

## Research Article

# Human Brain Activity Time-Locked to Narrative Event Boundaries

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**ABSTRACT**—*Readers structure narrative text into a series of events in order to understand and remember the text. In this study, subjects read brief narratives describing everyday activities while brain activity was recorded with functional magnetic resonance imaging. Subjects later read the stories again to divide them into large and small events. During the initial reading, points later identified as boundaries between events were associated with transient increases in activity in a number of brain regions whose activity was mediated by changes in the narrated situation, such as changes in characters' goals. These results indicate that the segmentation of narrated activities into events is a spontaneous part of reading, and that this process of segmentation is likely dependent on neural responses to changes in the narrated situation.*

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Although activity in the world is presented to observers as a stream of continuous information, people perceive activity as a series of discrete units, or *events* (Newson, 1973; Zacks, Tversky, & Iyer, 2001). For example, when watching a person make a batch of cookies, an observer might perceive the activity as a sequence of events such as “making the batter” and “baking the cookies.” This ability to perceive continuous visual activity as discrete events is termed *event structure perception*, and it plays an important role in comprehending everyday activities in the real world (Newson, 1973; Zacks, Tversky, & Iyer, 2001).

Recent evidence suggests that the ability to segment activity into a series of events is not confined to visual perception. Readers, like viewers, are able to identify the structure of nar-

rated activities while listening to or reading descriptions of everyday activities (e.g., reading about a person making cookies; Speer & Zacks, 2005; Speer, Zacks, & Reynolds, 2006). These findings are not altogether surprising given theories of discourse comprehension, which suggest that readers comprehend text as a series of mental models (*situation models*) in order to understand and remember the situations described (van Dijk & Kintsch, 1983).

As events structure visual activity, situation models necessarily structure narrated activity. A reader constructing a situation model begins by laying a foundation for the mental representation based on the initial information from the text and the reader's prior knowledge (Gernsbacher, 1990). If the incoming information is consistent with the model currently under development (e.g., shares characters and locations), it is mapped onto the current model. If the incoming information does not overlap with the current model, the reader will shift his or her focus of attention to begin building a new structure that satisfies the constraints of the current information (Gernsbacher, 1990; Zwaan & Radvansky, 1998).

Research on situation-model construction during narrative comprehension has depended primarily on behavioral variables, particularly reading time, to infer that readers update situation models in response to narrative cues such as changes in a character's location or goals (e.g., Zwaan, Magliano, & Graesser, 1995; Zwaan, Radvansky, Hilliard, & Curiel, 1998). Therefore, it is not clear whether this process occurs spontaneously during relatively natural reading conditions. However, recent research on event understanding has demonstrated that neuroimaging methods are able to observe event-segmentation processes in a relatively naturalistic setting without overt behavioral measurement (Zacks, Braver, et al., 2001). By applying these event-segmentation methods to reading comprehension, one can measure spontaneous segmentation processes during reading. In addition, theories of situation-model construction that detail

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the conceptual features readers use to update their situation models (Gernsbacher, 1990; Zwaan & Radvansky, 1998) provide an efficient, theoretically grounded method for exploring the influence of these features on this segmentation process.

The current study took advantage of neuroimaging methods to test two specific predictions that arise from the literatures on event understanding and reading comprehension: First, if readers spontaneously segment the activity in narrative texts into series of events (i.e., create new situation models), then there will be transient increases in neural activity at the points subjects explicitly identify as boundaries between events. Second, if this process of segmentation is based on changes in the narrated situation, then the neural responses to event boundaries will be mediated by cues such as changes in characters, their locations, and their goals.

We tested these predictions by measuring neural activity using functional magnetic resonance imaging (fMRI) while subjects read narratives about everyday activities. Following the initial reading of the narratives, subjects divided the narrated activity into meaningful units. These behavioral data were used to identify regions whose activity during the initial reading of the narratives increased at points subjects later identified as event boundaries (cf. Zacks, Braver, et al., 2001). An additional set of analyses tested the prediction that cues such as changes in characters and their locations would mediate the relation between behavior and brain activity (i.e., tested whether the locations of readers' event boundaries accounted for additional variance in brain activity once the effects of changes in the narrated situation had been taken into account).

## METHOD

### Subjects

Twenty-eight individuals (ages 19–34; 20 women) volunteered to participate in this study for a cash payment. All were right-handed native English speakers with no history of language or reading disorders. For 5, we had data from only two ( $n = 1$ ) or three ( $n = 4$ ) narratives because of equipment error or subjects' fatigue. Informed consent was obtained in accordance with the guidelines set by the Human Studies Committee at the Washington University School of Medicine.

### Materials

We used four scenes from the book *One Boy's Day* (Barker & Wright, 1951). *One Boy's Day* is an observational record of the everyday activities of a 7-year-old boy ("Raymond Birch") during a single day in the late 1940s. Observers recorded Raymond's activities at 1-min intervals; consequently, there are no temporal discontinuities and very few explicit cohesion cues (e.g., "therefore" or "so that") in the narrative. Although the book is observational, the descriptions are quite articulate, and read more like stories than step-by-step lists of activities (e.g.,

"The school band started playing outside in the street. Raymond, along with several other children, jumped up immediately to watch the band from his seat. Raymond, seemingly satisfied with what he had seen, calmly sat down facing the front."). The four scenes used in the current study describe Raymond getting up and eating breakfast (Waking Up), playing with his friends on the school grounds (Play Before School), performing an English lesson in school (Class Work), and participating in a class music lesson (Music Lesson). All stimuli can be found on-line at <http://dcl.wustl.edu/stimuli.html>.

An LCD projector was used to project stimuli onto a screen positioned at the head of the scanner bore, and subjects viewed the stimuli through a mirror connected to the head coil. The stories were presented one word at a time in 52-point, white font on a black background, and all words were centered on the projection screen. Each word remained on the screen for 200 ms and was followed by a delay of 150 ms times the number of syllables in the word. Stimulus presentation and timing were controlled by PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) running on an Apple PowerMac G4 computer (Apple, Cupertino, CA). A PsyScope button box was used to record responses during the behavioral testing session.

### Tasks and Procedure

Subjects were given 10 to 15 min of practice with the word-by-word reading procedure prior to the functional scans. They then read each of the four stories in a separate fMRI scan; scans ranged in length from 8.5 to 10.9 min. The order of presentation of the stories was counterbalanced across subjects. The task procedure for the neuroimaging session is presented in detail elsewhere (Speer, 2005).

Subjects returned within 4 days of the scanning session to read the stories again while segmenting the activity in the stories (segmentation task). They were not told about this task until they returned after the scanning session, and therefore all were naive to the segmentation task during the initial reading of the stories. In the *coarse-segmentation* task, subjects were asked to identify the largest units of activity that seemed natural and meaningful, and in the *fine-segmentation* task, they were asked to identify the smallest units of activity that seemed natural and meaningful. All subjects performed both segmentation tasks, and the order of the tasks was counterbalanced across subjects. Subjects were given a practice narrative to acquaint themselves with the segmentation task and were required to identify at least three (coarse-segmentation task) or six (fine-segmentation task) unit boundaries before proceeding with the experiment. The order of the stories was the same as in the scanning session.

### Narrative Coding

Each narrative was divided into clauses (a clause was defined as a verb with its argument structure). The number of clauses in the four scenes was as follows: Waking Up, 192; Play Before School,

178; Class Work, 172; Music Lesson, 215. Two raters coded each clause for changes in each of six dimensions (mean Cohen's  $\kappa = .77$ ; discrepancies were resolved by discussion):

- Although there were no temporal changes in the stories, each clause was coded for the presence or absence of a temporal reference (e.g., “immediately” or “slowly”).
- Each clause was also coded for the presence or absence of a spatial change, that is, a change in the narrative location, such as moving from one room in a house to another, or a change in the locations of characters, such as moving from one side of a room to another.
- Object changes were coded any time a character changed his or her interaction with an object (e.g., Raymond picked up a candy Easter egg).
- Character changes were coded whenever the subject of a clause changed (e.g., if Raymond was the subject of clause  $n$ , and Susan was the subject of clause  $n + 1$ , clause  $n + 1$  would be coded as having a character change).
- A clause was coded as having a causal change whenever the activity described in the clause was not directly caused by an activity described in the previous clause (e.g., a character initiated a new action).
- Goal changes were coded whenever a character began a new goal-directed activity, such as when a character initiated speaking.

In addition, clauses were coded for terminal punctuation (e.g., periods and question marks) and nonterminal punctuation (e.g., commas and semicolons).

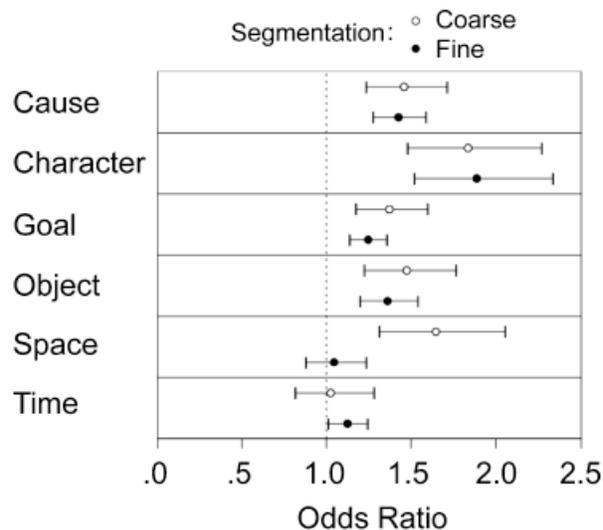
### Imaging

Images were acquired on a 3-T Siemens Vision MRI scanner (Erlangen, Germany). A pillow, washcloths, and tape were used to minimize head movement, and headphones and earplugs were used to minimize noise from the scanner. High-resolution ( $1 \times 1 \times 1.25$  mm) structural images were acquired using a sagittal MP-RAGE (magnetization-prepared rapid-gradient echo) T1-weighted sequence. Functional images were acquired using a T2\*-weighted asymmetric spin-echo echo-planar sequence, with 32 slices ( $4.0 \times 4.0$  mm in-plane resolution) acquired every 2.048 s. An additional T2-weighted fast turbo spin-echo scan acquired structural data in the same planes as the functional scans, in order to facilitate mapping between the functional and structural data. The functional data were preprocessed and warped to a standard stereotactic space (Talairach & Tournoux, 1988). Timing offsets between slices were corrected using cubic spline interpolation, and slice intensity differences were removed. All data were realigned within and across runs for each subject, and image intensity was normalized to a whole-brain mode value of 1,000.

## BEHAVIORAL RESULTS

Data from the behavioral session were analyzed to ensure that subjects performed the segmentation task appropriately by identifying more event boundaries in the fine-segmentation task than in the coarse-segmentation task. The number of boundaries identified in a narrative was divided by the total number of clauses in that narrative to measure the length (in clauses) of the units identified. Alpha was set at .05 for this and all following analyses. The average length of the units in the coarse-segmentation task was greater ( $M = 15.43$ ,  $SEM = 1.83$ ) than the average length of the units identified in the fine-segmentation task ( $M = 3.47$ ,  $SEM = 0.35$ ),  $t(27) = 7.05$ ,  $p_{rep} > .99$ ,  $d = 1.38$ , indicating that subjects were performing the segmentation tasks appropriately.

A series of logistic regressions was carried out to determine which situation changes predicted the locations of individuals' coarse and fine event boundaries. For each individual, separate regressions estimated the effect of the narrative variables on fine and coarse segmentation, and the regression coefficients were then entered into one-sample  $t$  tests, using subjects as a random factor. As Figure 1 shows, the situation-change variables reliably predicted patterns of segmentation in both the coarse- and the fine-grain tasks. In the coarse-segmentation task, spatial, object, character, causal, and goal changes were each associated with reliable increases in the likelihood that subjects would identify a clause as an event boundary, smallest  $t(27) = 4.24$ ,  $p_{rep} > .99$ ,  $d = 0.80$ . In the fine-segmentation task, object, character, causal, goal, and temporal changes reliably increased



**Fig. 1.** Mean odds ratios for the coefficients in the regressions analyzing the behavioral data. These odds ratios represent the change in the odds of identifying a boundary given the presence of each type of situation change. For example, an odds ratio of 1.5 for a situation-change variable would indicate that the odds of identifying a boundary at a given clause were 1.5 times greater if that clause contained a change on that dimension than if the clause contained no change on that dimension. Error bars indicate 95% confidence intervals. The dashed line represents the null hypothesis.

**TABLE 1**  
*Regions Showing Increased Activation in Response to Perceived Event Boundaries*

Region	Coordinates			Brodmann's area	Size (voxels)
	<i>x</i>	<i>y</i>	<i>z</i>		
Right middle frontal gyrus*	26	24	53	6/8	10
Right anterior middle temporal gyrus*	54	-13	-15	21	30
Right posterior superior temporal gyrus*	46	-57	26	22	13
Right posterior cingulate*	14	-54	20	23/31	131
Bilateral precuneus*	3	-66	37	7	549
Bilateral precuneus*	2	-49	67	7	16
Left subcallosal gyrus	-9	17	-12	25	8
Left posterior cingulate*	-7	-29	31	31	12

**Note.** Asterisks indicate regions that showed greater activation for coarse than fine boundaries.

the likelihood that a clause would be identified as an event boundary, smallest  $t(27) = 2.36$ ,  $p_{\text{rep}} = .92$ ,  $d = 0.45$ . These results directly replicate our previous findings (Speer et al., 2006).

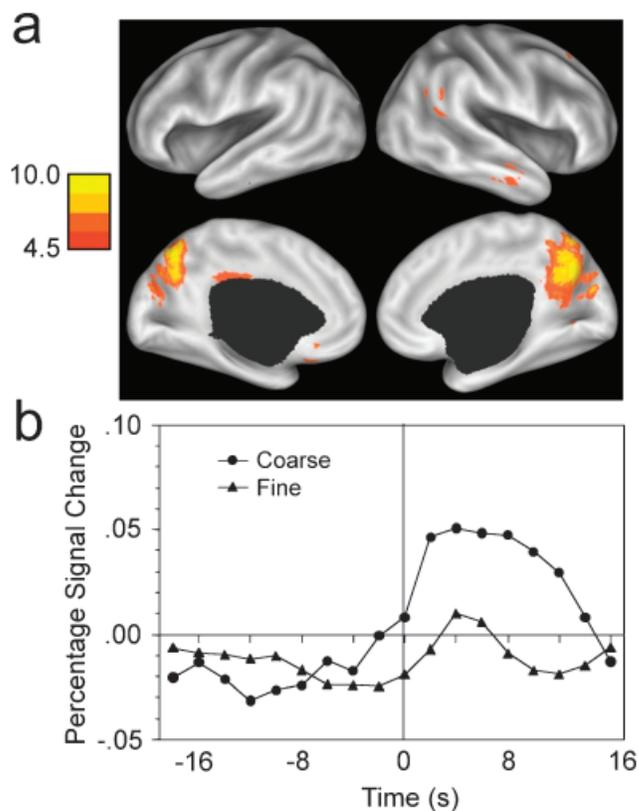
## IMAGING RESULTS

### Analysis of Event Perception

To identify brain areas with transient changes in activity at event boundaries, we followed the procedure used by Zacks, Braver, et al. (2001). Behavioral data from the coarse- and fine-segmentation scans were used to identify “trials” during the functional scans. Each trial consisted of a 36.86-s (18-frame) window around the onset of a word that a given individual later identified as an event boundary in the coarse- or fine-segmentation task. For each subject, general linear models (GLMs) were used to produce two 36.86-s time courses for each voxel (one time course for each of the two segmentation conditions). Thirty-six regressors coded for the effects of interest (2 segmentation grains  $\times$  18 frames), and 8 regressors coded for the effects of no interest (*nuisance variables*; 4 coding for differences across runs and 4 coding for the linear trend within each run). A voxel-wise random-effects  $2 \times 18$  analysis of variance (ANOVA) with grain (coarse and fine) and time (Frames 1–18) as the independent variables identified voxels whose activity was modulated by the presence of coarse and fine event boundaries identified during the segmentation tasks. To control the map-wise false positive rate at an alpha level of .05, we converted the voxel-wise ANOVA  $F$  map to  $z$  statistics and used a  $z$  threshold of 4.50 and a contiguity criterion of five contiguous voxels (McAvoy, Ollinger, & Buckner, 2001).

Table 1 lists the eight regions whose activity changed transiently in response to event boundaries (i.e., showed a statistically significant main effect of time) during passive reading of the stories. Figure 2a shows the locations of these regions mapped onto the cortical surface, and Figure 2b shows the mean time course of activation during the passive-reading task in response to coarse and fine boundaries across all eight regions.

Regions sensitive to the presence of an event boundary included a large region in posterior medial cortex, including posterior cingulate cortex and the precuneus (Brodmann's areas, BA, 7,



**Fig. 2.** Regions whose activation increased in response to event boundaries. In (a), the top images represent inflated left and right lateral views of cortex, and the bottom images represent the corresponding inflated medial views. The color coding indicates the  $z$  statistic for each region. The characteristics of each region are detailed in Table 1. These images were created using the Computerized Anatomical Reconstruction and Editing Toolkit (CARET; Van Essen, 2002a, 2002b; Van Essen et al., 2001; Van Essen, Drury, Harwell, & Hanlon, 2005). The graph (b) depicts the average time course of activation across all eight regions showing increased activation in response to event boundaries, separately for coarse and fine event boundaries. The vertical line represents the point where an event boundary was identified.

23, and 31). Two regions in right temporal cortex, one in anterior middle temporal cortex (BA 21) and the other in posterior superior temporal cortex (BA 22), also showed changes in activation in relation to event boundaries. In frontal cortex, the middle frontal gyrus (BA 6/8) and the subcallosal gyrus (BA 25) showed evoked responses to event boundaries. In all regions, the transient changes corresponded to brief increases in activity. In seven regions, the time course of activation interacted with segmentation grain, such that coarse-grained boundaries evoked a larger response than fine-grained boundaries, smallest  $F(17, 459) = 2.00, p = .01, \eta_p^2 = .07$ . The one exception to this pattern was the subcallosal gyrus, which failed to show a statistically significant difference between coarse and fine event boundaries,  $F(17, 459) = 0.72, p = .79, \eta_p^2 = .03$ .

### Sensitivity of Regions to Situation Changes

Activity in each of the regions that showed evoked responses to event boundaries was subjected to an additional ANOVA to determine whether the situation changes could account for any of the increases in activation associated with coarse and fine event boundaries. For each subject, two GLMs were created for each of the eight regions in Table 1, for both the coarse- and the fine-segmentation conditions. The first GLM coded for the nuisance variables and the event boundaries (coarse or fine), and the second GLM coded for the nuisance variables, situation changes (coded as assumed responses beginning at clause onset; Boynton, Engel, Glover, & Heeger, 1996), and event boundaries.

The coefficients for the event-boundary predictors in each model were subjected to a  $2 \times 18$  ANOVA, with GLM (first vs. second) and time (Frames 1–18) as the independent variables. The majority of the regions showed a statistically significant, Greenhouse-Geisser-corrected (Winer, 1971) interaction between GLM and time, for both models using coarse event boundaries and models using fine event boundaries, smallest  $F(17, 459) = 2.81, p = .03$  (see Fig. 3). The one exception was the subcallosal gyrus, in which the interaction was not statistically significant for coarse event boundaries,  $F(17, 459) = 2.24, p = .07$ , or for fine event boundaries,  $F(17, 459) = 1.90, p = .13$ . These results did not change when the second GLM included punctuation variables, in addition to the situation-change variables. Thus, including the situation-change variables in the GLM attenuated the relation between event boundaries and brain activity in seven of the eight regions.

### DISCUSSION

These results demonstrate that readers are sensitive to the structure of events in a narrative, and suggest that the perception of this structure is based on the processing of changes in the narrated situation. A network of brain regions responded selectively at event boundaries when people read about everyday activities, even when the readers were not explicitly attending to those boundaries. This network included a large portion of posterior medial cortex, anterior and superior temporal gyri, and right middle frontal and subcallosal gyri—a subset of the

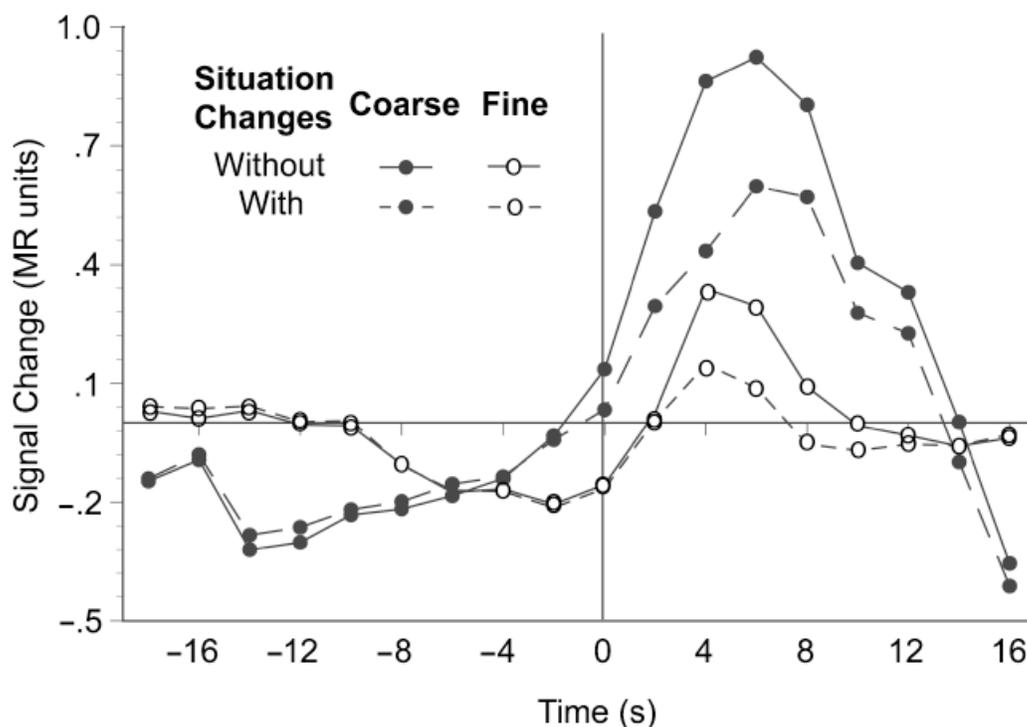


Fig. 3. Signal change based on the coefficients used in the general linear models for a representative region that responded to event boundaries (bilateral precuneus, 3, -66, 37—see Table 1). MR = magnetic resonance.

network of brain regions that responds to event boundaries while subjects are viewing movies of everyday events (Zacks, Braver, et al., 2001), as well as a subset of the network of brain regions that is more active when subjects are reading coherent stories than when they are reading unrelated or weakly related sentences (Ferstl & von Cramon, 2001; Huettner, Rosenthal, & Hynd, 1989; Mason & Just, 2004; Robertson et al., 2000). The majority of regions that responded to narrative event boundaries had responses that were modulated by segmentation grain: Coarse boundaries were associated with significantly larger evoked responses than fine boundaries. This larger evoked response associated with coarse boundaries is also observed when people view movies of everyday activities (Zacks, Braver, et al., 2001). These results suggest that the regions identified in this study are integrally involved in detecting the structure of narrated activities, and that this process of segmentation is part of a larger, modality-independent system involved in the comprehension of everyday activities (i.e., involved in comprehending real-world visual events as well as narrated descriptions of those events).

The behavioral data indicated that changes in characters, their locations, their goals, their interactions with objects, the causal relationships between clauses, and temporal references all increased the likelihood that subjects would identify a clause as containing an event boundary (replicating Speer et al., 2006). Theories of discourse comprehension (Zwaan & Radvansky, 1998) state that readers and viewers construct mental models of the current activity using a combination of information from the environment and knowledge about the typical structure of events in the world. As incoming information about the current event becomes less consistent with the current mental model, readers are more likely to update the current model to more accurately represent the state of the world (Gernsbacher, 1990; Reynolds, Zacks, & Braver, in press; van Dijk & Kintsch, 1983; Zacks, Speer, Swallow, Braver, & Reynolds, 2007; Zwaan & Radvansky, 1998). Therefore, readers may explicitly perceive the points where characters, goals, and other elements change as event boundaries because these changes drive the updating of readers' mental models at those points.

The design of the current study allowed us to test this claim. If readers' segmentation of continuous text is dependent on perceiving that incoming information is no longer consistent with the current mental model, then changes in various aspects of the narrated situation will mediate the relation between brain activity and event boundaries, leading to a severe attenuation of the relation between event boundaries and brain activity once these conceptual cues are taken into account. This attenuation is precisely what was observed: The relationship between event boundaries and brain activation in the majority of regions responsive to event boundaries was significantly reduced once changes in the narrated situation were taken into account. These results give further weight to theories suggesting that readers segment narrative text on the basis of changes in the narrated

situation (Gernsbacher, 1990; Zacks et al., 2007; Zwaan & Radvansky, 1998): The situation changes not only predicted reader's explicit perception of narrative structure, but also accounted for a portion of the influence of narrative structure on brain activity.

The current results have several implications for theories of discourse comprehension and event understanding. First, they provide evidence not only that readers are able to identify the structure of narrated activities, but also that this process of segmenting continuous text into discrete events occurs during normal reading. When readers were reading the stories in the scanner, they did not know they would later be asked to structure the activity in the text, and yet a network of brain regions exhibited increased activation at points readers later identified as event boundaries. These regions were a subset of regions previously implicated in reading comprehension (Ferstl & von Cramon, 2001; Huettner et al., 1989; Mason & Just, 2004; Robertson et al., 2000), and the current results suggest that these regions may be involved specifically in the process of updating readers' situation models.

Second, these data suggest that the segmentation of narrated activities is driven in part by changes in the narrated situation, such as changes in characters' goals. The neural response to event boundaries in narratives was partially accounted for by changes in the narrated situation. This result converges with the finding that the explicit perception of event structure in narratives is correlated with such changes (Speer et al., 2006), and is consistent with theories proposing that the perception of structure in discourse is driven by discrepancies between incoming information and the current mental model of the visual or narrated situation (Gernsbacher, 1990; Zacks et al., 2007; Zwaan & Radvansky, 1998).

Third, the spatiotemporal pattern of brain activation in response to event boundaries in narratives was similar to the pattern that has been observed in studies using movies rather than narrated descriptions of real-world activities (Zacks, Braver, et al., 2001). In light of recent discourse-comprehension theories proposing that readers simulate perceptual and motor experiences during text comprehension (Barsalou, 1999; Glenberg, 1997; Pulvermüller, 2005; Zwaan, 2004), we believe this similarity between processing of visual and narrated activities may be more than mere coincidence, and may reflect the existence of a general network for understanding event structure (Zacks et al., 2007). Future studies will need to address the relation between processing of visual and narrated activities more concretely.

Finally, this study demonstrates the feasibility of studying discourse comprehension in vivo, without interrupting the normal process of reading by requiring overt responses to measure cognitive processes. Using brain activity as a covert measure of the cognitive process of segmenting narrative text into events, we tested two hypotheses about discourse comprehension in a relatively naturalistic reading situation. These data not only

show that readers spontaneously segment narrated activities into events, but also provide insight into how readers use higher-level (i.e., at the situation-model level) features of activity to segment narrative text during comprehension.

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