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Semantic integration in reading: engagement of the right hemisphere during discourse processing

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Summary

We examined the brain areas involved in discourse processing by using functional MRI in 10 individuals as they read paragraphs, with or without a title, word by word for comprehension. Functional data were collected from 20 adjacent 5 mm axial slices. Discourse processing was associated with activation in inferior frontal and temporal regions of both cerebral hemispheres in the titled and untitled conditions. Moreover, there was substantially more right hemisphere activation for untitled than for the titled paragraphs. More specifically we found: (i) greater activation in the inferior temporal sulcus of both hemispheres for untitled than titled paragraphs; (ii) greater average volume of activation in response to untitled than titled paragraphs in the middle temporal sulcus of the right hemisphere and the reverse pattern in the left middle temporal sulcus. Consistent with previous studies of individuals with right hemisphere damage, we suggest that the right middle temporal regions may be especially important for integrative processes needed to achieve global coherence during discourse processing.

Keywords: functional MRI; language; semantic integration; right hemisphere

Abbreviations: BA = Brodmann area; ERP = event-related brain potential; fMRI = functional MRI

Introduction

Language comprehension involves processes at multiple levels of analysis including lexical, syntactic, semantic, pragmatic and discourse. Research on individuals with brain damage has led to the realization that both cerebral hemispheres are involved in language comprehension, albeit to varying degrees with regard to these different levels of linguistic analysis (Caplan, 1992). The present study is aimed at identifying regions of the right and left hemispheres that show systematic changes in blood flow [as measured via functional MRI (fMRI)] during processing of written text. We focus on discourse processes as they are an integral part of our daily communications, subsuming, but also going beyond, the processes engaged in recognizing words, syntactic parsing and comprehending isolated sentences (e.g. Gernsbacher, 1994).

The classic model of language organization, based on a century of studying aphasic patients, situates language comprehension and production squarely in the perisylvian regions of the left hemisphere (e.g. Wernicke, 1874; Geschwind, 1970). However, individuals with damage to various parts of the right hemisphere (e.g. following cerebrovascular accidents) also experience subtle language problems (Joanette *et al*., 1990). For example, patients with right hemisphere damage are often described as experiencing difficulties at the level of discourse. They tend not to elaborate on details of a discourse, producing fewer propositions and fewer complex propositions, although their basic knowledge of scripts or event schema appears to be intact. Right hemisphere damage patients are frequently unable to maintain the theme of a conversation, missing the main point altogether (Brownell and Martino, 1998). In laboratory experiments, right hemisphere damage patients have been found to have difficulties drawing certain types of inferences (Beeman, 1993) or revising them when new information comes up in a discourse (Birhle *et al*., 1986). Right hemisphere damage patients often fail to understand jokes (failing to connect the premise to the punch line) (Brownell *et al*., 1983), and are reported to experience difficulties in appreciating metaphors, idioms and indirect requests (Weylman *et al*., 1989). Altogether, the data suggest right hemisphere damage patients can recognize individual words and comprehend sentences (presumably with their intact left hemisphere), but have trouble connecting and integrating semantically and/or temporally distant concepts. By contrast, aphasic patients can produce relatively normal discourse structures using devices such as pronominalization and explicit connectives that

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create discourse coherence despite significant difficulties in producing words and sentences (Bates *et al*., 1983). Of course, as language impairments become especially severe, even aphasic patients lose their ability to produce coherent, elaborate discourse. It thus seems that both the left and the right hemisphere must be intact for proper understanding of discourse. Moreover, an intact right hemisphere seems to be especially important for higher level integrative processes that lead to functional coherence in discourse.

We chose to examine this hypothesis further by contrasting fMRI data from individuals as they read a series of paragraphs (see below) that were identical in all structural respects but one: namely, whether they were preceded by a title or were untitled (Bransford and Johnson,1972; see also Dooling and Lachman, 1971).

> *'This is very rewarding but tends to be quite expensive even if you own all that you need. The outfit does not really matter. One can get seriously injured without proper instruction even if it comes more naturally to some people than others. Some don't like the smell or the lack of control. So some people are scared to try it even if they've dreamed of it since they were a kid reading about it in books and watching it on television. A running start is uncommon, although there are some who do it. Typically, success requires that you start with your left leg, and make sure that it is securely in place. Then swing your body high into the air. The direction matters. Once you are settled, your thumbs should be pointing up. Sometimes there is no security but the animal's hair. Other times you can hang off to the side. In any case you will be sore if this is your first time.'*

Bransford and Johnson (Bransford and Johnson, 1972) found that without a title (in this case, *Horse-back riding*) paragraphs like this proved to be quite difficult for readers to understand and to remember. This was the case despite the fact that all the sentences within the paragraphs were grammatically well formed and meaningful. It was as if without a title, these paragraphs were meaningless as a discourse, nothing more than a series of disconnected and semantically vague propositions, which were thus difficult to recall. The mere presence of a title, however, seemed to render these paragraphs more comprehensible and effectively doubled the number of words that readers could recall from them.

Comprehending the sentences that comprise such paragraphs requires a whole host of operations for word recognition and syntactic analysis that have been shown to activate predominantly, if not exclusively, left hemisphere brain areas (e.g. Binder *et al*., 1997; Price *et al*., 1997). Thus, we would expect these regions to be active during the paragraph reading, with or without a title. In addition, discourse comprehension requires that mental connections be made between various parts of a text in order to understand it. Any given sentence can be connected to information in the previous sentence and/or within working memory to achieve 'local coherence' but needs to be connected to a text macrostructure or to information earlier in the text to achieve 'global coherence'. We believe it is this process that is faulty in right hemisphere damage patients and is typically the province of an intact right hemisphere. Accordingly, we also expect some increased activation in regions of the right hemisphere in both paragraph conditions as the readers attempt to achieve understanding at a discourse level. However, since the processes required to achieve global coherence are more taxed in the untitled condition, we predict relatively greater activation in the right hemisphere for the untitled than titled paragraphs.

Method

Subjects

The participants were 10 healthy, native English speaking volunteers (23–45 years of age; half of them were male). All were right-handed with the exception of one who considered herself ambidextrous. The subjects gave informed consent and the study was approved by the Human Subjects Committee of the University of California, San Diego.

Materials

Sixteen paragraphs (eight titled, eight untitled) were presented visuocentrically, one word (duration = 200 ms) every 300 ms. An additional half second delay followed the last word of each sentence. Paragraphs ranged between 8 and 14 sentences (mean 9.7) in length; sentences varied between 3 and 21 words (mean 9.6) in length. In the control task, words were replaced by strings of Xs of variable length. Whether a given paragraph appeared as untitled or titled was counterbalanced across subjects; no individual read the same paragraph twice. The materials were presented in four runs lasting 4.5 min each; each paragraph lasted 30 s and each run began and ended with 30 s of flashing Xs. In other words, each run consisted of 4.5 cycles (five half-cycles of Xs; four half-cycles of paragraphs), where a 'cycle' is the total time consumed by one experimental and one control task.

Imaging

Imaging was performed on a 1.5T GE Signa scanner fitted with a high performance local head gradient and an RF coil which is a quadrature transmit-receive elliptical endcapped birdcage that is optimized for brain imaging (Wong *et al*., 1992).

Axial images were acquired for 20 adjacent 5 mm slices [TR (repetition time) = 3 s] for eight subjects and 13 adjacent 5 mm slices with a TR of 2.5 for the other two subjects, using an echo planar single shot pulse sequence with a matrix size of 64×64, and in-plane resolution of 3.75×3.75 mm. The start point was at the bottom of the temporal lobes for all 10 subjects. The first axial image or slice began at approximately –28 mm in Talairach space (Talairach and

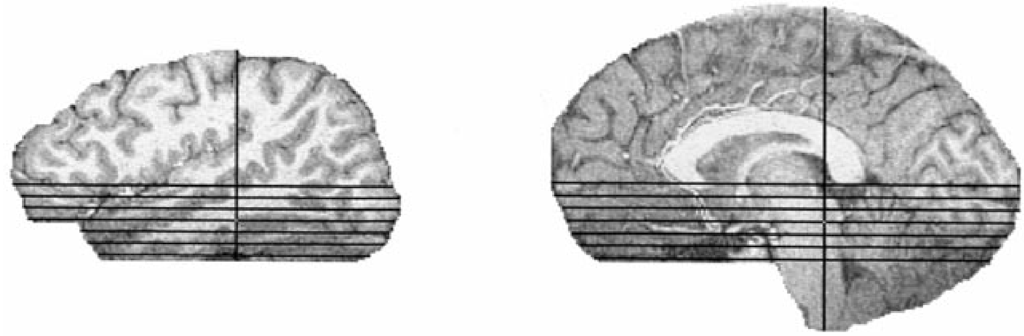

Fig. 1 Sagittal views of location of six functional slices selected for region of interest analyses.

Tournoux, 1988). Ninety-two images were acquired for each slice, while the participant alternated between control and task (30 s each) with a total of 4.5 cycles during each of the four trials. For anatomical localization, we acquired a T_1-weighted 3D MPRAGE sequence [TR = 30 ms, TE (echo time) = 5 ms, flip angle = 45°, $256 \times 192 \times 60$ mm matrix]; functional maps were subsequently overlaid on the corresponding structural images.

Procedure

Participants lay flat inside the magnet and viewed the stimuli (projected on to a screen at their feet) via a mirror located above their eyes. Each participant saw any given paragraph only once; paragraphs were counterbalanced (titled versus untitled) across participants. Participants saw all four paragraphs of each run as either titled or all untitled (i.e. presentation of conditions was blocked). Half of the participants saw an untitled run first, while the other half saw a titled run first; thereafter the conditions alternated.

Data analysis and results

Individual subject analysis

Before any analysis, the images were spatially registered so as to check and correct for motion artefacts. Timeseries data for runs of similar conditions (titled/untitled) were then averaged together. All of the subsequent analyses were performed using AFNI (Analysis of Functional Neuro Images) software, available through the Medical College of Wisconsin (Cox, 1996). The averaged titled and untitled runs were analysed by correlating the time course for each voxel with an ideal 4.5 cycle trapezoidal reference waveform as shown in Fig. 5 (Bandettini *et al*., 1993). Voxels meeting or exceeding a correlation coefficient of 0.50 ($P < 0.000001$) were considered reliably associated with the task. Clusters were defined as groups of activated voxels at least 400 μl in volume with a connectivity radius of 6 mm. Four regions of interest spanning six inferior slices were defined (see Fig. 1 for slice locations). All six horizontal slices imaged primarily temporal areas, with some frontal and occipital cortex as well, ranging from Talairach coordinates –20 to +10 (Talairach and

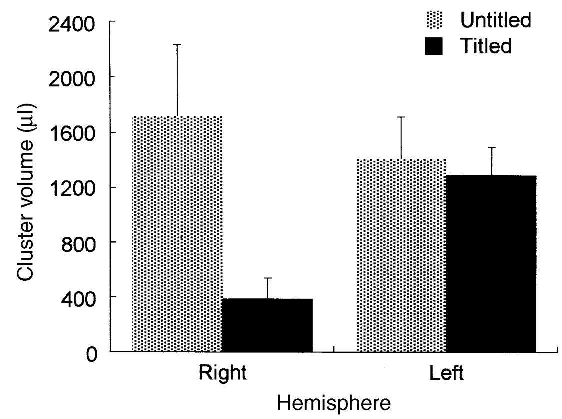

Fig. 2 Mean volume of activated clusters for the titled and untitled paragraph runs as a function of cerebral hemisphere.

Tournoux, 1988). Clusters of activity were found in frontal cortex [Brodmann areas (BA) 44, 45 and 47], inferior temporal sulcus (BA 19, 20 and 37), middle temporal sulcus (BA 21 and 38) and superior temporal sulcus (BA 22 and 42) in the six slices. The volumes of all clusters falling within an region of interest, across all six slices, were summed.

Across-subject analysis

These cluster volumes were then subjected to a $(2 \times 2 \times 4)$ repeated measures ANOVA with three within-participants factors: Context (titled, untitled), Hemisphere (left, right) and Region (frontal, inferior temporal sulcus, middle temporal sulcus, superior temporal sulcus).

Neither the main effect of Context (titled = 834; untitled = 1553) nor Hemisphere (left = 1343; right = 1045) reached significance [$F(1,9) = 1.81$, $P = 0.21$; $F(1,9) = 1.34$, $P = 0.28$, respectively]. The only reliable interaction was of Context by Hemisphere [$F(1,9) = 7.29$, $P = 0.02$]. As can be seen in Fig. 2, this interaction reflects the greater activation in the untitled compared with the titled condition [$F(1,9) = 8.9$, $P = 0.015$] in the right hemisphere but comparable activations in the left hemisphere [$F(1,9) = 0.32$, $P = 0.59$].

The raw data from each participant (timecourse for each voxel) were averaged across the eight for whom 20 slices at

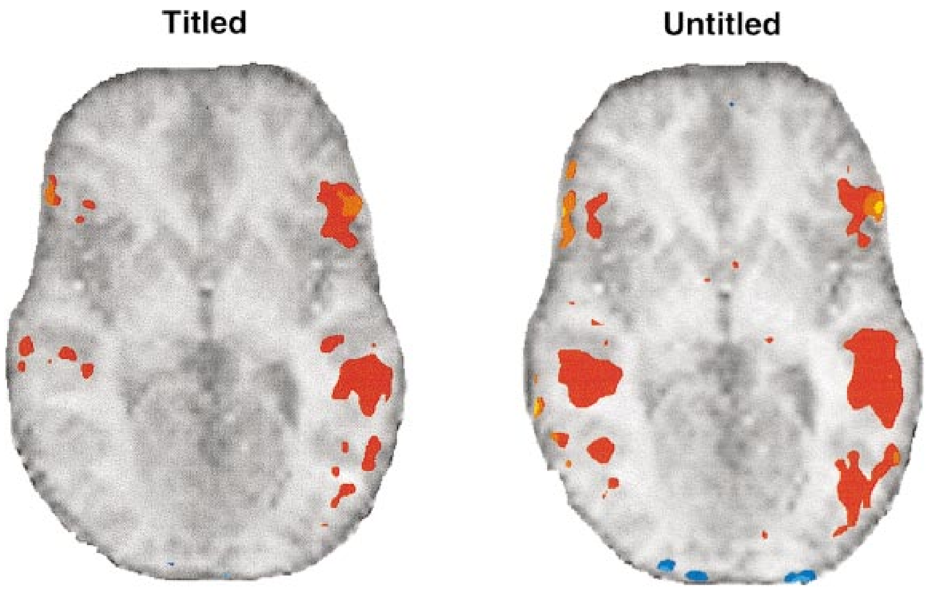

Fig. 3 Structural and functional data averaged across eight participants. Colour shading indicates percentage signal change (warm colours represent positive correlation; cool colours represent negative correlation), with thresholds set at $r = 0.60$ with the reference waveform. Note that the hemispheres are presented according to radiological convention, with the right hemisphere on the left side.

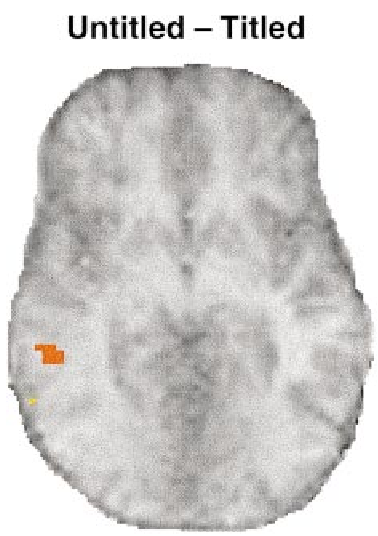

Fig. 4 Axial view of the untitled minus titled difference averaged across participants, with the threshold for right hemisphere activation (on the left of the image) set at $r = 0.60$ with the reference waveform.

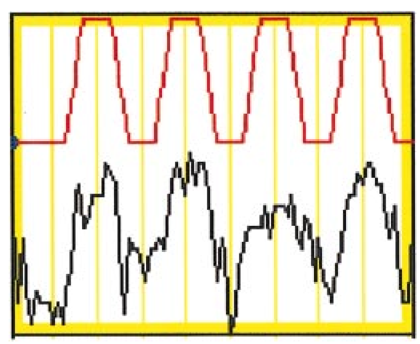

Fig. 5 Time course waveform in MRI units for a voxel in the middle temporal gyrus of the right hemisphere during reading of untitled paragraphs. The red waveform is the reference with which the data (time courses from every voxel) were correlated.

repetition time of 3 s were acquired; the other two could not be included in the average as their data were acquired with a slightly different protocol. The structural and functional datasets for each participant were resampled at 2.5 mm cubed and subsequently averaged. The averaged time-series dataset was then correlated with the ideal 4.5 cycle trapezoidal reference waveform mentioned previously. These data are plotted in Figs 3 and 4. Figure 3 shows the axial slices for untitled and titled conditions averaged across eight participants. Figure 4 shows the average difference between the two conditions (untitled minus titled) across eight participants. To do this, the raw data for the titled condition were subtracted from the untitled raw data, and then the difference waveform was correlated with the ideal reference waveform, mentioned above. The slice shown in Figs 3 and 4 corresponds to Talairach coordinate $Z = -1$ (Talairach and Tournoux, 1988). Figure 5 shows the timecourse of a voxel from the eight subject average that was highly correlated with the ideal 4.5 cycle reference waveform.

Planned comparisons were conducted to contrast the average volume for the titled versus untitled conditions in each region of interest in each hemisphere, separately. As can be seen in Table 1, the pattern of effects varied with region of interest. There were no reliable effects in the superior temporal sulcus and only a marginal effect in the right frontal region with slightly greater volume for the untitled than titled condition [$F(1,9) = 3.75$, $P = 0.063$]. As shown in Fig. 6, in the middle temporal sulcus, the pattern went in opposite directions in the two hemispheres: in the right hemisphere the untitled condition was associated with

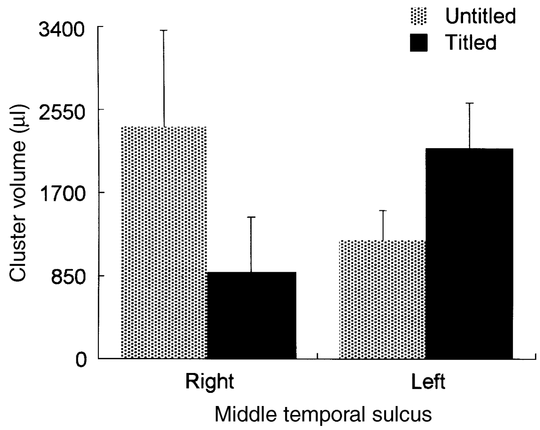

Fig. 6 Mean volume of activated clusters for the titled and untitled paragraph runs in the middle temporal regions of the right and left hemispheres.

Table 1 *Pattern of context effects by region of interest*

Region of interest	BA	Average volume (µl)			
		Left		Right	
		Titled	Untitled	Titled	Untitled
Fr	44, 45, 47	425	1125	207	1062
ITS	19, 20, 37	1259	2362	98	2306
MTS	21, 38	2158	1212	886	2367
STS	22, 42	1294	907	347	1085

Fr = frontal cortex; ITS = inferior temporal sulcus; MTS = middle temporal sulcus; STS = superior temporal sulcus.

larger volume [$F(1,9) = 10.37$, $P = 0.005$], whereas in the left hemisphere the titled condition was associated with the larger volume [$F(1,9) = 4.24$, $P = 0.05$]. In inferior temporal sulcus, the average volume was larger in response to the untitled than titled paragraphs in both hemispheres [right hemisphere: $F(1,9) = 25.03$, $P = 0.0001$; left hemisphere: $F(1,9) = 6.26$, $P = 0.02$].

The response to titled and untitled paragraphs (see Fig. 7, top and bottom, respectively) is shown for the left and right hemispheres in folded, unfolded and flattened views for a single female participant. The main effect described above is visible in the pattern of positive responses (red-orange) shown in the figure. Untitled paragraphs elicited an increased response in both hemispheres but the increase was more prominent in the right hemisphere; left is greater than right for titled while right is greater than left for untitled. Five major regions of activity are present in both hemispheres in both conditions, and are labelled at the lower right. Several of the foci that were significantly activated in this participant did not reach significance in the overall Talairach average (Talairach and Tournoux, 1988). This partly reflects the effects of cross-subject anatomical variability. It may also reflect differences in strategy and more prosaically, head stability, across subjects.

The reconstructed cortical surface passes through the deep layers of the cortex, which is why it is possible to see into the sulci in the folded views. The unfolded view was made from the folded one by unfolding without stretching. The flattened view was made by making five medial cuts in each hemisphere's surface (along the calcarine sulcus, at the temporal pole, at the anterior pole, and in the anterior and posterior cingulate regions) to allow the cortex to lie flat without undue distortion. Light and dark grey indicate the local curvature of the folded cortex (convex and concave) which approximately correspond to gyrus and sulcus.

Discussion

As expected, we observed increased blood flow (fMRI signal) in both cerebral hemsipheres as individuals read short paragraphs word by word for comprehension. In addition, we found that the extent and degree of right hemisphere activation was modulated by the presence or absence of a title for the paragraph: a greater volume of the right inferior temporal sulcus and right middle temporal sulcus were activated for the untitled than the titled paragraphs. Our results are thus consistent with a handful of functional imaging studies using primarily cerebral blood flow measures reporting bilateral activation to spoken or read narratives compared with rest (Mazziotta *et al*., 1982; Huettner *et al*., 1989; Lechevalier *et al*., 1989), reading or listening to word lists (Mazoyer *et al*., 1993; Binder, *et al*., 1994 using fMRI) and paragraphs of random sentences (Fletcher, *et al*., 1995). The most common finding across these studies has been increased activation of the temporal poles and middle temporal gyri, often with more diffuse activation in the right than left hemisphere.

The relatively greater involvement of the right hemisphere during the processing of written and spoken narratives contrasts with numerous neuroimaging studies concluding that '. . . cortical activation associated with language processing is strongly lateralized to the left cerebral hemisphere' (e.g. Binder *et al*., 1997). Most of them have found either no or substantially little right hemisphere activation for language processing at the level of the letter, word or literal comprehension of single sentences (e.g. Bavelier *et al*., 1997; Helenius *et al*., 1998) (for bilateral activation to single words, see Wise *et al*., 1991; Pugh *et al*., 1996).

We can look to our data together with that of previous studies to suggest at least part of right hemisphere's role in natural language processing. Bilateral activations have also been obtained for stimulus materials that patients with right hemisphere damage find especially taxing and thus it has been suggested that the right hemisphere areas are invoked primarily to deal with special types of language materials such as jokes, metaphors and fables. For example, Bottini *et al*. (Bottini *et al*., 1994) found bilateral PET activation of the middle temporal gyrus for the processing of metaphors compared with literal sentences in a task that required participants to indicate whether the sentence was or was not plausible, where approximately 50% were not. They attributed the increased activity in the right hemisphere to its specific role in the processing of figurative

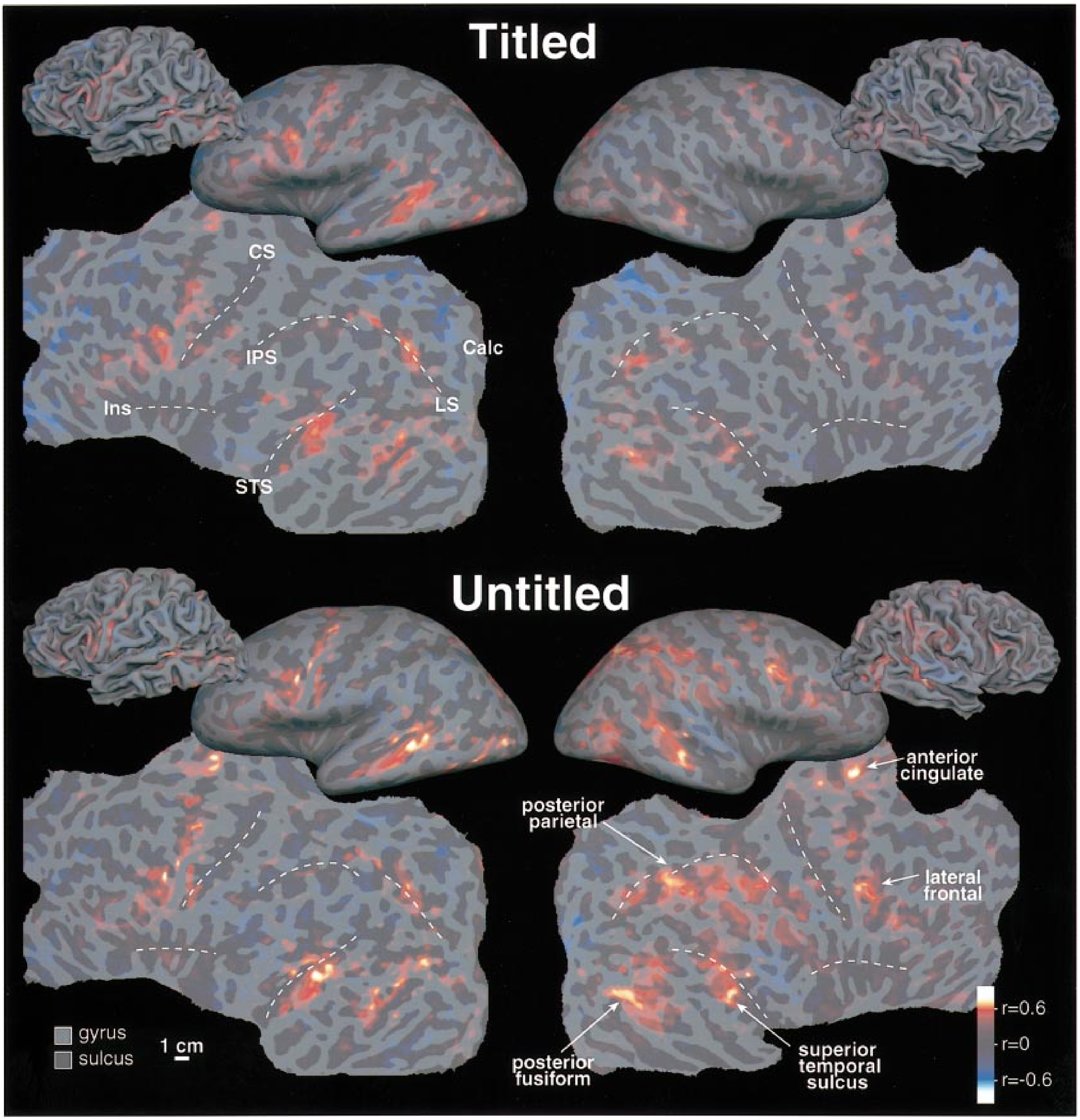

Fig. 7 The response to titled and untitled paragraphs (*top* and *bottom*) is shown for the left and right hemispheres (*left* and *right*) in folded, unfolded and flattened views (all to the same scale) for a single female subject. The main effect described in the text is visible in the pattern of positive responses (red-orange). Dotted lines on the flattened representation indicate the general trend of several major sulci to help in identifying corresponding points on the folded and unfolded representations. These include the central sulcus (CS), lateral sulcus and the insula (Ins), the intraparietal sulcus (IPS), the superior temporal sulcus (STS), the calcarine sulcus (Calc) and the lunate sulcus (LS—also sometimes called the transverse occipital sulcus or even the intraparietal sulcus).

aspects of language. Likewise, Nichelli *et al*. (Nichelli *et al*., 1995) observed greater activation in BA 21, middle temporal gyrus, as well as the inferior frontal gyrus (BA 47) of the right hemisphere when participants monitored Aesop's fables for their moral rather than for their semantic features of a main character (e.g. is it an animal with scales?) and interpreted the increase in terms of the right hemisphere's specific role in thematic processing (for fable morals). Our results, however, clearly show that right hemisphere engagement during sentence comprehension is not specific to the processing of figurative aspects of language. Rather, right hemisphere engagement appears to be a more general phenomenon that occurs routinely as readers attempt to construct a unitary coherent model of a discourse and discover the producer's intent.

Our stimulus materials are relatively ordinary paragraphs, in some cases much like the instruction manual one might find for assembly of a newly purchased product. Each of our sentences is semantically congruent and internally cohesive; there are no outright violations or denotative violations as Bottini *et al*. (Bottini *et al*., 1994) called metaphors or idioms. Our paragraphs do not include indirect requests and can readily be interpreted literally. Moreover, our participants were not asked to render any extraneous decisions (e.g. lexical decision, plausibility, etc.) about any aspect of the stimulus materials, but merely to read them for comprehension so as to be able to answer occasional comprehension queries. In fact, we used exactly the same texts and the same task in both our experimental conditions, which differed only in the presence or absence of a title. Specifically, our titled and untitled paragraphs are orthographically (the size and shape of the letters and words), lexically (the frequency, length and meaning of the words) and syntactically (level of complexity of the sentence structure) identical. Readers saw the same words at the same position on the screen, in the same orders, within the same sentences in both conditions. The *only* difference between the conditions is the presence or absence of a title and what this entails about the paragraphs' processing (discussed below).

Sentences within a coherent discourse differ from a string of isolated sentences in being formally connected (via referential links or sentence connectors), with each sentence being logically consistent with the previous one, as well as pragmatically relevant to the underlying discourse theme or topic. Thus, in processing text, readers need to infer the nature of the relations among ideas, events and states described therein and make use of referential cohesion, causal cohesion, relational cohesion, etc. to create a coherent representation of the discourse. Based on our experience as readers, we expect sentences in a discourse to sustain a sense of continuity in time, place, participants and episodes. Accordingly, we routinely use various integrative processes to find the connectedness between adjacent or nearby sentences as well as the overall topic. We believe that a good title serves to cue our semantic knowledge in such a way as to ease and/or expedite these processes of global coherence, i.e. in the generation of a meaningful message-level representation, which are, nonetheless, part and parcel of comprehending any titled or untitled discourse.

Our paragraphs, however, were designed such that without a title constructing a coherent message level representation would require more time and more effort. Accordingly, one might argue that the increased activity in the right hemisphere merely reflects greater arousal or effort in the more difficult untitled condition. Greater difficulty might be reflected in a general increase in effort or arousal or in a specific increase in effort at one or more linguistic levels. A general increase in effort is likely to lead to increased activation of exactly the same areas, or perhaps activation in an additional area. For example, many researchers have found that manipulations of task difficulty do modulate activity in the anterior cingulate (e.g. D'Esposito *et al*., 1995); thus, it has been suggested that the anterior cingulate may be involved in the mediation of motivational and/or affective responses to task difficulty (Barch *et al*., 1997). While some of our participants did show activity in the anterior cingulate, neither of these patterns was what we observed. Instead, we found that increased activation in the right middle temporal suclus during the untitled condition was coupled with *decreased* activation in the left middle temporal sulcus. Although we do not yet have a good hypothesis as to the function of the decreased activity in the left middle temporal sulcus, we cannot reconcile this particular pattern of activations with any explanation based solely on increase in non-specific arousal. Given the highly controlled nature of our materials, insofar as there is an increase in difficulty from the titled to the untitled paragraphs, it must be linked to higher level processes that cut across individual sentence boundaries. Thus, we think that the middle temporal gyrus and inferior frontal gyrus contribute to language processing at the level of semantic integrative processes at the level of discourse. Perhaps the decreased activity in the left middle temporal sulcus and increased activity in the right middle temporal sulcus reflects a trade-off in processing resources. That is, the decreased activity in the left middle temporal sulcus in the untitled condition reflects reduced effort devoted to matching individual words with their meanings, i.e. lexical integration (responsibility of the left middle temporal sulcus) in the absence of top-down constraints and greater effort devoted to figuring out what the discourse is about (which is the responsibility of the right middle temporal sulcus, and may feed back to the left).

Electrophysiological recordings have shown that within the temporal domain this same title manipulation has its effects on the processing of any word within the text between 250 and 550 ms after its appearance. Specifically, St George *et al*. (St George *et al*., 1994) recorded event-related brain potentials (ERPs) from the scalp of individuals as they read these texts one word at a time either with or without a preceding title. The significant difference between the ERPs elicited by words in the two experimental conditions was in the amplitude of a negativity (N400) starting around 200 ms and peaking around 400 ms after each word; this N400 was reliably larger for words from paragraphs without than with a title. Much research has linked N400 amplitude to semantic processing, especially semantic or contextual integrative processes (for review see Osterhout and Holcomb, 1995). Such research has shown that N400 amplitude is sensitive to (i) semantic relatedness in word pairs, being smaller for related than unrelated words; (ii) semantic congruity at a sentence level, being smaller for congruous than incongruous endings; and (iii) extra-sentential semantic constraints within discourse, being smaller for more than less predictable words.

The N400 has a broad distribution across the scalp. In response to words within sentences, the N400 is often slightly laterally asymmetric, being larger over posterior regions of the right than left hemisphere. Some researchers have suggested that it may be a composite of multiple negative components (e.g. Pritchard *et al*., 1991). Given the inverse problem, it is impossible unequivocally to infer neural generators from scalp recordings. Intracranial recordings from one or both hemispheres of patients with intractable epilepsy, however, have led to the hypothesis that at least some of the N400 is generated bilaterally in the neocortex near the collateral sulcus and the anterior fusiform gyrus (McCarthy *et al*., 1995). This conclusion is based on the intracranial pattern of field potentials and their sensitivity to the same task manipulations (e.g. semantic congruity, word class) that modulate the scalp N400. In the present study we obtained reliable bilateral increases in fMRI activations in the inferior temporal sulcus and fusiform gyrus as the untitled paragraphs were being read. These may eventually prove to be related to the N400 amplitude modulations elicited by these same stimulus texts.

The mechanisms by which the right hemisphere achieves global coherence or integrates information across sentences within a discourse remain unknown as there is not even a consensus on just how discourse coherence should be defined (Hellman, 1995). Integration requires that there be multiple pieces of information to be integrated; clearly, both temporal and spatial summation can aid integrative processes. Thus, we can look to see whether stimulation of the right and left hemisphere lead to different types or amounts of information being activated, different time courses of information activation, or both. Both behavioural and ERP data suggest greater possibility for integration in the right than the left hemisphere. For example, Beeman *et al*. (1994) found that in visual half-field semantic priming experiments target processing in both hemispheres benefited from ‘direct’ primes (one strongly related word and two unrelated words) but only the right hemisphere benefited from viewing ‘summation’ primes (a series of words weakly related to target). In a similar vein, Swaab and colleagues (Hagoort, *et al*., 1996; Swaab, *et al*., 1998) found that, whereas elderly controls showed N400 priming effects for both the strongly (e.g. cottage-cheese) and weakly (e.g. skirt-shoe) related word pairs, right hemisphere damage patients showed priming effects only for the strongly-related word pairs. Beeman (Beeman *et al*., 1994; Beeman, 1998) accounts for these sorts of effects in terms of the concept of ‘coarse coding’ borrowed from vision research. Specifically, Beeman hypothesized that each word is associated with a large, diffuse ‘semantic’ field in the right hemisphere and a smaller, more focal ‘semantic’ field in the left hemisphere. In other words, in the right hemisphere, many concepts give rise to weak activation for some time, whereas in the left hemisphere that activation is limited to the target and its most closely linked associates. The presence of large semantic fields in the right hemisphere thus leads to a greater potential for overlap (and integration through spatial and temporal summation) of many different, but related concepts. In this way, semantically distant words needed to understand metaphors, draw inferences and appreciate the many nuances of discourse, can be accessed and integrated. Such an account may explain the bilateral cerebral activation for discourse materials as well as for the processing of metaphors and fables. In addition, we suggest that the size of the semantic fields for any given word might be even larger in our untitled paragraphs as readers search for sense with no title to help constrain the semantic activation. To summarize, we suggest that our pattern of fMRI activations is consistent with the view that the right hemisphere serves to maintain the activation of distantly related concepts, perhaps via ‘coarse’ coding. In so doing, the right hemisphere (especially inferior temporal regions and middle temporal sulcus) contributes to the establishment of global coherence for effective discourse processing. It remains to be seen whether this search for coherence is specific to language processing or may also be invoked as we attempt to make sense of input from other domains.

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