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Verbs, events and spatial representations

Anjan Chatterjee[a,*], M. Helen Southwood[b], David Basilico[c]

[a] *Department of Neurology, The University of Alabama at Birmingham, Birmingham, Alabama, 35294-0017, USA*
[b] *Department of Speech and Hearing Sciences, The University of Alabama at Birmingham, Birmingham, Alabama, 35294-0017, USA*
[c] *Department of English, The University of Alabama at Birmingham, Birmingham, Alabama, 35294-0017, USA*

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Abstract

Are concepts expressed in language also represented spatially? To pursue this question we investigated the structure of events. Events are defined as actions with spatial trajectories that can be perceived by our senses and described in language. Events are expressed linguistically in sentences containing verbs which determine the thematic roles of the arguments (e.g., who is doing what to whom, where). Because of previous observations we focused on whether events are represented spatially by location of thematic roles and direction of actions. Location and direction were dissociated by contrasting different kinds of verbs: 'push' vs 'pull' in which actions move toward or away from the agent. To control for spatial effects produced by the surface structure of a left to right written language, we kept the structure of sentences constant and sought for spatial biases produced by differences in the meaning of these sentences. From three experiments using drawing and sentence-picture matching reaction time tasks, we found that normal subjects located agents to the left of patients and represented actions with a left to right directionality. These results are not easily explained by features of the surface structure of language or properties of propositional representations. We suggest that events have spatial representations in addition to their propositional counterparts of verbs and thematic roles. The specific spatial properties observed may relate to functional properties of the left hemisphere.

Keywords: Language; Space; Thematic roles; Mental representations; Concepts; Aphasia

1. Introduction

What is the relationship, if any, between mental representations of language and mental representations of space? These two forms of representations are structured differently [11]. Language is propositional, algebraic and discrete. Space is analog, geometric and continuous. Yet, we use language to convey spatial concepts and acquire many of our concepts through spatial interactions [17]. According to Talmy, language has to address several independent spatial notions. These include the geometry of relationships, appreciating spatial perspectives, distinguishing figure from ground and understanding the dynamics of force [19]. In this report we focus on geometric relationships in events described by action verbs. Verbs establish the propositional framework for events by describing the action and constraining the logically possible thematic roles such as the doer (agent) or the recipient (patient or theme) of the action [9, 10].

How are stable propositional representations extracted from perceptions? Analog 'on-line' perceptions of events are fleeting. For example, when watching a runner, the perception of the runner is continuously updated by incorporating changes in the retinal image as well as changes in the observer's head and eye positions. The observer is somehow able to cohere this dynamic sensory input into stable knowledge of the event. We suggest that there exists an intermediate form of representation with the stability of propositional representations and the analog structure of perceptions. Following Jackendoff, we suggest that such representations are structured spatially according to simple or primitive spatial principles [12]. These primitives are elementary, abstract schemes that resist further decomposition and serve as building blocks for more complex representations. In the spirit of Jackendoff's claims, we sought experimental evidence for the existence of spatial representations of events. Events are coded propositionally in sentences containing action verbs. For reasons reviewed below, we focused on whether events are also coded spatially by the location of thematic roles and the direction of actions.

Our investigation was triggered by previous observations in JH, a fluent agrammatic patient with a thematic role assignment [2, 3, 18]. JH was unable to

* Corresponding author. Tel.: +1_205_934-3874; fax: +1_205_975-7365; e-mail: a_chatterjee@email.neuro.uab.edu

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decipher who was doing what to whom in sentences deficit [16]. For example, he could not reliably match the sentence 'The boy kisses the girl' to a picture of a boy kissing a girl as opposed to a picture of a girl kissing a boy. The most striking aspect of JH's performance was that, rather than performing randomly, he used a temporal or spatial strategy [4]. He consistently assigned items on the left of pictures as the agent (the doer of the action) in sentences, and items on the right of pictures as the patient (recipient of actions). These observations led to the idea that when stripped of normal linguistic operations, JH used primitive spatial representations to assign thematic roles. This underlying primitive representation would normally be obscured by more complex linguistic processes, the kind of transformations and restructuring involved in producing a sentence from a preverbal communicative intent [7].

If thematic roles of agent and patient have underlying primitive spatial representations, then traces of this primitive structure might be observed in normal subjects. To test this hypothesis, a subsequent study was conducted in normal subjects to see if they drew stick figures depicting the agent and the patient of sentences with systematic spatial biases. Subjects tended to draw the agent to the left of where they drew the patient supporting the idea that events are represented spatially [5]. Similar results have also been reported independently [8].

In the current study, we wished to extend these earlier observations by addressing two issues. First, could the earlier observations be due to reading and writing habits? Since we read and write English from left to right and active sentences are canonical, perhaps the results simply reflect an acquired association of agents appearing to the left of patients in written sentences. One could argue that the spatial bias observed was an epiphenomenon of the spatial layout of written language and not a clue to the structure of underlying representations. Second, in the previous studies two spatial concepts, location of thematic roles and direction of action were conflated. The tendency to conceive the agent to the left of where the patient was located could occur because thematic roles are represented spatially by location (agents to the left of patients) or actions are represented spatially by direction (a left to right vector). We do not know if these two spatial properties interact or are independent primitive constituents of putative spatial representations of events. Such representations may have several discrete spatial properties of which location and direction are a subset.

To address these issues we exploited differences in the meaning of verbs while keeping the surface structure of the sentences constant. Different verbs convey actions with different spatial trajectories in relation to the agent. By separating *meaning* from *structure*, we hoped to get beyond the effects of the surface structure of written language and to disentangle the effects of location from direction. The demonstration that thematic roles are represented by locations or actions are represented by direction would provide strong evidence for the existence of spatial representation of events.

2. Methods

2.1. Experiment 1: locating thematic roles

2.1.1. Rationale

We wished to learn if thematic roles are represented spatially by location. Specifically, we tested the hypothesis that agents are represented to the left of patients. Such biases in the location thematic roles could be due to the structure of canonical English sentences in which the subject appears to the left of the object. However, effects of the surface structure of sentences should be identical for all simple active sentences. Verbs can describe actions with different spatial trajectories or simply describe states and not actions, such as 'love'. We assumed that any spatial biases observed with state verb sentences would most likely be due to the effects of the surface structure of simple active sentences since the states are not spatial events. However, any modulation of this spatial bias when action verbs are present in sentences would suggest that meaning imposes a bias beyond that produced by the structure of the sentence alone. Such a finding would support the existence of underlying spatial representation of events.

2.1.2. Procedures

Twenty seven right-handed subjects [1], with a mean age of 21.1 ± 2.4 years and an average education of 14.8 ± 1.6 years, participated in the experiment. Three sets of simple active sentences were used as stimuli. In one set, the actions moved away from the agent or towards the patient. The following verbs were used: *push*, *throw*, *kick*, *shoot*, *hit* and *punch*. In the second set, the actions moved towards the agent or away from the patient. The following verbs were used: *pull*, *drag*, *lead*, *leave*, *escape* and *tug*. The third set of sentences described states rather than actions. The following verbs were used: *love*, *know*, *hate*, *like*, *admire* and *bore*. Subjects heard six examples of each sentence type. Agents and patients were either a 'circle' or 'square', for example 'The circle hits the square.' Circle and squares were used as the nouns in sentences to avoid any semantic associations with the agent or patient. At the end of each sentence, subjects were asked to draw either a circle or square stick figure on 11×8.5 in sheets of paper with the longer axis oriented horizontally. Subjects heard each sentence twice, and drew either the agent or patient. The sentences and thematic roles to be drawn were ordered randomly. Circle and square targets as agent or patient were counterbalanced.

The dependent measure was the difference in distance from the left edge of the page between the location of the

agent and location of the patient for a given sentence. A positive value refers to the patient being drawn to the right of the agent and a negative value to the patient being drawn to the left of the agent. For example, for the sentence 'The circle hits the square' if a subject drew the agent (circle) 3 cm from the left edge of the page, and the patient (square) 4 cm from the left edge of the page, the difference would be +1.0 cm. The method of measurement was the same as used by Chatterjee et al. (1995). If the stick figures were drawn vertically, measurements were made from the left edge of the paper to the location of the vertical line representing the torso. When figures were drawn in oblique or horizontal orientations, then the measurement was made from the left edge of the paper to the point exactly in the center of the horizontal extension of the figure. Fifty percent of the sentences were repeated to measure reliability on this task. Consistency was measured by correlating the distances from the left edge of the paper that each item (agent or patient) was drawn when the sentence was repeated. Each subject drew a total of 54 figures (6 examples × 3 sentence types × 2 thematic roles × 1.5 times).

2.1.3. Results

Only 10/27 (37%) subjects drew the locations of agents and patients with consistency (0.50). Given the variance in the performances with identical stimuli, data from subjects with inconsistent performances would have introduced considerable noise in our measurement of the effects of the meaning of verbs on placement of drawings. Therefore, their data were not included in the analysis. For the consistent subjects, agents were drawn further to the left of where patients were drawn for actions moving away from the agent (1.38 cm, range—0.03–7.48 cm) than for actions moving towards the agent (0.68 cm, range—1.30–4.23 cm) or for sentences describing states (0.63 cm, range—2.05–7.12 cm). These locational biases were significantly different, Friedman ANOVA by ranks, Chi square (d_f 2) = 9.8, $P < 0.008$.

2.1.4. Comment

We draw three conclusions from these data. First, the task was limited as a probe to assess whether thematic roles have spatial locational representations. Subjects' performances were often too 'noisy' to allow an adequate test of the hypothesis. Second, when subjects were consistent in their placements of their drawings, the general finding that agents are placed to the left of patients was replicated. However, the surface structure of sentences alone produces a locational bias, as evidenced by sentences with state verbs. Third, and most importantly, the meaning of verbs modulated the locational bias beyond the effects of the structure of the sentence. Events with actions moving away from the agent were drawn with greater differences between the locations of the agent and patient than events in which the patient is brought closer to the agent. This modulation of the location of thematic roles is compatible with the notion that thematic roles are represented by location along a continuous metric. Such a continuous metric implicates a continuous spatial rather than discrete propositional form of representation.

2.2. Experiment 2: depicting event trajectories

2.2.1. Rationale

This experiment was designed to determine if verbs incorporate spatial representations of direction. We wished to learn if events along the horizontal axis are conceived with a directional bias moving from left to right. To avoid effects of surface sentence structure, simple phrases were used as the linguistic probes. Events traversing vertical axes, such as 'fall' or 'rise' were used as foils. We were interested in the structure of events that occur horizontally. To eliminate effects of biases produced by distal motor habits, all subjects used their non-dominant hand.

2.2.2. Procedure

Thirty six right-handed subjects heard 20 phrases, ten of which described actions that could move along the horizontal axis (e.g., 'staggering drunk'), and ten that could move along the vertical axis (e.g., 'falling book'). Foil stimuli were the phrases describing vertical motion. Subjects were asked to imagine a single light source on the object in motion and to draw the trajectory of this light. All subjects used their left hand. They closed their eyes when drawing. The dependent measure was whether horizontal events were drawn with a directional bias, either left to right or right to left.

2.2.3. Results

Subjects drew actions proceeding left to right an average of 7.9 times compared to 1.4 times going right to left (see Fig. 1). These numbers do not add to 10.0 because some of the 'horizontal' actions were drawn with a vertical trajectory. Thirty three of the thirty six subjects drew trajectories proceeding left to right more often than right to left, demonstrating a robust group directional bias, Chi sq. (d_f 1) = 25, $P < 0.001$.

2.2.4. Comment

Normal right handed subjects have a tendency to conceive of events as traversing space from left to right. Thus, when subjects are forced to depict events spatially, their depictions have a systematic directional bias rather than being random. These results are not explained by distal motor habits induced by writing, since subjects used their non-dominant hand. These results suggest that actions are represented spatially by direction, in addition to being represented propositionally by verbs. However, it remained possible that enculturation in a left to right

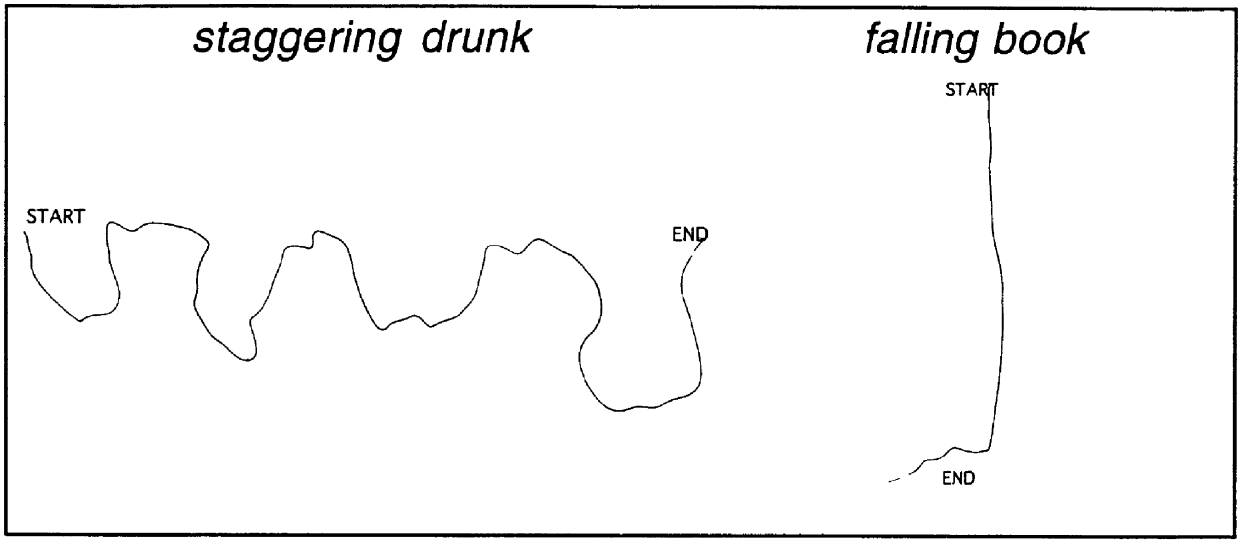

Fig. 1. Example of horizontal and vertical trajectories drawn in Experiment 2.

language may have influenced these performances at a level more abstract than the level of motoric habits.

2.3. Experiment 3: location of thematic roles and direction of actions in sentence picture matching

2.3.1. Rationale

We explored further the hypothesis that events are conceptualized by spatial location and direction using a sentence-picture matching task. If the propositional representations of events interact with spatial representations, then processing sentences should be influenced by spatial features of corresponding pictures. Therefore, we examined the influence of the location of thematic roles and the direction of actions in pictures on subjects' reaction times (RTs).

We anticipated that subjects' RTs would be faster if the agent was located on the left of the picture. Such a finding would be compatible with the hypotheses that thematic roles have locational spatial representations, or that the surface structure of sentences affects processing of pictures. According to the surface structure explanation, subjects might match sentences heard more quickly to pictures with a similar structure. Sentences with the agent on the left in simple active sentences would be matched more quickly to pictures with the agent depicted on the left. In contrast to locational effects, our probe for directional effects on sentence processing would not be affected by surface sentence structure. The experiment included sentences in which the direction of action either moved away from or towards the agent such as the contrasting verbs, 'push' and 'pull'. If the direction of action is an important feature in representing events, then the opposing vectors entailed in the meaning of these verbs (towards or away from the agent) would have different effects on sentence picture matching RTs, despite the sentences having identical structures.

2.3.2. Procedure

The twelve sentences describing actions from Experiment 1 were used in this experiment. Half the sentences described actions moving away from the agent and half described actions moving towards the agent. Sentences were presented in random order. Pictures depicting events consisted of circle and square stick figures. The agent was depicted either on the left or the right of the picture. Directions of actions proceeding either from left to right or right to left (see Fig. 2). The pictures matched the event described in the sentence or depicted another event. Non-matching stimuli consisted of either thematic role reversals or action non-matches. For the sentence 'the circle pushes the square' a non-match might depict the square pushing the circle, or the circle kicking the square.

The thirty six subjects from Experiment 2 listened to the sentences through headphones in a sound-proof booth. At the sentence offset, a picture appeared on a computer monitor before them. Using their right hand, subjects pressed the left mouse button if the sentence and picture matched and the right mouse button if they did not. They were instructed to respond as quickly as possible, while maintaining accuracy. The intertrial interval between sentence-picture pairs was 3 s. Reaction times were recorded by computer. Subjects were given a practice trial of twelve sentence-picture matching stimuli to familiarize them with the procedure. Errors in responses were excluded from analyses. Reaction times to matches and non-matches were analyzed separately.

2.3.3. Results

Reaction times are presented in Table 1. For matched sentence picture pairs, repeated measures ANOVA

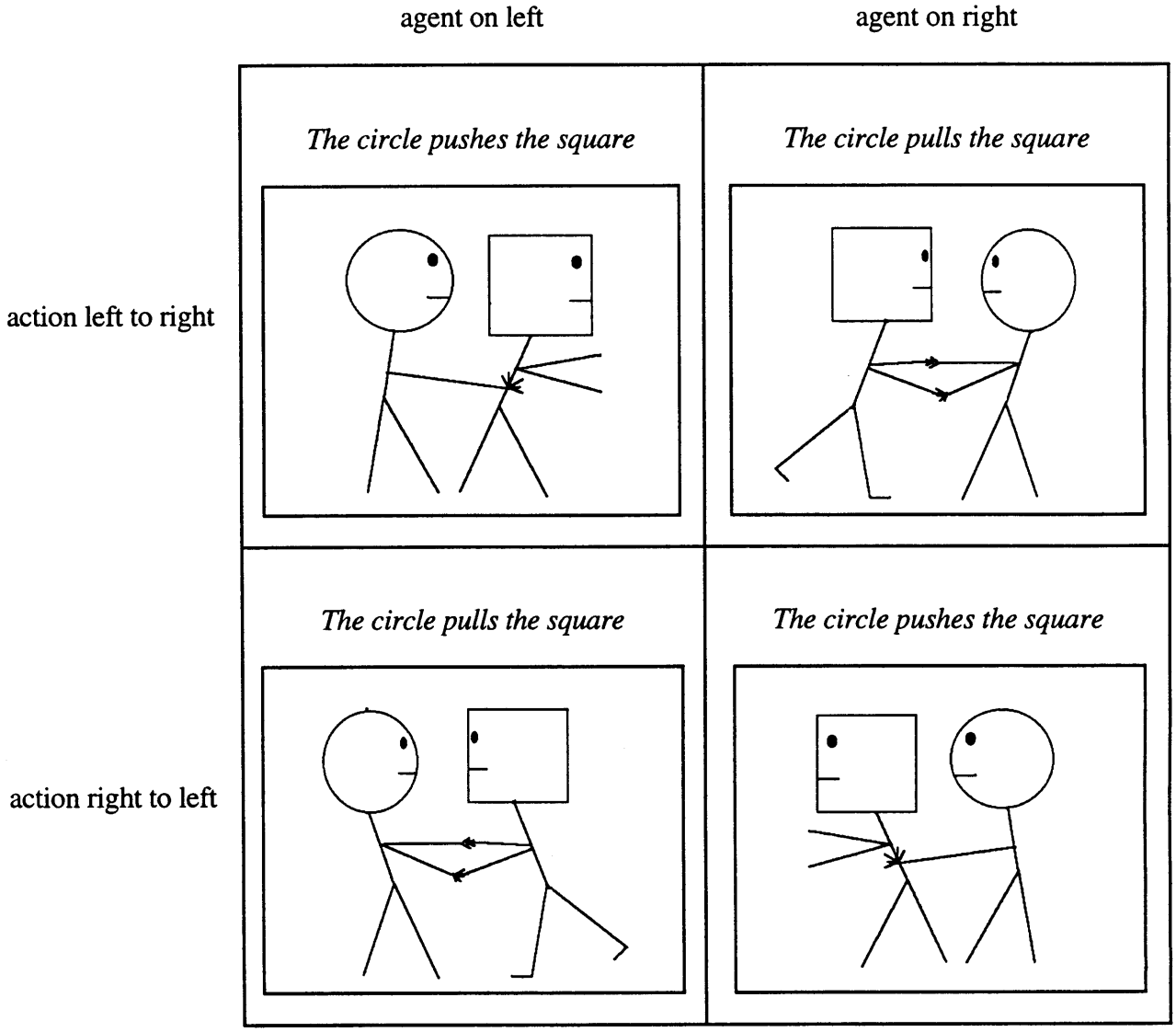

Fig. 2. Examples of pictures used in the sentence-picture matching task in Experiment 3.

Table 1
Reaction times in ms for the sentence-picture matching task in Experiment 3

Matches	Agent on left	Agent on right
Action left to right	1119 (±382)	1318 (±499)
Action right to left	1312 (±594)	1415 (±592)
Noun non-matches	Agent on left	Agent on right
Action left to right	1338 (±383)	1649 (±521)
Action right to left	1665 (±537)	1459 (±454)
Verb non-matches	Agent on left	Agent on right
Action left to right	1013 (±380)	1083 (±325)
Action right to left	1347 (±541)	995 (±397)

showed that subjects responded more quickly if the agent was located on the left ($F_{1,35} = 17.78$, $P < 0.0002$) and if the action proceeded from left to right ($F_{1,35} = 17.78$, $P < 0.0002$) and if the action proceeded from left to right ($F_{1,35} = 7.64$, $P < 0.01$). There were no significant interactions. For sentence and picture pairs which did not match, subjects responded faster to the action than thematic role non-matches ($F_{1,35} = 84.96$, $P < 0.00001$), and responded more quickly when the action in the pictures was depicted going from left to right ($F_{1,35} = 7.2$, $P < 0.02$). Although there was no significant main effects for location of agent, this variable interacted significantly with both the action/verb non-matches ($F_{1,35} = 11.3$, $P < 0.002$) and with the direction of action ($F_{1,35} = 60.3$, $P < 0.00001$). There were no statistically significant differences in the occurrence of errors, which were rare, by different types of sentence picture pairings.

2.3.4. Comment

The subjects responded more quickly to pictures with the agent on the left. This observation may reflect an

analogous primitive representation for location or be the consequence of acquired reading and writing associations in which the first noun encountered in simple active sentences is on the left. Both hypotheses make the same prediction.

Subjects responded more quickly when pictures depicted actions proceeding from left to right. The effects of the direction of the action on this task cannot be explained by the surface structure of these sentences. This effect supports the idea that events are represented by a directional spatial primitive. A similar directional effect on sentence-picture matching was observed in the non-match trials. Subjects rejected picture non-matches more quickly if the action in the pictures moved from left to right. Location effects on these trials were not significant since the location of pictures and the putative representational locations would be at odds, making conflicting predictions.[1] This conflictive situation makes it difficult to interpret the interactions between the locational and directional effects when subjects rejected the non-matching stimuli. The interaction may suggest that the location of the agent (right or left) proffers an advantage in processing the direction of action if the action is moving away from the agent.

3. Discussion

Humans perceive and encode events in the world. Events are clearly represented propositionally since we refer to them using language. What is not clear is whether events are also represented spatially. We wished to learn if right-handed subjects conceptualize thematic roles by location, with agents to the left of patients, and if they conceptualize actions by direction, with a left to right trajectory. We focused specifically on events that occur horizontally.

In seeking evidence for spatial representations of events, we were concerned that cultural habits acquired by individuals immersed in a language written from left to right could complicate interpretation of our results. The surface structure of English sentences could potentially produce spatial biases and undermine our claim that events are encoded spatially. Our strategy to sort between these alternatives was to use sentences and phrases with identical linguistic surface structures, while exploiting differences in their meaning.

In all three experiments we found that subjects responded to linguistic stimuli with spatial biases. In the first experiment, when subjects drew thematic roles with consistent locations, they drew the agent to the left of where they drew patients. This locational bias was exaggerated in drawings of thematic roles of events with actions moving away from the agent. In the second experiment, subjects drew trajectories of actions along the horizontal plane proceeding from left to right. In the third experiment subjects matched sentences more quickly to pictures if the agent was located to the left and if the direction of action proceeded from left to right. As we discuss below, these data are not easily explained either by properties of propositional representations or properties of the surface structure of language. Taken together, these data support the notion that events have spatial representations.

An important distinction between the structure of propositional and spatial representations is that propositional representations are discrete, whereas spatial representations are continuous [11]. In the first experiment, we found that subjects located agents to the left of patients in ways suggestive of an underlying representation of location that is continuous. The exaggerated differences in locating agents and patients particularly for sentences depicting actions moving away from the agent is difficult to explain on the basis of a discrete, or categorical notion of location. A categorical notion of location might index the agent as being to the left of the patient, but it would not specify varying degrees of placement on the left. All the sentence had an identical subject-verb-object surface sentence structure. Modulation of thematic role locations by the meaning of verbs goes beyond the effects of the sentence structure. We content that these metric differences more likely mirror an analog representation of thematic role locations.

Similarly, it is difficult to explain directional biases of event trajectories solely by propositional properties. A propositional representation of events might incorporate the notion of actions with paths or motions in space. However, it is difficult to see how the symbolic representation of such paths should translate into a specific left to right vector. Since the subjects used their left hand for this task, the specific trajectory observed cannot be explained by acquired motor habits induced by writing. The specific path suggested by our data again argue for an analog spatial representation of actions. We shall return to the implications of this specific left to right vector.

In matching sentences to pictures, if the event conveyed in sentences are represented only propositionally, then the layout of the pictures would not matter to the task. However, if the match/non-match decision requires that sentences and pictures be referenced to a mental representation with a spatial format, then the spatial features of the picture become important. The decision would be

[1] If a subject hears the sentence 'the circle pushes the square', he/she would be expected to respond more quickly with a picture with *the circle as agent* on the left. In the noun mis-match condition, when the circle is on the left of the picture, it is in the expected location, but the agent is on the right, setting up a conflict. Similarly, when the circle is on the right, the agent is in the expected location on the left, but the circle is on the right, again setting up a similar conflict. Therefore, the hypothesis in question makes no prediction for the location of the agent in the noun mis-match condition.

made more quickly if the layout of the picture is similar to the spatial feature of its mental representation. The subjects' quicker responses to pictures with agents on the left and the directions of actions proceeding left to right suggest that mental representations of events might be structured similarly. In this experiment, the effects of location of thematic roles on the RTs could be the result of the surface structure of sentences. However, the effects of the left to right direction of actions cannot. Subjects responded more quickly when the action moved from left to right than right to left independent of whether the spatial layout of the pictures matched the spatial layout of written sentences. These spatial influences were produced by the meaning of the verbs and not the structure of the sentences.

Converging empirical evidence for our claim that events have spatial, in addition to propositional, representations might be found in damaged and developing brains. In the nineteenth century, Hughlings Jackson advocated a general principle of dissolution of brain functions. He thought that brain damage to higher more complex brain functions exposed simpler primitive processes [13]. According to this view, damage to the more complex propositional representation of events might reveal underlying primitive spatial representations. We think that the agrammatic patient JH, who used a spatial strategy in making thematic role assignments in an example of such baring of primitive representations [4, 16]. We are currently conducting systematic studies of aphasic subjects to further test this hypothesis.

In the developing brain, spatial primitives probably play an important role in the acquisition of concepts. Mandler argues that infants extract simple spatial schemes from their perceptions of actions in the world [17]. She suggests that these schemes are subsequently mapped onto linguistic codes and are the precondition of further elaboration of concepts. Our findings suggest that such spatial schemes, or primitive spatial representations as we have been calling them, are not discarded (like baby teeth), but remain present in the adult brain. We do not know if these spatial primitives are simply vestigial. They may serve as the bases for more complex cognitive operations such as aesthetic judgments [6] or spatial mental models of reasoning [14].

Finally, does the specific left to right vector for the representation of actions have any further implications? Logically, such a vector could be related to the structure of events in the world, the structure of verbs, or the structure of the nervous system. It makes little sense to think that events would be organized around a specific directional vector since events are not linked intrinsically to the specific vantage point of a viewer. Everyone is exposed to events with random spatial trajectories. Similarly, it makes little sense for verbs themselves to be tied to a specific vector. Although meanings of some verbs may distill into simple primitive notions like 'movement' or 'path', nothing about verbs dictates the direction of that movement or path. The left to right directional bias is likely to be linked to the neural encoding of events. Both cerebral hemispheres deploy spatial attention with vectors in opposing directions. The left hemisphere deploys spatial attention with a vector from left to right [15]. As previously speculated [4, 5], development of language in the left hemisphere may have coopted left hemisphere spatial attentional networks opportunistically. An overlap of neural circuits mediating spatial attention, the directional representations of events and the instantiation of verbs, may provide the neural link between the spatial and propositional representation of events.

In summary, events are represented mentally in both spatial and propositional formats. Right-handed subjects may represent events spatially with the thematic role of agent to the left of their representation of patient. They represent actions with a left to right directional trajectory. The propositional organization of verbs and their argument structure is superimposed on these primitive spatial representations of events. We propose that the properties of these spatial representations are linked to the functional properties of the left hemisphere.

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