicated in the figure/ground discrimination with the preposition *next to*, remained available to J.P. We should also note that stored semantic information is not the only type of conceptual/semantic knowledge concerning objects available to J.P. J.P. could also accurately incorporate new features into the representations of objects, as when he correctly identified which object in an array took a specific spatial location (e.g., *top* or *left*). This result is of particular relevance in the context of locatives, which often involve spatial arrangements encountered for the first time ("a pink dog behind a blue tree") or do not presuppose fixed relations among objects (a spoon is typically *in* a cup, but it can also be *behind* or *under* a cup). These results allow us to rule out the possibility that J.P.'s difficulties with locatives reflect a more general problem in updating the representations of objects.

To the extent that the semantics of locatives and syntactic processes were intact, and by the logic of exclusion adopted in previous studies (e.g., Caramazza & Miceli, 1991; Linebarger et al., 1983), damage affecting thematic role assignment appears to be the most plausible locus of J.P.'s failures with locatives (but also words of other classes, including verbs and adjectives). This conclusion is consistent with the finding we demonstrated in several of our tasks that J.P.'s problems of figure/ground discrimination disappeared with objects preventing role reversals (see result summary in Table 2) or when cues such as page edges provided a framework for reliably determining the thematic role of an object. Insofar as thematic roles emerged naturally from object semantics or other reliable cues, it was no longer necessary to assign thematic roles on the basis of contextual information provided by pictures (in the production task) or spoken sentences (in the comprehension task). Such conditions effectively neutralized J.P.'s problems with thematic roles.

Theories in linguistics, psycholinguistics, and cognitive neuroscience have attempted to detail the processes implicated in thematic role assignment, and we should turn to these theories to further characterize J.P.'s thematic-role deficit and its implications for language processing. A particularly appealing proposal is the extended argument dependency model (eADM) advanced by Bornkessel and Schlesewsky (2006), as it combines a rather detailed description of the cognitive processes responsible for thematic role assignment with a theory of the neural underpinning of such processes. The model focuses on comprehension and has been applied to verbs, more specifically the assignment of the core roles of actor and undergoer, terms that in current linguistic theories correspond to the agent and patient prototype roles (see, e.g., Dowty, 1991; Van Valin & LaPolla, 1997). Actor and undergoer are assumed to stand in a dependency relationship, with the undergoer hierarchically dependent upon the actor. Locatives resemble verbs in that they imply the core roles of figure and ground, which also appear to stand in a hierarchical relationship. Given these similarities, the model can be feasibly extended to locatives, thus providing a framework for interpreting J.P.'s results.

In the eADM model, two types of partially independent processes are assumed to determine the actor/undergoer (and figure/ground) assignment. The first process uses prominence information, a set of features that allow listeners to determine the core thematic roles and their hierarchy in the absence of information about the specific verb (or locative). Prominence information can be language specific. Linear position is a language-specific prominence feature of English. Actors and figures typically precede undergoers and grounds in English sentences. On the basis of linear position, the first argument in an English sentence receives the role of actor or figure. Other types of prominence information could be critical in other languages, including morphological case in languages like German or Russian, or animacy in languages like Fore, spoken in Papua New Guinea. A second process for core role assignment draws upon the stored semantic representations of verbs or locatives, which specify the number and hierarchy of thematic roles taken by each lexical form. This second process is responsible for linking the role structure associated with a specific verb or locative to the core arguments obtained from prominence information, agreement, and voice (active, passive).

Within the eADM model, the role exchange errors that J.P. made in the *comprehension tasks* with verbs and locatives can be accounted for in terms of a failure to use the prominence feature of linearization. This type of deficit led J.P. to incorrectly assign the role of actor (or figure) to the second argument encountered in the sentence. According to this account, J.P.'s deficit would arise at the interface between syntax and semantics. Positing this form of damage, the eADM model also predicts that J.P. would be able to understand semantically constrained locative sentences. The model assumes a system that integrates all available sources of information to determine the final argument structure. This system is sensitive to factors like plausibility and world knowledge and can allow implausible argument structures to be repaired to plausible ones. Thus, using the knowledge that, for example, cats can be on the roof and not vice versa, J.P. can short-circuit the linearization problem that otherwise would have prevented him from correctly interpreting the sentence "the cat is on the roof".

However, this account of J.P.'s deficit makes it difficult to explain the parallel findings in sentence *production*—in this task, J.P. made role reversal errors but not when the roles in the sentence were semantically constrained. First, it is not clear that a deficit that causes problems in mapping linear positions to arguments would also yield problems in mapping arguments to linear positions. However, even if we assume that a linearization problem in English could affect the responses in the production tasks, this deficit would not explain the intact performance that J.P. demonstrated with semantically constrained sentences in the production tasks. Indeed, semantic or pragmatic knowledge would be of little help to circumvent a linearization problem in the production tasks. Even if semantic knowledge could have established "cat" as the object likely to be "on" in a scene describing a cat on the roof, a linearization problem would jeopardize the correct insertion of "cat" in sentence initial position. The hypothesis of a linearization problem predicts the wide occurrence of thematic role confusion in the production tasks, without any effect of whether or not the semantics of the objects would naturally prevent role exchanges. But this is not what we observed with J.P., whose performance was virtually flawless when production tasks with locatives involved objects with constraining semantic characteristics. In essence, the hypothesis of a linearization deficit at the interface between syntax and semantics is unlikely to account for the entire pattern of errors observed with J.P.

If the syntax-semantic interface is not the locus of J.P.'s deficit with thematic role assignment, the hypothesis that gains plausibility is one that locates J.P.'s deficit at the semantic level. With this hypothesis, J.P.'s problem consists of linking the semantic roles of figure and ground specified by the locative with object concepts that temporarily instantiate these roles. To the extent that the semantic level of processing is equally involved in speech comprehension and production, this account is naturally consistent with the type of deficit observed in J.P., which spans both of these modalities. Although a problem of this nature is expected to affect the assignment of any kind of thematic role, it is effectively neutralized by previously acquired semantic knowledge concerning what locatives can apply to which objects. Like the pieces of a jigsaw puzzle that naturally join, J.P. could combine an object's semantic feature (e.g., *cavity*) to the proper role (*container)* given a certain spatial relation (*in/containment*). This approach to the understanding and encoding of spatial relations is certainly limited, lacking the capacity and flexibility to which thematic roles empower language. Taken at face value, J.P.'s results with locatives suggest a fractionation within semantic processing, whereby distinct neural mechanisms are implicated in the representation of word meaning and thematic role assignment.

Identical patterns of results were found with J.P. for locatives and verbs: Both word classes led to role reversal errors despite evidence of preserved knowledge of their meaning. J.P.'s results converge with the data recently reported by Wu, Waller and Chatterjee (2007), who investigated thematic roles with locatives and verbs in a group of left-hemisphere-damaged patients using a sentence–picture matching task. The numbers of role reversal errors with locatives and verbs were significantly correlated in the group of patients tested by Wu et al.[2] Altogether, the neuropsychological evidence suggests that the processing of the thematic roles of verbs and locatives is supported by neural mechanisms that, to a certain extent, are shared between these word classes. This conclusion does not rule out that discrepancies could exist in the way in which thematic roles are represented for verbs and locatives, as advocated by linguistic theories and cognitive neuroscience accounts. Various linguistic theories have proposed that though marked differences exist among the thematic roles corresponding to individual verbs, these roles coalesce into prototypical categories, which have been differently labelled in the literature as macroroles (Foley & Van Valin, 1984), protoroles (Dowty, 1991; Primus, 1999), hyperroles (Kibrik, 1997), and generalized semantic roles (Van Valin & LaPolla, 1997). Most of the proposals identify the core roles of agent-like and patient-like as the cardinal arguments of the transitive predication expressed by verbs. Arguably, these core roles do not map into the prototypical roles of figure and ground implied by the locatives. Within the neural-functional account put forward by Wu et al. (2007), differences between the representation of the thematic roles of verbs and spatial terms stem from the distinct neural networks supporting the processing of each of these word classes. Specifically, it is hypothesized that a postero-lateral temporal network involved in the processing of visual motion provides what Wu et al. refer to as the "point of entry" for the thematic relations of verbs, whereas a fronto-parietal network associated with the visual tracking of moving objects and the reaching and grasping of objects in the environment represents the "point of entry" for the thematic roles of locatives.

The dissociation we observed in J.P. between impaired thematic role assignment and intact grammatical processing as a result of left frontal damage is in line with neuroimaging results that demonstrate the involvement of different left frontal areas in semantic versus syntactic processes. For example, Newman, Just, Keller, Roth, and Carpenter (2003) compared violations that differentially affected the syntactic structures and thematic roles of sentences presented in a grammaticality judgement task. Activation differed between the two left inferior frontal areas of interest, namely the pars triangularis and the pars opercularis, with the first area responding more to semantic violations and the second area more to syntactic violations. A similar pattern was observed in these areas by Friederici, Opitz, and von Cramon (2000) in a task requiring the identification of semantic and syntactic features of single words (i.e., concreteness vs. grammatical class). A series of neuroimaging findings reported by Bornkessel and collaborators (Bornkessel & Schlesewsky, 2006; Bornkessel, Zysset, Friederici, von Cramon, & Schlesewsky, 2005; Grewe et al., 2005, 2006) further highlighted the involvement of the left inferior frontal gyrus (the LIFG), particularly the pars opercularis, in thematic role processing in tasks that investigated the comprehension of written sentences in German. From the perspective of the eADM model we discussed above, Bornkessel and collaborators hypothesized that the pars opercularis of the LIFG is engaged in the processing of prominence features that allow an automatic interpretation of thematic roles and sits at the interface between semantics and syntax. In particular, the results indicated that both word order and animacy are processed within the pars opercularis for the purposes of thematic role assignment, thus suggesting that this neural structure can process information of different types (morphosyntactic, semantic) when engaged in

[2] Wu et al. (2007) also observed dissociations in a small number of their patients, who showed impaired scores only when tested on the thematic roles of verbs or locatives. Data about semantic knowledge were only reported by Wu et al. for verbs. The patients who failed specifically with the thematic roles of verbs also obtained scores that were borderline or below controls' range in the verb semantic test, suggesting that the impaired performance with the thematic roles of verbs could have reflected a more general problem with the semantic of verbs. The patient reported by Wu et al. with a selective deficit for the thematic roles of locatives could have had a more general impairment with spatial relations, like the cases reported by Tranel and Kemmerer (2004).

sentence comprehension. As we argued earlier, it is unlikely that J.P.'s deficit reflected a problem in using prominence features for the purposes of deriving thematic roles. Consistent with this interpretation, and on the basis of the neuroimaging data that we have reviewed here, one would anticipate that the pars opercularis is relatively spared in patients who exhibit the pattern of performance that we demonstrated in patient J.P. Patients like J.P., whose difficulties with thematic roles are rooted in semantic processing, seem more likely to have suffered from a lesion affecting the pars triangularis, which neuroimaging data link to thematic role assignment that draws upon semantic processing.

The implications of J.P.'s results that we have discussed up to this point hold for thematic roles in general, given that convergent results were obtained with thematic roles from word categories as different as locatives, verbs, and adjectives. However, our focus on locatives has further implications for neurocognitive accounts of locative processing. There is converging evidence from the few neuroimaging studies that have investigated the production of locatives that a cluster of areas are associated with this task, including the left frontal operculum and the left supramarginal gyrus (Damasio et al., 2001; Emmorey et al., 2002; for a review, see Kemmerer, 2006). The data from neuroimaging studies further converge with the lesion data reported by Tranel and Kemmerer (2004) and Wu et al. (2007). Deficits in the naming and comprehension of locative prepositions were most likely to be observed in patients with lesions affecting the posterior left frontal operculum, the white matter subjacent this region, and the inferior parietal operculum. These problems with spatial locations could not be explained by impaired object recognition or spatial processes, given that patients performed relatively well in tasks assessing object identification and spatial processes. J.P.'s intact knowledge about the meaning of spatial locations paired with the fact that his lesion was circumscribed to left frontal regions may provide additional clues for understanding the functional organization of the structures underpinning the processing of spatial terms. J.P.'s data suggest that knowledge critical for spatial terms is likely to rely upon left parietal regions rather than on more frontal structures. A similar proposal was put forward by Landau and Jackendoff (1993) based on the idea that the parietal lobe, as part of the "where" system, could play an integral role in the processing of spatial meaning. J.P.'s data further indicate that frontal structures are involved in the processing of spatial terms not because such structures are spatial specific, but probably as a result of the linguistic characteristics that spatial terms share with other word classes, particularly thematic role assignment and phonological processing. The disruption of these general linguistic processes would affect the processing of spatial terms, whereas the disruption of parietal regions would selectively affect the processing of the meaning of spatial terms. Although these conclusions are tentative at present, they make the clear predictions that left frontal lesions would not produce selective deficits for locatives, whereas left parietal damage would not affect thematic role assignment.

In closing, we would like to emphasize our choice of approaching the study of semantics from the perspective of locatives. The study of semantics is notoriously challenging. Our choice was purely a matter of convenience; the relative simplicity of locatives, coupled with detailed linguistic and behavioural descriptions of their pragmatics and semantics, makes these forms ideal objects of investigation for understanding the neural mechanisms of sentence processing and their breakdown in conditions of brain damage. We hope that our study could encourage the analyses of locatives in future investigations of semantic deficits. More importantly, however, we hope that as semantic theories become increasingly detailed for a broader set of word categories, cognitive neuroscientists will be able to reach more confident conclusions on the nature of semantic impairments.

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