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A DOUBLE DISSOCIATION BETWEEN LINGUISTIC AND PERCEPTUAL REPRESENTATIONS OF SPATIAL RELATIONSHIPS

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This paper explores from a neuropsychological perspective the relation between the meanings of English locative prepositions (e.g., *in, on, above, below*) and the kinds of representations that are used for many visuospatial processes such as recognising, drawing, and constructing spatially complex objects. One possibility that has been proposed by some psycholinguists is that the meanings of prepositions are the same as the representations used in these other processes. An alternative possibility, which has been proposed by a different group of researchers, is that the relation is more distant such that the meanings of prepositions constitute language-specific semantic structures that are distinct from the representations that underlie many visuospatial abilities.

Here we report a detailed assessment of the linguistic as well as perceptual and cognitive representations of spatial relationships in two brain-damaged subjects. Four tests were administered that involve both the production and comprehension of English locative prepositions. In addition, four standardised neuropsychological tests that probe high-level nonlinguistic visuospatial perception and cognition were administered. Case 1 was significantly impaired on all of the preposition tests but was normal on all of the visuospatial tests. In striking contrast, Case 2 was normal on all of the preposition tests but was significantly impaired on all of the visuospatial tests. The subjects also had entirely different brain lesions: Case 1 had a left-hemisphere lesion in the frontoparietal region, and Case 2 had a right-hemisphere lesion in the frontoparietal and temporal regions. Together, the results constitute a "double dissociation," suggesting that the preposition tests and the visuospatial tests require cognitively and neurally distinct mechanisms that can be disrupted independently of each other. We interpret the data as supporting the second possibility described—namely, that the meanings of locative prepositions may be language-specific semantic structures that are separate from the mental representations underlying many other kinds of high-level nonlinguistic visuospatial abilities.

INTRODUCTION

Over the past few decades, an increasing amount of research has addressed the relationship between linguistic and perceptual representations of space. This work has come from many different perspectives, including linguistics (e.g., Haviland & Levinson, 1994; Jackendoff, 1983; Lakoff, 1987; Pütz & Dirven, 1997; Senft, 1997; Svorou, 1994; Talmy, 1983; Zelinsky-Wibbelt, 1993), anthro-

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pology (e.g., Danziger, 1998; Levinson & Brown, 1994; Perkins, 1992), psychology (e.g., Bloom, Peterson, Nadel, & Garrett, 1996; Bryant, 1997; Miller & Johnson-Laird, 1976; Pederson et al., 1998), artificial intelligence (e.g., Herskovits, 1986; Regier, 1996), and neuroscience (e.g., Friederici, 1982, 1985; Landau & Jackendoff, 1993; Leikin, 1996). The focus of this paper is on the question of whether the meanings of locative prepositions (e.g., *in, on, above, below*) are independent of the mental representations that are used in many visuospatial tasks such as recognising, drawing, and constructing spatially complex objects. We describe here two brain-damaged subjects who exhibit a double dissociation between knowledge of English prepositions and performance on a variety of visuospatial tasks, suggesting that linguistic and perceptual representations of spatial relationships are cognitively and neurally distinct. We begin by reviewing background information on how spatial relationships are encoded in language and in the visual system.

The linguistic representation of spatial relationships

The standard linguistic expression of an object's location contains three elements: a description of the object to be located (henceforth "figure"); a description of a reference object (henceforth "ground"); and a locative element that specifies the spatial relationship between the figure and the ground. Descriptions of figure and ground objects are generally provided by noun phrases (NPs), and locative elements generally consist of a restricted set of grammatical morphemes (usually no more than 100) whose syntactic category varies across languages—prepositions, postpositions, affixes, or other predicates such as verbs. This is illustrated in the English sentence *The cat is on the mat.* The NP *the cat* describes the figure; the NP *the mat* describes the ground; and the preposition *on* specifies the nature of the spatial relationship between the two objects—roughly, "the figure has contact with, and is supported by, the ground."

Most locative prepositions have a network of distinct but closely related meanings, i.e., they are polysemous. One meaning is usually considered basic or prototypical, while the others are nonbasic or extended because they violate certain semantic features that are essential to the central meaning (Lakoff, 1987; Langacker, 1987; Pustejovsky, 1995; Sandra & Rice, 1995; Taylor, 1995). For example, *in* prototypically designates a spatial relation of interiority in which (1) the ground is a three-dimensional object, (2) the ground is a hollow container, and (3) the ground completely, or nearly completely, encloses the figure. But each of these features can be violated, yielding extended meanings of the preposition. Consider, for instance, the following situations: (1) a person standing *in* a circle painted on the floor (ground is two-dimensional); (2) a nail *in* a board (ground is solid); and (3) an apple *in* a bowl, even though it rests on top of other fruit such that it is technically above the horizontal upper edge of the bowl (figure not enclosed by ground).[1]

Locative prepositions can be divided into two broad classes—topological and projective (Frawley 1992). Topological prepositions designate spatial relationships that do not depend on a particular point of view and that remain invariant under many kinds of change to the objects involved. The only thing that matters is that certain structural properties of the spatial relationship between figure and ground are satisfied. For example, a ball may be *in* a box regardless of whether the box is upright or turned on its side, and regardless of whether the contours of the box are bent or twisted or otherwise distorted; what must remain constant is simply that the ball is within the boundaries of the box. Besides *in,* which specifies containment, other topological prepositions in English include *on* (contact and support), *around* (encirclement), and *through* (penetration). In contrast to topological prepositions, projective prepositions designate regions of space,

[1]Although there is substantial evidence that most prepositions are polysemous and display prototype effects, some researchers have argued that all prepositions have a single, highly abstract meaning and that variation in interpretation comes from contextual and pragmatic factors (e.g., Levinson, 1983, 1995; Ruhl, 1989). This controversy is not directly relevant to the present study, however.

i.e., locations, that are projected from the major dimensional axes of the ground object. Thus, *above* and *below* specify relations of superiority and inferiority defined in terms of the up-down axis of the ground; *in front of* and *in back of/behind* specify relations of anteriority and posteriority defined in terms of the front-back axis of the ground; and *beside* and *between* specify relations of adjacency and mediality defined in terms of the horizontal axis of the ground. Sometimes the determination of the principal axes of an object depends on the frame of reference that is adopted (Carlson-Radvansky & Irwin, 1993; Jackendoff, 1996; Landau, 1996; Levinson, 1996a). For example, many objects, such as persons, have an intrinsic front and back, but others, such as trees, do not, in which case the "orientation-mirroring observer frame" is adopted such that the front of the object is typically construed as the side facing the figure.[2]

Extensive crosslinguistic research has shown that an especially interesting feature of locative elements is that their meanings do not seem to depend on detailed spatial properties of the figure and ground objects but instead are highly schematic. Usually the only properties they are sensitive to are very general geometric features (volumes, surfaces, lines, and points), axial structure (top/bottom, front/back, left/right), and quantity (e.g., *between* requires two ground objects, and *among* requires an aggregate). No constraints are placed on the specific shapes of the figure and ground objects, leading Landau and Jackendoff (1993) to suggest that no language should have a locative element like the hypothetical *sprough,* which means "reaching from end to end of a cigar-shaped object," as in *The rug extended sprough the airplane.* In addition, no constraints are placed on the constituent parts of the figure and ground objects, ruling out hypothetical prepositions like *betwaft,* which requires the ground to have a protruding part, as in *The stripe extended betwaft the cup,* i.e., it went along/down the junction between the body of the cup and the handle (Landau & Jackendoff, 1993). As a third and final illustration, no constraints are placed on the specific sub-regions of ground objects that are containers, rendering impossible such hypothetical prepositions as *plin,* which means "contact with the inner surface of a container," as in *Bill sprayed paint plin the tank,* i.e., on the inside surface of the tank (Landau & Jackendoff, 1993).[3]

The perceptual representation of spatial relationships

It is generally accepted that multiple representations of space coexist and cooperate in generating our perceptual understanding of the visual world (e.g., Feldman, 1985; Lieblich & Arbib, 1982; Paillard, 1991; Thier & Karnath, 1997). In one of the most well-developed theories of high-level visual perception and cognition, Kosslyn (1994) argues for a distinction between two fundamental types of spatial representation—coordinate and categorical.[4] Coordinate representations encode

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[2]In some languages, however, such as Hausa (Chadic, Africa), the "orientation-preserving observer frame" is adopted such that the front of the object is construed as the side facing away from the observer, or, more precisely, the side facing in the same direction as the observer.

[3]It is important to note, however, that a few languages have been reported that appear to violate the tendency for locative elements to designate highly schematic spatial relationships. The most striking example is Tzeltal (Mayan, Southern Mexico), which has approximately 240 closed-class "positional" verbs (deriving from roughly 70 roots) that classify on the basis of specific geometric features of the figure. For instance, there are separate terms for the following types of figure "to be located": a bowl-shaped object, a narrow-mouthed container in upright position, an inverted object with flat surface down, a small sphere, a large sphere, and things in a bulging bag (P. Brown, 1994). Another language that seems to violate the schematicity principle, only this time with regard to the spatial properties of the ground object, is Makah (Wakashan, Northwest Coast). This language has closed-class grammatical morphemes that designate the following types of locations: at the margin along the water, at the rear of a house, at the base of an upright object, at a rocky point of land, at the head of a canoe, and so forth (Davidson, 1999). The implications of rare languages like these for theories of the semantics of locative expressions are still being explored.

[4]This distinction is similar to others that have been proposed, such as continuous ("dynamic") vs. discrete ("symbolic") (Turvey & Carello, 1986), fine-grained vs. prototypical (Huttenlocher, Hedges, & Duncan, 1991), metric vs. topological (Poucet, 1993), and low-frequency vs. high-frequency (Ivry & Robertson, 1998).

metric relations of distance, orientation, and size (e.g., two inches long, 60° angle). Because they are very precise, these representations are especially useful for guiding action. In particular, Kosslyn suggests that they play an important role in the visuomotor control of reaching, grasping, and throwing behaviours as well as in the programming of saccadic eye movements. In addition, they may contribute to object recognition when it is necessary to discriminate between objects that have subtle shape differences (e.g., the neck of a swan vs. that of a goose). In contrast, categorical representations encode fairly large equivalence classes of schematic spatial relationships between entities (e.g., connected/disconnected, left/right, above/below, near/far, etc.). Because of their generality, these repesentations are useful for specifying the rough locations of different objects relative to one another (using an allocentric frame of reference) or relative to the self (using an egocentric frame of reference). Kosslyn points out that another major function of categorical representations is in object recognition. As he put it, "very few types of objects must be discriminated based purely on the metric spatial relations among their parts. Rather, to identify a stimulus as a member of a category, such as a dog or bike, one needs to ignore the precise spatial arrangements among parts—which vary for different exemplars" (Kosslyn, 1994, p. 193). Consider, for example, a dog that is curled up with one leg wrapped around its head. If one has stored information about the categorical spatial relations among typical dog parts (e.g., "the head is at the *front* of the body"), this information can be used to guide attention so that important characteristics can be identified (Kosslyn & Koenig, 1992, p. 101).

A large body of evidence indicates that the neural substrates of spatial representation include the parietal lobes. Although both hemispheres contribute to both coordinate and categorical spatial representations, it appears that the right parietal cortex is dominant for coordinate ones and the left for categorical ones. For example, lesion studies have shown that tasks requiring coordinate representations—such as determining whether two angles have the same orientation, or encoding the precise position of a dot—are impaired more by right than left parietal damage (Goldenberg, 1989; Hannay, Varney, & Benton, 1976; Laeng, 1994; Mehta & Newcombe, 1991; A.M. Taylor & Warrington, 1973; Warrington & Rabin, 1970). Conversely, lesions in the left parietal cortex, especially in the region of the angular gyrus, sometimes lead to Gerstmann syndrome, one aspect of which is difficulty distinguishing left from right—a categorical judgement (e.g., De Renzi, 1982; Mayer et al., 1999; see also Laeng, 1994). In addition, PET and fMRI studies have revealed activation in both left and right parietal lobes for both types of spatial representations, but greater right-hemisphere activation for coordinate than categorical representations and greater left-hemisphere activation for categorical than coordinate representations (Baciu et al., 1999; Kosslyn, 1994). Finally, psychological studies have shown that the right hemisphere is faster than the left for judging coordinate relations, whereas the left is faster than the right for categorical relations (Kosslyn et al., 1989; Servos & Peters, 1990); however, these hemispheric asymmetries in reaction times are only true of right-handers—left-handers do not exhibit significant laterality differences (Laeng & Peters, 1995).

Are linguistic and perceptual representations of spatial relationships independent?

Given the foregoing discussion, it seems clear that the meanings of locative prepositions should be independent of the coordinate spatial representations that are used in visuomotor control and in precise geometric aspects of object recognition. This is because the kinds of spatial representations encoded by prepositions are highly schematic in nature and hence more categorical than coordinate. But then the question arises as to the relation between the meanings of locative prepositions and the categorical representations that are used in understanding the general locations and the internal spatial organization of objects. For instance, are the meanings of prepositions like *in* and *out* identical to representations involving containment that are used in perception and cognition, or are they separate language-specific structures?

Evidence from developmental psycholinguistic studies suggests a close relation between linguistic and perceptual representations of space. Crosslinguistic research has shown that children tend to acquire locative elements in a consistent order: first come elements for topological and functional notions like containment (*in*), contact and support (*on*), and occlusion (*under*); next come elements for notions involving proximity (*next to, beside, between*); then come elements for the projective relationships *in front of* and *in back of/behind* when the ground has an intrinsic front and back; and finally come elements for these same projective relationships only when the ground does not have an intrinsic front and back so that an egocentric frame of reference must be invoked (see Bowerman, 1996a, for review). This progression corresponds to Piaget and Inhelder's (1956) claims about the developmental course of nonlinguistic spatial knowledge, and for this reason it has been taken as strong evidence that the acquisition of locative elements is significantly influenced by the maturation of the relevant spatial notions (H. Clark, 1973; Freeman, Lloyd, & Sinha, 1980; Johnston, 1984, 1985; Johnston & Slobin, 1979; Mandler, 1992, 1996; McCune-Nicholich, 1981; Parisi & Antinucci, 1970; Slobin, 1973). In reviewing this literature, Bowerman (1996a, p. 386) points out that "for many years it has been widely assumed that the meanings children assign to spatial words reflect spatial concepts that arise in the infant independently of language, under the guidance of both built-in perceptual sensitivities and explorations with the spatial properties of objects." Thus, according to this view, the acquisition of locative prepositions simply involves mapping particular words directly onto particular pre-existing spatial representations that developed for perceptual and conceptual purposes. But although it is undoubtedly the case that nonlinguistic spatial development plays an important constraining role in how children learn the meanings of locative elements, this does not necessarily imply that the categorical representations encoded by prepositions are the same as the ones used in perception and cognition.

In fact, evidence from crosslinguistic studies of spatial semantics suggests a more distant relation between linguistic and perceptual representations of space. The major finding of these studies is that languages vary considerably in how they carve up space for purposes of communication; indeed, languages often partition space into completely orthogonal, crosscutting categories (for reviews, see Bowerman, 1996a, 1996b; Levinson, 1996a, 1996b). For example, consider the different ways in which English, Dutch, and Finnish refer to the spatial relations shown in Figure 1 (Bowerman, 1996b). English treats (a) as a containment relation designated by the preposition *in;* all the other relations involve some kind of contact and support and hence are designated by the preposition *on:* (b) handle on pan, (c) bandaid on leg, (d) ring on finger, (e) fly on door, (f) picture on wall, and (g) cup on table. Like English, Dutch distinguishes (a) from the other situations, using the cognate preposition *in.* However, it divides the remaining situations into three different classes: (d) is designated by *om,* which specifies relations involving encirclement;[5] (b) and (f) are designated by *aan*, which specifies relations in which the figure has contact with the ground by means of attachment, typically in the form of hanging or projecting;[6] and (c), (e), and (g) are designated by *op,* which specifies relations in which the figure is supported by the ground either by gravity or by some inherent force.[7] In Finnish yet another categorisation system is employed, this one using postpositional case-markers instead of prepositions. Briefly, situations (a) through (e) are designated by the marker *-ssa,* which specifies relations in which the figure is either inside the ground or

[5]Bowerman (1996b) points out that *om* is similar to English *around* but is used much more freely for relations of encirclement: "English speakers prefer or even insist on *on* for encirclement relations involving contact with and support by the ground (e.g., ring on/??around finger, diaper on/??around baby, pillowcase on/??around pillow), while Dutch speakers typically use *om* for these relations.

[6]Other situations that would be designated by *aan* include icicles hanging from a roof, a dog on a leash, and a helium balloon on a string (Bowerman, 1996b).

[7]*Op* would also be used to designate paint on a door and raindrops adhering to a window (Bowerman, 1996b).

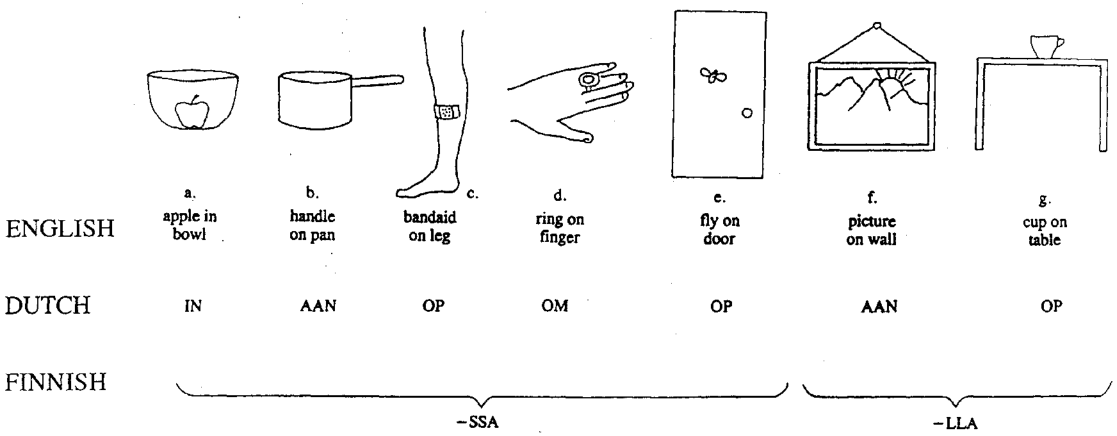

Figure 1. *Crosscutting semantic categories of locative elements in English, Dutch, and Finnish. Adapted from Bowerman (1996b).*

"intimately" in contact with it, and situations (f) and (g) are designated by the marker *-lla,* which designates relations in which the figure has some form of loose or non-intimate contact with the ground. Another striking example of crosscutting spatial categorisation systems involves the contrasts between English and Korean (Bowerman, 1996a, 1996b; Choi & Bowerman, 1991). In English an apple *in* a bowl and a video cassette *in* its case are treated as similar (both containment relations), and a cup *on* a table and a lid *on* a pan are treated as similar (both contact relations); but in Korean a video cassette in its case and a lid on a pan are treated as similar (both *kkita* "bringing a figure into a relation of tight three-dimensional meshing or fit vis-á-vis a ground"), an apple in a bowl is treated as a distinctive spatial relation (*nehta* "putting a figure into a loose container"), and a cup on a table is treated as another distinctive spatial relation (*nohta* "putting a figure loosely onto a surface"). A final example demonstrates that crosslinguistic differences extend to projective spatial relations. In English and other Indo-European languages, the use of familiar terms like *left* and *right* is based on an egocentric frame of reference, but in many other languages, such as Arandic (Pama-Nyungan, Australia), terms like these do not exist; instead, the location of a figure with respect to a ground is designated by elements that specify absolute geocentric directions like (in rough translation) *north, south, east,* and *west* (Levinson, 1996a, 1996b; Pederson et al., 1998). Remarkably, these elements are commonly used at every level of scale, from inches to miles.

The point of these examples is as follows. Because there is so much diversity and idiosyncrasy in how languages carve up space, the development of nonlinguistic spatial knowledge is probably not sufficient to provide children with the spatial categories that are encoded by their native language. Thus it is possible, even likely, that children build entirely new, language-specific representations of categorical spatial relationships in response to the linguistic input they are exposed to. It is as if the spatial expressions in the native language serve as "invitations" to discover and construct new spatial categories that reflect the unique perspective on the spatial world that is embodied in the language (Bowerman, 1996a, 1996b; R.W. Brown, 1958). These representations would of course derive from visuospatial experience, but it is reasonable to assume, at least tentatively, that they would nevertheless be structurally independent of the categorical representations used in perception and cognition. After all, if the linguistic representations of space were also used in perceptual and cognitive processes, there would potentially be substantial cross-cultural differences in rather fundamental aspects of mental life—a situation that is generally considered to be highly improbable. We take up this delicate issue of cross-cultural relativity at greater length in the "Discussion."

The approach taken by this study

The purpose of this study is to adopt a neuropsychological perspective in exploring the question of whether linguistic and perceptual representations of space are independent. As stated earlier, the meanings of locative prepositions appear to be independent of coordinate spatial representations. This predicts that the two types of mental representations have different neural substrates and hence should dissociate from one another in brain-damaged subjects. On the other hand, different theories take different stances on the issue of whether the meanings of locative prepositions are independent of the categorical spatial representations used in perception and cognition. According to one theory, the two types of mental representations are actually identical such that, for example, the specific notion of "intimate contact" encoded by Finnish *-ssa* serves double duty, being activated not only when the locative marker is used but also when the notion of "intimate contact" is involved in nonlinguistic perceptual or conceptual processing. In other words, the same mental representation is shared by both linguistic and nonlinguistic systems. This theory predicts that performance on linguistic and nonlinguistic tasks should always pattern together in brain-damaged subjects, either always being impaired together or always being preserved together. Conversely, according to the other theory the two types of mental representations are more distantly related such that, for example, the meaning of *-ssa* is a language-specific semantic structure that is activated when the locative marker is used but is not necessarily involved in various kinds of nonlinguistic perceptual and conceptual processing. In other words, the semantic structure is only activated when a person has to structure his or her conceptualisations of space in such a way that they can be mapped into language—what Slobin (1996) calls "thinking for speaking." This theory predicts that the two types of mental representations have at least partially different neural substrates and that, for this reason, brain-damaged subjects might manifest dissociations between linguistic and nonlinguistic tasks. We describe here two brain-damaged subjects who exhibited a double dissociation between locative prepositions and perceptual representations of both coordinate and categorical spatial relationships, thus supporting the latter theory which maintains that linguistic and perceptual representations of space are cognitively and neurally distinct.

EXPERIMENT 1

Methods

Subjects

Two brain-damaged subjects participated in this experiment after giving informed consent in accordance with the Human Subjects Committee of the University of Iowa. 1978JB is a 53-year-old right-handed female with 12 years of education. She had a left-hemisphere lesion involving the inferior and middle temporal gyri, the inferior half of the pre- and post-central gyri, and the most anterior sector of the supramarginal gyrus, the insula, and part of the lenticular nucleus. She was tested 4 years post-onset. 1688PG is a 53-year-old right-handed male with over 20 years of education. He had a right-hemisphere lesion involving cortex in the inferior and middle frontal gyri, the pre- and post-central gyri, the inferior parietal lobule, the temporal pole, the superior and middle temporal gyri, and the insula; part of the basal ganglia; and much of the white matter in the right hemisphere. He was tested 9 years post-onset. Before participating in the experiments described here, both subjects had undergone extensive neuropsychological and neuroanatomical investigation according to the standard protocols of the Benton Neuropsychology Laboratory (Tranel, 1996) and the Laboratory of Neuroimaging and Human Neuroanatomy (Damasio, 1995; Damasio & Damasio, 1989). Neither subject had significant difficulty attending to visual stimuli, and neither subject had aphasia severe enough to prevent understanding instructions or producing coherent verbal responses. It should be noted that although 1688PG had left-sided visual neglect in the acute phase of his disease, this manifestation had essentially resolved by the time the experiments reported here were administered.

These two subjects were compared with 10 brain-damaged control subjects. All of the control subjects were right-handed; six were male and four female; age ranged from 29 to 70 years (mean = 49.0, S.D. = 13.4); and education ranged from 11 to 16 years (mean = 13.3, S.D. = 2.1). Three subjects had left anterior temporal lobectomies; two had left occipital lesions and one had bilateral occipital damage; two had right superior temporal lesions; one had a left ventromedial frontal lesion; and one had a right basal ganglia lesion.

Materials

Four tests were administered that assessed the subjects' production and comprehension of English locative prepositions. The stimuli for all four tests consisted of black-and-white photographs of objects in various spatial relationships. Some of these photographs were taken from the Photo Resource Kit (Pro-Ed, 8700 Shoal Creek Blvd., Austin, TX 78758), and others were specially constructed by the authors. Each picture was intended to correspond to a single English preposition, although in some cases two prepositions were appropriate. In each picture, the figure was explicitly indicated by a red arrow and the ground by a green arrow. These arrows were meant to help the subjects identify the relevant objects in the pictures. A total of 80 pictures were used, and these were associated with the following prepositions: topological—*on* (13), *in* (13), *around* (3) and *through* (3); projective—*above/over* (13), *below/under* (13)[8] *in front of* (6), *in back of/behind* (6), *next to/beside* (6) and *between* (4). Instances of many of the prepositions varied with regard to prototypicality so that the range of the subjects' competence could be evaluated in a controlled fashion. This variation is discussed in detail in Appendix A, where all 80 stimuli are described.

The first test, which is called Naming, included all 80 pictures organised in random order. The pictures were presented on a Caramate 4000 slide projector in free field. Each picture was associated with a question that was designed to elicit the preposition describing the spatial relationship between the figure and the ground—e.g., "Where is the cord in relation to the telephone?" (answer: *around*). Subjects were instructed to respond with single prepositions and avoid other types of words such as nouns, verbs, and adjectives. They were also told to be as precise as possible in selecting prepositions, e.g., being careful to distinguish between near-synonyms like *above* and *over.* The intent here was that the mental operations required by this test would involve mapping the visuospatial representation of the picture onto the most appropriate prepositional semantic structure, and then retrieving the phonological form of the preposition so that it can be articulated.

In the second test, called Matching #1, the same 80 pictures were presented again in the same order, only this time the subjects were asked to choose which of three prepositions best describes each situation—e.g., "The dog is *in/on/above* the box" (answer: *in*). The sentences were both read aloud to the subjects and presented to them in written format, so short-term memory requirements were negligible. For each item, one of the distractors was intended to be closely related to the target preposition whereas the other was intended to be more distantly related. For example, the picture for the item just described shows a dog sitting in a box, but the dog's shoulders, neck, and head extend above the top edges of the box, thereby making the preposition *above* a possible description of the situation, but not as pragmatically appropriate as *in.* This test differs from the Naming test insofar as it requires

[8] *Over* and *under* are not synonymous with *above* and *below*, respectively, because the former prepositions sometimes include a topological component. In particular, they can be used to designate spatial relationships in which one object is not only superior to another but also extends down around it to some degree; in other words, the relation is one of partial encompassment or covering. For example, it seems more appropriate to say that a penny is *under* than *below* an inverted cup on a table. This difference between the two pairs of prepositions was systematically manipulated in designing the stimuli for this study (see Appendix A for details).

comprehension rather than production of prepositions. In addition, it has a linguistic emphasis since it requires comparing the visuospatial representation of each picture with the semantic structures of three different prepositions, and then selecting the best match.

In the third test, called Matching #2, subjects were shown 50 sets of three pictures drawn from the ones in the Naming test and were asked to choose which picture in each set best represents a given preposition. Each set was presented on a legal size page with the pictures arranged verti-cally. At the top of the page was a question that asked which picture best represents a given preposition, e.g., *in*. As with the Matching #1 test, one of the distractors was closely related to the target while the other was distantly related. Pictures showing *between* relationships were not included because they necessarily involve three key objects, whereas pictures for all of the other prepositions involve only two key objects. The number of pictures representing each preposition was as follows: *on* (8), *in* (8), *around* (3), *through* (3), *above/over* (8), *below/under* (8), *in front of* (4), *in back of/behind* (4), *next to/beside* (4). In contrast to the Matching #1 test, the emphasis here is more on visuospatial processing, since the subject must compare the representations of three different pictures with the semantic structure of a single preposition and then select the best match.

In the last test, called Odd One Out, subjects were shown 45 sets of 3 pictures drawn from the ones in the Naming test, with each set composed and presented in the same manner as in the Matching #2 test. For this test, however, the question at the top of each page read: "Which spatial relationship does not match the others?" The red and green arrows pointing to the figure and ground objects were crucial because without them subjects would not be constrained in selecting which objects, and hence which spatial relationships, to attend to. Care was taken, however, to ensure that subjects could not rely on just the placement of the arrows in performing the task but rather had to focus on the objects that the arrows pointed to. For some of the picture sets, the two "similar" pictures both represented prototypical instances of the same preposition (e.g., radio on table, and cap on chair), whereas for other picture sets, one of the pictures represented a prototypical instance and the other a nonprototypical instance of the same preposition (e.g., cat on kitchen counter, and telephone on wall). Pictures showing *between* relationships were excluded for the same reason as in the Matching #2 test.

Many of the items in this test probably require access to the language-specific semantic structures of prepositions.[9] For example, one item has the following three pictures: design on side of coffee cup, boy on tricycle, and eggs in carton. In order to determine that the first two pictures are similar while the third is the "odd one out," one has to recognise that the first two pictures both represent spatial relationships that involve "contact" but not "containment," whereas the third picture represents a spatial relationship that involves both of these features, especially the latter. These are the language-specific semantic features that distinguish *on* from *in*. If one did not take these semantic features into account but instead relied solely on nonlinguistic perceptual features to perform the task, it is unlikely that one would be able to arrive at the correct answer because there are so many perceptual dimensions along which the pictures could be compared. For instance, one could treat the first picture as the "odd one out" because it represents a spatial relationship in which the figure is literally part of the ground, whereas the second and third pictures represent spatial relationships in which the figure and ground are independently moveable entities. In fact, in some languages in the world it is precisely this distinction that is relevant to the semantics of locative elements; in such languages, e.g., Polish, the first type of spatial relationship is not really treated as a spatial relationship but rather as a relationship involving "inalienable possession" which is expressed by a genitive construction such as "the design *of* the cup" (Bowerman, 1996a). It is also worth noting that speakers of a language like Tzeltal, which incorporates specific geometric features of the figure and ground objects into the

[9]We do not yet know, however, exactly how many of the items in the test are like this. It is a topic of ongoing research.

meanings of locative elements, would probably perform very differently on this test than English speakers because they would categorize the spatial relationships shown in the pictures according to criteria that are simply not relevant to English (see Footnote 3).

Norming

Longer versions of the Naming and Matching #1 tests containing 150 pictures were administered to 2 separate groups of normal control subjects. Each group consisted of 60 college students who obtained course credit for their participation, and each group was administered only one of the tests. Only pictures that elicited a high degree of name agreement (the degree to which subjects produce the same naming response to a given stimulus) were included in the final 80-item versions of the tests. Sixty-four of these pictures were given the same preposition, or else what we consider to be synonymous prepositions such as *beside/next to,* by 90% or more of the control subjects. The remaining 16 pictures all showed spatial relationships involving verticality, and although the control subjects' responses were restricted to either *above* or *over* (for superiority relations) and to either *below* or *under* (for inferiority relations), less than 90% of the subjects had a preference for one of the two near-synonymous terms in each pair. Further details about these 16 pictures are provided in Appendix A. We assume that the name agreement properties of all 80 items transfer to the Matching #2 and Odd One Out tests because the same pictures were used in these tests.

Scoring

For each item in the Naming and Matching #1 tests, the brain-damged subjects' responses were scored as correct or incorrect based on the proportion of normal control subjects who gave the same responses. As pointed out earlier, most of the pictures were associated with a single preposition (or with synonymous prepositions) by 90% or more of the control subjects, so if a brain-damaged subject selected a different preposition, this was counted wrong. For the items involving verticality relationships in which there was more variation across the control subjects regarding *above/over* and *below/under* responses, either preposition from each near-synonymous pair was considered correct for brain-damaged subjects. The picture-name associations derived from the Naming and Matching #1 tests were used to establish scoring protocols for the Matching #2 and Odd One Out tests.

Results and discussion

The performances of 1978JB and 1688PG were evaluated by comparing their responses with those of the 10 brain-damaged control subjects. The results are shown in Table 1, which presents the percentage of correct responses made by the subjects on each of the four tests. Across all four tests, the mean scores for the 10 brain-damaged control subjects were only slightly lower than the baseline established by the normal control subjects, which indicates that these subjects have intact knowledge of locative prepositions.[10] Subject 1688PG also performed extremely well on the four tests, with scores that were within 2 SDs of the mean for the brain-

[10] Although the scores for the brain-damaged control subjects are near ceiling, this should not be interpreted as evidence that the tests are not challenging enough to serve as effective tools for measuring knowledge of locative prepositions. First of all, the items in the tests varied in terms of semantically determined difficulty because they covered prototypical as well as nonprototypical senses of the prepositions. In addition, 1978JB performed poorly on all four tests, which demonstrates that it is certainly possible to fail them. Finally, if the items in the tests had been made more difficult in order to avoid ceiling effects, this would have led to the following problems. Normal control subjects would probably associate each picture with several different prepositions instead of just one, and this decrease in name agreement would considerably weaken the power of the tests to evaluate knowledge of prepositions. Having test items with a high degree of name agreement is especially important in the domain of locative prepositions because they constitute a very small class, and an important goal of the tests is to assess knowledge of the distinctions between the members of the class. Furthermore, it is likely that increasing the difficulty of the items would increase the extent to which subjects use nonlinguistic problem-solving resources to carry out the tests, and then it would be hard to determine whether poor performance was due to a linguistic impairment or a more general cognitive impairment.

Table 1. *Percentage correct on each preposition test for 1978JB and 1688PG; scores for the brain damaged control subjects are given as mean percentages (*SD*s)*

Test	*1978JB*	*1688PG*	*Controls*
Naming	45	94	95.4 (3.9)
Matching #1	83	99	97.8 (2.3)
Matching #2	72	96	99.4 (1.3)
Odd One Out	73	98	97.1 (4.0)

Table 2. *Distribution of 1978JB's errors across prepositions in the Naming and Matching tests: Cells indicate the number of items that were missed out of the total possible*

Preposition	*Naming*	*Matching #1*	*Matching #2*
on	7/13	0/13	0/8
in	8/13	4/13	3/8
around	2/3	1/3	0/3
through	1/3	0/3	1/3
above/over	12/13	4/13	4/8
below/under	2/13	1/13	2/8
in front of	6/6	2/6	2/4
in back of/behind	1/6	1/6	1/4
next to/beside	3/6	1/6	0/4
between	1/4	0/4	-
Total errors	43/80	14/80	13/50

damaged control subjects (in some cases, higher). However, 1978JB's scores for all four tests were well over 2 SDs below the mean for the brain-damaged control subjects, indicating that her knowledge of locative prepositions is severely impaired.[11] Her worst performance was on the Naming test, where she got less than half of the items correct and obtained a score that was over 12 SDs below the mean for the control subjects. Her performances on the other three tests were somewhat better, but still far below normal. It is important to note that the fact that her percentage correct on the Naming test was considerably lower than on the other tests does not necessarily imply that the Naming test was more difficult for her than the other tests. This is because in the Naming test there is a wide variety of possible responses, whereas in the other tests there are only three possible responses. Hence the chances of making errors are much greater in the Naming test than in the other tests.

An investigation of the errors that 1978JB made on the tests provides further insight into her impaired knowledge of locative prepositions. Table 2 shows the distribution of her errors across the prepositions in the Naming test and in the two Matching tests. For all three tests, the errors were distributed fairly evenly across topological and projective prepositions, and there were no appreciable differences between error rates for prototypical and nonprototypical instances of the various prepositions. For the Naming test, there was a much greater proportion of errors for *above/over* than *below/under,* and for *in front of* than *in back of/behind,* but these asymmetries were not manifested as strongly in the two Matching tests. It is worth noting that the greater proportion of errors for *above/over* than *below/under* may be due to the fact that for many of the *above/over* items only one of the two prepositions was considered appropriate, whereas for all of the *below/under* items either preposition was considered appropriate (see the Appendix for further details). In fact, several of 1978JB's errors for the *above/over* items consisted of producing *over* instead of *above* (see Table 3). Another interesting feature of Table 2 is that a large number of errors were made for *on* in the Naming test but not in the two Matching tests. Finally, it is important to note that 8 of the errors for the Naming test consisted of no response whatsoever, and 13 errors involved perseverative uses of the preposition *over.*

A drawback of having very strict scoring criteria for the Naming test is that a subject could produce a

[11]Several sources of evidence suggest that 1978JB's poor performance on the preposition tests cannot be attributed to an impaired ability to recognise the relevant objects in the pictures. First, although her scores were defective on an independent test of *naming* different categories of living and nonliving concrete entities, her scores were within normal limits on a test of *recognising* the same entities (see Tranel et al., 1997, for description of the tests). Second, her object recognition abilities were sufficient to perform well on the Hooper Visual Organisation Test (see Experiment 2). Third, during the testing session she gave no indications of having difficulty in recognising the objects in the pictures. Finally, the figure and ground objects in every picture were clearly marked wtih red and green arrows, respectively, and 1978JB's colour perception is normal, so even if she did have some mild problems with object recognition, at least the arrows designated the relevant objects in each picture.

preposition which, from an objective point of view, accurately characterises the spatial relationship shown in the picture, but which is nevertheless considered wrong because less than 90% of the normal control subjects produced the same preposition for the picture. An example would be saying that a clock is *over* instead of *above* a sign. Some of 1978JB's errors were of this type; however, a large proportion of her errors were prepositions that were not produced by any of the 60 control subjects and that clearly suggest an underlying semantic disorder. Table 3 lists all of 1978JB's naming errors (excluding the eight "no response" errors) and also provides measures of the proportion of control subjects who gave the same prepositions in response to the pictures (see the Appendix for additional details about the specific items). Examples of errors that stand out as being especially unusual are the following: a boy *over* instead of *on* a tricycle, a boy *over* instead of *on* a swing, a baseball *over* instead of *in* a glove, eggs *on* instead of *in* a carton, a spoon *by* instead of *in* a cup, a knife *beside* instead of *in* a jar,

Table 3. *1978JB's naming errors together with measures of the number and percentage of 60 normal control subjects who produced the same response*

Situation and target preposition	*1978JB's response*	*Controls who gave same response as 1978JB*
hat on floor	over	0
boy on tricycle	over	0
pictures on wall	front	0
plant on table	over	1/60 (1.6%)
design on cup	in	0
cat on counter	over	0
boy on swing	over	0
spoon in cup	by	0
plant in circle	over	0
lightbulb in socket	over	2/60 (3.3%)
knife in jar	beside	0
comb in hair	front	0
baseball in glove	over	0
eggs in carton	on	0
top outlet above bottom outlet	beside	0
2nd floor window above 1st	over	0
title above author	on top	0
"passport" above design	over	0
kite above woman	up	0
stamp above address	on top	0
clock above sign	over	0
"P" above "anytime"	over	1/60 (1.6%)
top drawer above second one	on	0
1st floor window below 2nd	beneath	0
umbrella over/above woman	by	0
table over/above hat	on top	0
hat under/below table	on	0
stapler in front of cup	behind	1/60 (1.6%)
woman in front of man (1)	under	0
woman in front of man (2)	under	0
boy in front of boy	under	0
pole in front of boy	between	0
boy behind boy	under	0
boy beside bicycle	over	0
spoon beside cup	under	0
apple beside banana	by	0

one electrical outlet *beside* instead of *above* another, one drawer *on* instead of *above* another, and an umbrella *by* instead of *over* a woman. Many blatant errors were also made in the two forced-choice Matching tests, supporting our conclusion that there is a disruption of 1978JB's knowledge of the meanings of locative prepositions.

For the Odd One Out test, 1978JB made errors on 12 of 45 items. Five of the items that were missed require distinguishing the "odd" picture from two that show spatial relationships designated by *in*. The other items that were missed contain two pictures exemplifying several other topological and projective prepositions—*on, around, over,* and *beside.* As with the Naming and Matching tests, errors did not depend on whether the pictures illustrated prototypical or nonprototypical instances of the prepositions.

EXPERIMENT 2

Methods

Subjects

The subjects for this experiment were 1978JB and 1688PG. No brain-damaged control subjects were necessary, since all of the tests used in this experiment are conventional neuropsychological tests for which extensive demographically corrected normative data are available.

Materials and procedure

To assess the subjects' nonlinguistic visuospatial abilities, four standardised neuropsychological tests were administered. The first of these was the Benton Judgement of Line Orientation test (Benton, Hamsher, Varney, & Spreen, 1983; Benton, Hannay, & Varney, 1975; Benton & Tranel, 1993), which measures the ability to represent coordinate spatial relationships more or less independently of categorical ones. The subject is shown a semicircular array of 11 lines that are of equal length and that vary in orientation by evenly spaced angular degrees, from 0° (line 1, horizontal) through 90° (line 6, vertical) to 180° (line 11, horizontal). Two shorter lines of different orientations are presented above the semi-circular array, and the subject's task is to determine which lines in the array they correspond to. While performing this task, cerebral blood flow increases bilaterally in the temporal and parietal lobes, but the greatest increase is in the right hemisphere (Hannay et al., 1987). In addition, performance is impaired more by right than left posterior lesions (Benton et al., 1975, 1983; Benton & Tranel, 1993). Because locative prepositions encode categorical rather than coordinate spatial relationships, it would be natural for brain-damaged subjects to exhibit a dissociation between performance on the preposition tests and performance on the Line Orientation test.

The remaining three tests were used because, although they were not specially designed to evaluate the integrity of perceptual representations of categorical spatial relations in a pure fashion, there are good theoretical reasons for believing that mental representations of this type are required by the tests. (Moreover, it is likely that the tests also depend on perceptual representations of coordinate spatial relations.) Because the tests probably require perceptual representations of categorical spatial relations, they provide a suitable nonlinguistic comparison with the preposition tests. The aim is to determine whether performance on the visuospatial tests can dissociate from performance on the preposition tests, since a dissociation would support the view that the kinds of categorical spatial representations encoded by locative prepositions are language-specific semantic structures independent of the kinds of categorical spatial representations that are used for perceptual purposes.

In the Hooper Visual Organization test (Hooper, 1983), the subject is shown line drawings of familiar cut-up objects with the parts arranged at unusual orientations, and is asked to name each object. Categorical spatial representations may be required because stored information about how the parts of the objects are related may need to be accessed and used to guide the mental reconstruction process—e.g., one may need to know that the spout of a teapot is "on the side of the body," that the head and claws of a hammer are "opposite each other," that the dorsal fin of a fish is "on the top," that the whiskers of a mouse are "at the front" and the tail is "at the back," and so forth. The task may also require coordinate representations because the subject may need to mentally re-orient the object parts and piece them back together such that the edges are properly aligned. Because both types of spatial representations are employed in performing the test, it is not surprising that low scores do not differ on the basis of side of lesion (Lezak, 1995).

In the Taylor Complex Figure test (L.B. Taylor, 1979), the subject is shown an abstract, geometrically complex line drawing with many distinguishable components arranged in various spatial relationships, and is asked to copy it as accurately and quickly as possible. Categorical representations are probably used by most normal subjects to capture the organisational features of the figure—e.g., "square and circle are in bottom right quadrant," "circle is inside square", "triangle is on left side of left rectangle," "star is in upper left part of upper right square", etc. In fact, the scoring system for many aspects of the test is expressed in terms of these kinds of categorical relationships, and many subjects work through the test by treating the figure as a complex design with many componential structures that can be handled in stages. Perceptual representations of coordinate spatial relations may also be necessary to capture the precise lengths, orientations, and sizes of the different parts of the figure. Performance on the test is impaired by both left-side and right-side lesions (Lezak, 1995).

The last test was Three-Dimensional Block Construction (Benton et al., 1983), which is similar to the Complex Figure test but includes the features of three-dimensionality and more complicated manual praxis. The subject is shown three increasingly complex configurations of wooden blocks of different sizes and shapes, and is asked to reconstruct each configuration as accurately and quickly as possible with an assortment of loose blocks. Once again, both categorical and coordinate representations may be employed in carrying out the task, since it may be necessary to recognise and reproduce not only the particular schematic spatial relationships between the blocks but also their precise sizes, angles, and distances. Failure on the task occurs twice as often in subjects with right-side lesions as in subjects with left-side lesions, perhaps because of the praxis component (Benton, 1967).

Results and discussion

The subjects' performances were evaluated according to standardised protocols (Lezak, 1995). The results for each subject on each of the four tests are shown in Table 4. 1978JB performed within the normal range on all four tests, which suggests intact perceptual representations of spatial relationships. In contrast, 1688PG had difficulty with all four tests, with his best performance being at the "borderline impaired" level on the Line Orientation test. On the Hooper Visual Organisation test, he missed 15 of 30 items. Some of his errors were as follows: fish → duck or egg; teapot → telephone; cat → person; flower → bird or bush; mouse → goose; lighthouse → map; shoe → firetruck. On the Taylor Complex Figure test, his score placed him just above the 20th percentile norms for control subjects, and he made a considerable number of both coordinate and categorical errors. Finally, on the Three-Dimensional Block Construction test, his score placed him in the "grossly defective" category, and he made a total of nine block omissions and two block substitutions.

GENERAL DISCUSSION

The results of these two experiments reveal a double dissociation between linguistic and perceptual representations of spatial relationships. 1978JB has impaired knowledge of locative prepositions as shown by her significantly low scores on all four tests and by the kinds of errors that she committed. Her impairment appears to affect topological as well as projective prepositions and is not sensitive to

Table 4. *Scores on nonlinguistic visuospatial tests for 1978JB and 1688PG*

Test	*1978JB*	*1688PG*
Line Orientation	22 (low average)	20 (borderline)
Visual Organization	43 (normal)	75 (impaired)
Complex Figure	28 (normal)	22 (impaired)
Block Construction	29 (normal)	20 (impaired)

the distinction between prototypical and extended meanings of prepositions. In striking contrast to her performance on the preposition tests, she was within normal limits on all of the nonlinguistic visuospatial tests. On the other hand, 1688PG displays exactly the opposite profile. He performed quite well on the preposition tests but clearly has a severe impairment of nonlinguistic visuospatial abilities as indicated by his scores and error patterns on the four standardised neuropsychological tests in the second experiment.

It was predicted that the kinds of categorical spatial representations encoded by locative prepositions should dissociate from the kinds of coordinate spatial representations that are specifically required by the Benton Line Orientation Judgement test, but the two subjects did not perform very differently on this particular visuospatial test—1978JB's score of 22 was classified as "low average" and 1688PG's score of 20 was classified as "borderline impaired." However, the two subjects did manifest substantial differences in their performance on the other three visuospatial tests, and because these tests are also hypothesised to require coordinate representations, the prediction was still confirmed. Even more interesting, though, is that these three visuospatial tests, especially the Hooper Visual Organisation test, provide measures of categorical spatial representations. For this reason, the double dissociation between the preposition tests and these three visuospatial tests supports the view that the categorical representations encoded by prepositions are independent of the ones necessary for nonlinguistic perceptual and cognitive tasks.

1978JB's left frontoparietal lesion included the supramarginal gyrus, and there is evidence suggesting that this brain area contributes to the neural implementation of the meanings of locative prepositions. Specifically, a recent PET study found that this region is significantly activated when subjects retrieve locative prepositions to name line drawings of objects in different kinds of spatial relationships (Damasio, Grabowski, Hichwa, & Damasio, 1998). Thus it is possible that 1978JB's lesion disrupted the categorical representations encoded by prepositions while largely sparing the left-hemisphere categorical representations necessary for carrying out the visuospatial tasks. One might think that 1978JB simply relied on coordinate spatial representations, for which the right hemisphere is dominant, to carry out the visuospatial tasks, but this is unlikely. First, it is probably not possible to perform well on the Hooper Visual Organization test by using just coordinate representations because the test may require knowledge of the *general types* of spatial relationships among the parts of structurally complex objects—the sort of information that, by definition, is provided not by coordinate representations but rather by categorical ones. In addition, 1978JB's performances on the Complex Figure and Block Construction tests were not at all out of the ordinary; in fact, her score on the Complex Figure test was slightly above the mean for her age range. Yet if she was relying solely on coordinate spatial representations to accomplish these tasks, one would expect her performances to be somewhat deviant since it is likely that normal subjects employ both coordinate and categorical representations to execute the tasks. On the other hand, although it is possible that 1978JB's lesion spared the left-hemisphere categorical representations involved in perception, an alternative possibility is that the lesion disrupted those representations together with the ones encoded by prepositions, and that her good performance on the visuospatial tests was due to reliance on categorical representations in the right hemisphere. After all, it is only assumed that the left hemisphere is dominant for these types of representations, not that they are mediated solely by this hemisphere.

Turning to 1688PG, his lesion included regions of the right frontal, parietal, and temporal lobes. Because the lesion was in the right hemisphere, it did not affect the categorical spatial representations encoded by locative prepositions. It did, however, affect the coordinate spatial representations that are employed in the Benton Line Orientation Judgement test and presumably also in the other three visuospatial tests. Moreover, it is reasonable to suppose that the lesion also disrupted categorical representations in the right hemisphere since this would explain his extremely poor performance on the three visuospatial tests that are hypothesised to require these types of representations. In fact, this subject's profile suggests that the categorical representations in the left hemisphere are not sufficient to achieve good performance on these visuospatial tests.

Given that the results of this study support the independence of linguistic and perceptual representations of space, the question arises as to how these distinct types of representations are "translated" for purposes of language production and comprehension. Although this is not the place to enter into a full discussion of the relevant issues, we can say that the process of converting perceptual and conceptual representations into language-specific semantic structures probably involves some kind of metamorphosis of the information content, an operation that Slobin (1996) calls "thinking for speaking." As Levinson (1997, p. 22) put it, "we will have to hold that there is some kind of regimentation, reorganisation, and embellishment of the original thought into a fully specified form that matches the grammatical and semantic structure of the language" (see also Pinker, 1989; Wienold, 1995; Kemmerer, 1999). This becomes more understandable when one considers the extent of crosslinguistic diversity in spatial semantics reviewed in the Introduction. It is worth emphasising that such diversity is not restricted to the domain of spatial semantics but encompasses many other aspects of lexical and grammatical meaning. For instance, in discussing the English sentence *The man is sick* and the corresponding expressions in a variety of American Indian languages, Boas (1911/1966) pointed out that in Siouan one would have to indicate whether the man is moving or at rest; in Kwakiutl one would have to indicate whether he is visible or nonvisible to the speaker and also whether he is near to the speaker, hearer, or a third person; and in Eskimo one would just say "man sick" without having to specify definiteness, tense, visibility, or location. Boas remarked that "when we consider for a moment what this implies, it will be recognised that in each language only a part of the complete concept that we have in mind is expressed, and that each language has a peculiar tendency to select this or that aspect of the mental image which is conveyed by the expression of the thought" (Boas, 1911/1966, pp. 38–39; see Slobin, 1996 for further discussion).

Recently an increasing amount of research has been concerned with the question of whether language-specific semantic structures have an influence on the habitual thought patterns of speakers (e.g., Gumperz & Levinson, 1996; Lee, 1996; Lucy, 1992a, 1992b; Pederson et al., 1998). For example, Pederson et al. administered a battery of visuospatial tests involving perception, memory, and reasoning to speakers of languages that use geocentric terms like *north, south, east,* and *west* instead of egocentric ones like *left* and *right* (e.g., Arandic), and also to speakers of languages that use egocentric terms instead of geocentric ones (e.g., Dutch). The investigators found that there was a significant tendency for the different groups of subjects to employ the linguistically encoded spatial frame of reference in the nonlinguistic visuospatial tests. At first sight, these results appear to be at odds with the results of the present study. However, the findings can be reconciled in the following way. It is possible that normal subjects often use self-directed inner speech to cognitively "negotiate" many tasks so that the layout of the task is not just represented in perceptual and motor formats but is also linguistically metarepresented for purposes of reflection and analysis (Carruthers, 1998; Clark, 1998; Dennett, 1998; Frawley, 1997). When the linguistic system is impaired, however, as in 1978JB, it may still be possible to accomplish many of the same tasks by relying on the primary representational systems. It should be apparent, though, that much more research on this topic must be conducted before a detailed understanding of the issues will be possible.

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APPENDIX A

The stimuli for the preposition tests consisted of 80 pictures that were associated with the following prepositions: *on* (13), *in* (13), *around* (3) and *through* (3); *above/over* (13), *below/under* (13), *in front of* (6), *in back of/behind* (6), *next to/beside* (6) and *between* (4). All of the items are described here.

For *on* there were 13 pictures. These pictures are described in Table A1 together with indications of their degree of prototypicality as defined in terms of which of the following semantic features are satisfied: figure supported by ground, figure superior to ground in gravity frame of reference, and figure contacts ground. Seven items satisfied all three features; three satisfied only the first and third features; one satisfied only the first and second features; and two satisfied only the third feature. With respect to the feature of "support," we assume that it only applies when the figure and ground are separate objects that can be moved independently of each other.

For *in* there were also 13 pictures. Table A2 provides descriptions of these pictures as well as prototypicality rankings in terms of the following features: ground is three-dimensional, ground in hollow, and ground mostly contains figure. Seven items satisfied all three features; one satisfied only the second

Table A2. *Descriptions and feature analyses of pictures for* in

Picture	*G is 3D*	*G is hollow*	*G mostly contains F*
1. dog in box	+	+	+
2. guitar in case	+	+	+
3. spoon in cup	+	+	+
4. knife in jar	+	+	+
5. eggs in carton	+	+	+
6. ball in mitt	+	+	+
7. liquid in glass	+	+	+
8. plant in circle	–	+	+
9. seeds in watermelon	+	–	+
10. hammer in hand	+	+	–
11. bulb in socket (of lamp)	+	+	–
12. fork in potato	+	–	–
13. comb in hair	+	–	–

Table A1. *Descriptions and feature analyses of pictures for* on

Picture	*F supported by G*	*F superior to G in gravity frame of ref*	*F contacts G*
1. hat on floor	+	+	+
2. boy on sidewalk	+	+	+
3. boy on tricycle	+	+	+
4. boy on swing	+	+	+
5. cat on kitchen counter	+	+	+
6. radio on table	+	+	+
7. cap on chair	+	+	+
8. cap on pen	+	–	+
9. pictures on wall	+	–	+
10. phone on wall	+	–	+
11. plant on table (papers & books intervene)	+	+	–
12. design on coffee cup	–	–	+
13. fingernail on finger	–	–	+

Table A3. *Descriptions and feature analyses of pictures for* above/over *and* below/under

Picture		*F superior to G*	*F aligned with G*
1.	one button above another on coat (below/under)	+	+
2.	top outlet above bottom (below/under)	+	+
3.	2nd floor window above 1st (below/under)	+	+
4.	"P" above "any time" on "no parking" sign (below/under)	+	+
5.	clock above sign on wall (below/under)	+	+
6.	top drawer above second (below/under)	+	+
7.	umbrella over/above woman (under/below)	+	+
8.	bridge over/above river (under/below)	+	+
9.	table over/above hat (under/below)	+	+
10.	title above author on book (book tilted 45°) (below/under)	–	+
11.	"Passport" above design (passport tilted 45°) (below/under)	–	+
12.	kite above woman (kite also to the right) (below/under)	+	–
13.	stamp above address (stamp also to the right) (below/under)	+	–

and third features; one satisfied only the first and third features; two satisfied only the first and second features; and two satisfied only the first feature.

Three pictures exemplified the kind of spatial relationship designated by *around,* and three were also used for *through.* All of these pictures showed prototypical instances of the meaning of the respective preposition: *around*—cord wrapped around telephone, scarf around neck, person's arms around tree; *through*—shoelace through "eye" in shoe, paperholder spike poked through paper, pencil poked through paper.

The projective prepositions *above* and *below,* and their near-synonymous counterparts *over* and *under,* were illustrated with 13 pictures. Each picture was used twice, once to show an *above/over* relationship, and then again, with the figure and ground objects reversed (by switching the red and green arrows), to show a *below/under* relationship. As with *on* and *in,* the pictures varied in prototypicality as determined by whether they satisfied the following features: figure superior (for *above/over* relationships) or inferior (for *below/under* relationships) to ground, and figure aligned with ground. The pictures and feature analyses are described in Table A3. The picture descriptions are for *above/over* relationships. Nine items satisfied both features; two satisfied only the second feature; and two satisfied only the first feature. When only a single preposition is given, this means that it was used by 90% or more of the normal control subjects to name the picture; when both prepositions are given, this means that the first one was used more frequently than the second but that the second was used by over 10% of the subjects. Following each picture description, it is indicated whether *below, under,* or both were used by the control subjects to name the reversed spatial relationship for the picture. It is interesting to note that for items 1–6 and 10–13, the control subjects strongly preferred *above* instead of *over,* but when the figure-ground relationship was reversed they were more willing to use either *below* or *under.* Also, for items 7–9, *over* and, for the reversed relationship, *under* were used more often than *above* and *below.* This is consistent with the fact that, as mentioned in footnote 8, *over* and *under* are more appropriate when the relationship involves partial encompassment or covering.

Six pictures were used to represent the meanings of the prepositions *in front of* and *in back of/behind* (these are considered to be synonymous for purposes of this study). The same pictures were used to illustrate relationships of anteriority and posteriority, with the figure and ground objects reversed to capture the different relationships. In four of the pictures, both object-centred and observer-centred frames of reference converged on the same interpretation, whereas for two of the pictures, the correct interpretation depended solely on the observer-centred frame of reference. We originally had complementary pictures that depended solely on the object-centred frame of reference, but these pictures did not elicit consistent responses from normal control subjects and hence

Table A4. *Descriptions and feature analyses of pictures for* in front of *and* in back of/behind

Picture		*object-centered frame*	*observer-centered frame*
1.	car in front of man	+	+
2.	one boy in front of other boy	+	+
3.	woman in front of man (both facing viewer)	+	+
4.	woman in front of man (woman facing man, man facing viewer)	+	+
5.	stapler in front of plain styrofoam cup	–	+
6.	boy in front of pole	–	+

could not be included in the final versions of the preposition tests. The six pictures that were used are described in Table A4; only the situations for *in front of* are presented.

Finally, six pictures were used to illustrate *next to/beside* (considered synonymous in this study), and four were used to illustrate *between*. The pictures for *next to/beside* were all prototypical: boy beside bicycle, dog beside firehydrant, spoon beside cup, fork beside spoon, apple beside banana, and soda can beside beer bottle. For *between*, two of the pictures showed prototypical situations—girl between boys, and girl between tricycles—and two showed nonprototypical situations in which the figure was not placed directly along the imaginary line connecting the two ground objects but was rather placed above the line to a certain extent—apple between bananas, and spoon between forks.