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# Brain Processes of Relating a Statement to a Previously Read Text: Memory Resonance and Situational Constructions

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## Abstract

One of the most fundamental characteristics of texts consists in the coherence among its sentences. We investigated by fMRI where in the brain such coherence relations are established and the relative duration of these processes by a behavioral experiment. In four experimental conditions, the coherence between a sentence and a subsequent test statement ranged from an explicit and a paraphrastic to an implicit and the lack of a precise relation (control condition). The participants had to decide whether the test statement was true with respect to the previously read sentence. For this decision the blood oxygen level dependent (BOLD) response differentially indicated five brain regions (posterior cingulate, STG, left and right IFG, frontal medial gyrus). These results could consistently be interpreted to distinguish two interacting but separate brain processes involved in coherence formation. One of these processes may be termed memory resonance and the other one situational constructions.

## Introduction

A defining characteristic of a text is that its sentences are not unrelated to one another but cohere. To understand a text, a reader must therefore cognitively establish the specific relations between a new statement and a previously read text. The coherence between sentences may be established in different ways: For example, by anaphora resolution (Glenberg, Meyer, and Lindem, 1987), by identifying overlaps in the arguments of different propositions (Kintsch & van Dijk, 1978), by memory processes which resonate for words with closely related meanings (O'Brien, Rizzella, Albrecht & Halleran, 1998) or by more effortful inference processes which are driven by a search for meaning (Graesser, Singer & Trabasso, 1994).

O'Brien et al. (1998) postulate the resonance process in memory to be both, autonomous and dumb and to be based on the strengths of preexisting associations in semantic memory. Thus, memory resonance is considered to be a basic bottom-up activation process which may interact with more goal-directed processes of forming a mental model for the here and now description of a situation.

Memory resonance is assumed to be passive and in some aspects similar to the bottom-up saliency-based processes of attention (Itti & Koch, 2001). While bottom-up attention processes assist an organism in analyzing a present scene,

memory resonance processes assist in a similar manner in analyzing a reader's past experiences (verbal and non-verbal) as they have become represented in memory. In addition to this passive reactivation mechanism, there may also be a task-dependent and more strategic process which is driven by the reader's goal of constructing a model of the situation that is described by the text (cf. Graesser et al. 1994). Whereas the postulated memory process would involuntarily reactivate memory contents, the task-dependent process would be more under the control of the reader's intentions (cf. Calvo et al., in press).

Experiments employing brain imaging techniques such as functional magnetic resonance imaging (fMRI) and event-related potentials (ERP) can provide more detailed insights on how text coherence is established (Ferst & von Cramon, 2001; Hagoort et al., 2004). In quite general terms, one would expect that a passive memory resonance process would occur earlier after the presentation of the critical words and more likely in posterior areas of the brain. The more effortful, task dependent processes of situation constructions, on the other hand, should be more likely to involve frontal areas of the brain, and possibly occur later in relation to the onset of the critical words.

In agreement with this expectation, Ferstl & von Cramon (2001) have already found that prefrontal midline areas and the left posterior cingulate gyrus (BA 31) together with neighboring inferior precuneal areas (BA 23) are involved for establishing coherence by inferencing. Hagoort et al. (2004) found that the left inferior prefrontal cortex is involved in the integration of newly presented words with both, meaning and world knowledge and that such processes occur in the vicinity of 400 ms after the onset of the critical word.

In the current study we investigated the brain processes of relating a statement to a previously read text by more fine-grained experimental contrasts. We employed experimental materials that have been widely used in many behavioral studies as well as for theoretical analyses (cf. Schmalhofer, McDaniel and Keefe, 2002).

A small time window of 1.8 seconds was used, where a statement consisting of two or three words had to be related to the previously read sentences by determining whether or not the statement would be true with respect to the described

situation. To determine whether or not different components would be more or less important in different occasions, we experimentally manipulated the preceding sentences in four different conditions.

In the *explicit condition*, the test statement is explicitly stated by the preceding sentence. In the *paraphrase condition*, the test statement has been introduced by different words (paraphrased). In the *inference condition*, the previous sentence invites the reader to draw a predictive inference, possibly coinciding with the test statement that is subsequently presented (cf. McDaniel, Schmalhofer & Keefe, 2001). In the fourth condition, the *control condition*, there is not even such an inferencing invitation, so that the test statement at first appears quite unrelated to the preceding sentence. Nevertheless, even in this case, an integration may be cognitively achieved.

A sample text material is shown in Table 1 together with the test statement that was identical for all four experimental conditions. For the specific purpose of our experiment, we modified 120 such sets of materials so that all sentences would be of equal length. These materials were constructed on the basis of the materials which had been used in a behavioral experiment (McDaniel, et al., 2001) as well as in an ERP-experiment (Yang, Perfetti, & Schmalhofer, submitted). In addition, we constructed filler materials (18 trials) which had different sentence structures. Furthermore, we introduced a pseudo word reading condition (18 trials) by scrambling the letters within a sentence so that the newly constructed letter strings would be pronounceable.

Table 1: English translation of a sample text material and test statement

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Title: Air Travel

Words 1-12 (all conditions): While the flight attendant served the passenger a full glass of wine

Words 13-18 (explicit): turbulence caused the wine to spill.

Words 13-18 (paraphrase): turbulence caused the wine to splash.

Words 13-18 (inference): turbulence occurred which was very severe.

Words 13-18 (control): the plane was at cruising altitude.

Test statement: wine spilled

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We predicted that the time it takes to verify a statement should increase from the explicit to the paraphrase and inference conditions. The control condition should yield the longest response times. We tested this prediction in a behavioral experiment. It was in all respects identical to the fMRI experiment, which we would perform thereafter except that the participants sat in front of a computer terminal instead of lying in an fMRI-scanner. For the fMRI experiment, we expected posterior areas (e.g. cingulate and/or parietal lobe) to be differentially involved in the explicit and paraphrase conditions. In addition, for the inference and control conditions, the middle frontal gyrus and inferior prefrontal gyrus were expected to be

differentially involved. Activations in the temporal lobe may furthermore indicate the interplay between memory and situation construction processes.

## Behavioral Experiment

### Method

Forty students (19 women and 21 men) from the University of Osnabrueck between 19 and 29 years of age (average of 21 years) participated in this experiment for course credit. The design and experimental procedure were completely identical to the subsequently performed fMRI-experiment.

### Results

Table 2 shows the proportion of correct responses in the four experimental conditions and the mean latencies for the correct responses. There was a significant difference in the mean latencies among the five experimental conditions ( $F(4,156) = 19.7, p < .001$ ). Pairwise *t*-tests furthermore showed that the latency of explicit, paraphrase, inference and control condition were all significantly different from each other (see Table 2).

As predicted the response latencies decreased with the degree of the explicitness of the coherence between a test statement and the preceding sentence.

## fMRI-Experiment

### Method

*Participants.* Thirteen right handed students with a mean age of 22.8 years, all native speakers of German (7 women, 6 men) participated and received course credit.

*Procedure.* All subjects received written instructions as well as a training session outside the scanner to become familiar with the type of stimuli and the corresponding tasks. Participants were instructed to press the YES key when the test statement was true with regard to the situation described by the just read sentence and the NO key otherwise. For the pseudoword condition, they were told to press the YES key when the pseudowords of the test statement were identical to the last two presented letter strings of the pseudoword reading phase and the NO key otherwise.

After a training session in the scanner, participants were presented with the three functional scanning sessions. Each session took 16 min 12 sec. The participants were allowed to rest up to three minutes between sessions.

For each trial, the words of a sentence were displayed by a rapid serial visual presentation (RSVP) technique. Table 3 shows the timing of a trial including the test statement and fixation phases in between sentences. The start of each stimulus block was jittered by 0, 1 or 2 seconds. The experiment ended with the acquisition of a structural image, which lasted 5 minutes.

Table 2: Mean response latencies and response frequencies from the behavioral experiment and the fMRI-study.

Condition	Behavioral Study N = 40			fMRI-Experiment N = 13		
	*Response freq. (SE)	Response time in ms (SE)	<i>t</i> -test (Response time difference)	*Response freq. (SE)	Response times in ms (SE)	<i>t</i> -test (Response time difference)
Pseudoword	.94 (.02)	826 (43)	<i>t</i> (39) = .62, <i>p</i> > .05	1 (.00)	828 (37)	<i>t</i> (12) = 3.01, <i>p</i> < .01
Explicit	.99 (.00)	850 (28)		.99 (.01)	961 (54)	
Paraphrase	.98 (.01)	886 (29)	<i>t</i> (39) = 4.59, <i>p</i> < .01	.98 (.01)	999 (57)	<i>t</i> (12) = 2.45, <i>p</i> < .05
Inference	.89 (.02)	994 (45)		.89 (.04)	1085 (61)	
Control	.93 (.01)	1058 (38)	<i>t</i> (39) = 2.04, <i>p</i> < .05	.90 (.02)	1207 (65)	

\* Response frequencies denote the relative frequency of correct responses (hits and correct rejections) in the pseudoword condition and the relative frequency of “yes”-responses in the explicit, paraphrase and inference conditions. In the control condition the proportion of “no”-responses is indicated.

Table 3: The timing of single trials in ms.

Stimulus	Duration in ms
Blank screen	0, 1000 or 2000
Title	600
Blank screen	600
Word	300
Blank screen	300
Fixation cross	1700
Test task*	4300
Inter trial interval	9000, 8000 or 7000

\* test statement disappeared after participant’s response

**Image Acquisition:** All MR-images were acquired in a 1.5 T Siemens Sonata whole body MRT equipped with an 8-channel head coil (MRI-devices). The head of the participant was fixated by pads. Earplugs and earphones were used for noise shielding and to instruct participants between functional image acquisition. During the functional scans, the BOLD response was measured using a gradient echo EPI sequence (TR = 3 s; TE = 50 ms; flip angle = 90°; resolution 3x3x3 mm<sup>3</sup>, number of slices = 35, acquisition sequence “interleaved”, slice thickness = 3mm, distance factor: 0-10 %). The acquired slices were rotated approximately 10° relating to the AC-PC line in order to cover prefrontal, parietal and temporal regions in full and the majority of the occipital cortex, sometimes excluding V1. In each of the three functional sessions 326 images were recorded. Structural images were acquired for each subject using a T1 weighted MPRage sequence (TR = 1900 ms; TE = 3.93 ms; resolution 1x1x1 mm<sup>3</sup>) at the end of the experiment.

**Data Preprocessing and Analysis:** All MR-data were preprocessed and statistically analyzed using SPM2 (Functional Imaging Laboratory, Wellcome Department of Imaging Neuroscience, London, UK). Functional images were corrected for acquisition timing, realigned to the first

image and coregistered to the structural images. Movement corrections were below 6 mm for all but one participant who showed a translation across the three functional scanning session of close to 8 mm. After normalizing all images to the MNI template, functional images were resampled to 2x2x2 mm<sup>3</sup> and spatially smoothed using an isotropic Gaussian kernel with 10 mm FWHM.

A general linear model was applied to the individual data. For each condition, the processing of the title, the sentence and the test task were modeled. The modeling of sentence presentation was split into 3 blocks of equal length covering the entire sentence presentation to account for differences in sentence encoding before the verification.

The verification process was modeled by a block, beginning with the onset of the presentation of the test task. The length of the block was selected to coincide with the average response time in the inference condition of the slowest participant (1.8 seconds). *t*-test contrasts were calculated between test tasks in the inference, explicit, paraphrase, and control conditions. For statistical analyses, a Random Effects Model was used bringing the appropriate individual contrast measures into a simple *t*-test on 2<sup>nd</sup> level. Statistical maps were thresholded with *t* = 3.93 (uncorrected *p* = .001) and clusters surpassing a corrected *p* value of .05 on cluster level (approx. 110 voxels) are reported as significantly activated.

## Results

**Behavioral results.** The response latencies to the test statements showed again an increase from the explicit to the paraphrase and the inference conditions. The mean latency was longest in the control condition. While the difference between explicit and paraphrase was not significant, all other differences were (see Table 2). This pattern of results is in good agreement with the behavioral experiment. The most noticeable difference is that the latencies are overall somewhat longer than in the behavioral experiment.

*FMRI results.* An overview of the significant differences in the statement verification task is presented in Table 4. The rows and columns of this table are arranged so that differences predicted by a levels theory (cf. Schmalhofer et al., 2002) would show up in the lower left triangle. As seen from Table 4, 5 of the 6 predicted and 12 possible differences yielded significant differences. Thus, the experimental conditions which according to a levels theory require more processing indeed showed more brain activities. By identifying the brain areas which caused these additional brain activities, we may furthermore examine whether the particular brain area and the specific function proposed by the theory fit together. The specific clusters which were identified by these comparisons are shown in Figure 1 and described in more detail in Table 5.

Table 4: Overview of significant differences in the one sided tests between the row and the column conditions.

Row>Column	EX	PA	IN	CO
EXplicit	-	o	o	o
PARaphrase	X	-	o	o
INference	X	X	-	o
COntrol	X	X	o	-

Note: "X" denotes that at least one significant cluster was identified and "o" denotes otherwise.

The comparison *Paraphrase > Explicit* showed one significant cluster in the right posterior cingulate gyrus. The posterior cingulate gyrus has been consistently found in successful episodic memory retrieval (Cabeza & Nyberg, 2000; Wheeler & Buckner, 2004). Fletcher et al. (1995) attributed posterior cingulate regions to be involved in visual imagery and possibly the incorporation of information into an evolving discourse structure. Posterior cingulate and neighboring cuneal and precuneal regions are also activated when picture stories are processed

(Gernsbacher & Kaschak, 2003). These areas may thus reflect mental imagery processes in story comprehension (Maquire et al., 1999).

The comparison *Inference > Paraphrase* showed a large cluster in the medial portion of the left and right superior and middle frontal gyri. Such middle frontal activations have been attributed to theory of mind inferences and more generally, inferences that are needed to establish a coherent conceptual representation as it is established in situation models (Ferstl & von Cramon, 2001, 2002; Fletcher et al. 1995; Mazoyer, Tzourio, Frak, & Syrota, 1993). Frontomedian activations have also been implicated for the generation of plans and internally guided force in general (Vaillancourt, Thulborn & Corcos, 2003). These areas exceed the functions that are unique to memory and language processes and may in particular be relevant for constructing a particular situation to act in it.

The comparison *Inference > Explicit* showed in addition to the significant results of the two previous contrasts, a third large area in the inferior frontal gyrus overlapping with Broca's areas 45 and 47.

The comparison *Control > Explicit* showed once more the middle frontal gyri and the left inferior frontal gyrus to a somewhat larger extent and with higher activations than the *Inference > Explicit* comparison. In addition to these areas a region at the junction of the left temporal and parietal lobes, covering parts of the middle and superior temporal gyri and the supramarginal gyrus was significant. Furthermore clusters in the posterior cingulate gyri bilaterally, in the right middle frontal and precentral gyri, as well as an area in the right inferior frontal gyrus were found.

The comparison *Control > Paraphrase* yielded similar results as the comparison of *Control > Explicit*. The regions most prominently activated were in the fronto-median wall and the right inferior frontal gyrus. A posterior midline activation was found in the precuneus. Further clusters in

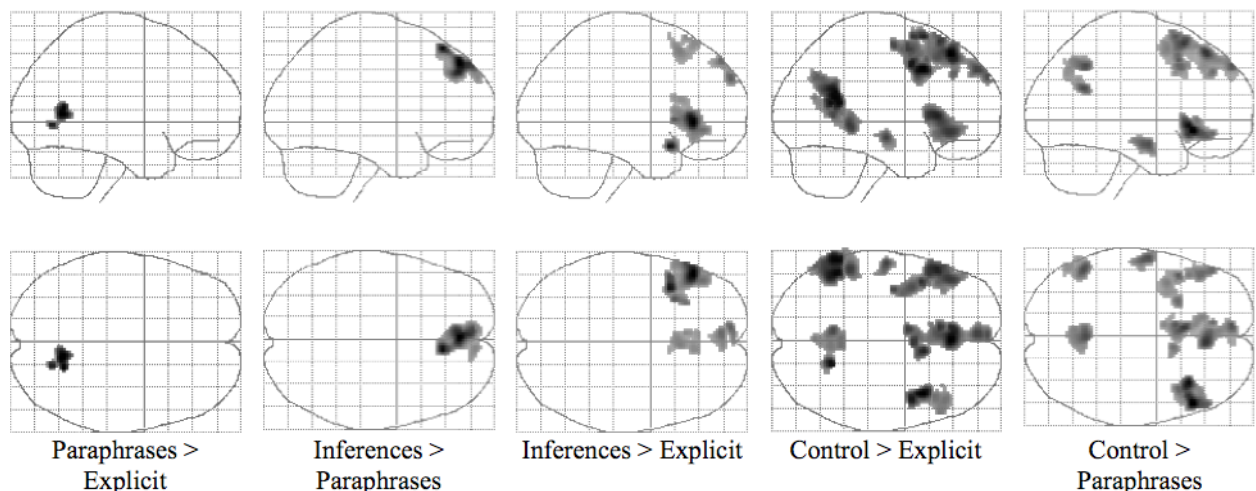


Figure 1: Statistical activation maps showing significant clusters in the statement verification tasks of the four experiment conditions.

the left inferior frontal gyrus, the middle frontal gyrus, the left temporo-parietal junction, the right middle frontal and precentral gyri as well as an area in the inferior and middle temporal gyri also showed significant activation.

### Discussion

The current results can also be interpreted consistently and comprehensively. For language and memory tasks (cf. Ullman, 2004), posterior and prefrontal regions form an interdependent network. The posterior cingulate's connections to prefrontal regions (Morris, Petrides & Pandya, 1999) show its link to a more integrative, structure-building region of the brain. Memory retrieval may depend on an interaction between posterior cingulate, posterior parietal association areas, prefrontal areas and mid temporal lobe structures. The medial temporal lobe retrieves information from memory and parietal regions maintain representations of remembered information. The prefrontal cortex exerts an important role concerning activated memory representations in the parietal lobe as well as

offline memories in temporoparietal regions. It sets up retrieval mode, initiates the retrieval attempt in temporal regions and monitors and selects upon activated memory representations. The extensive connections between those regions would indeed allow for a coordinated interplay. The interdependency between passive and strategic components in inferencing has recently also been demonstrated in a behavioral experiment by Calvo et al. (in press).

The fMRI experiment showed which brain areas become differentially involved in relating one and the same statement to variations of a previously read text. The posterior cingulate gyrus, supposedly signifying routine memory processes, was found to be active when an integration is achieved via a paraphrase. The medial frontal gyrus, supposedly indicating more effortful and strategic construction processes, becomes involved when an additional coherence link needs to be established.

The constructive processes of the *control condition* require more extensive memory retrievals involving the posterior cingulate gyrus and the left STG. In addition, coarse semantic relations may become activated in the right

Table 5: Brain regions, cluster size and their activation level of the significant clusters.

Region	BA		Cluster size	$p_{corr}$	z-max	X	Y	Z
<b>Paraphrase &gt; Explicit</b>								
posterior cingulate gyrus	30	R	179	0.010	4.03	12	-62	6
<b>Inference &gt; Paraphrase</b>								
SFG & MFG	8/9/6	R/L	733	0.000	4.68	-2	46	46
<b>Inference &gt; Explicit</b>								
IFG	45	L	754	0.000	4.81	-50	32	0
SFG & MFG	8	R/L	269	0.001	3.62	2	22	52
SFG & MFG	8/9	L	160	0.015	3.87	-10	60	32
<b>Control &gt; Explicit</b>								
SFG & MFG	6/8/9	R/L	1225	0.000	4.70	0	34	50
MTG, STG & supramarginal gyrus	21/22/39/40	L	1096	0.000	4.62	-60	-52	18
IFG	45/47	L	736	0.000	4.28	-54	24	4
MFG	6	L	410	0.000	4.13	-44	12	38
posterior cingulate gyrus	23/29/30	R/L	366	0.000	4.49	16	-56	14
MFG & precentral gyrus	9	R	356	0.000	4.74	40	14	40
IFG	47	R	154	0.013	3.51	42	22	-8
<b>Control &gt; Paraphrase</b>								
SFG & MFG	6/8/9	R/L	1097	0.000	4.35	4	36	52
IFG	47	R	430	0.000	4.91	52	28	-8
Precuneus	7	R/L	270	0.001	4.14	0	-54	42
MFG	6/8	L	261	0.002	3.98	-46	16	46
STG, angular gyrus & supramarginal gyrus	39/40	L	250	0.002	4.13	-50	-56	24
IFG	47	L	239	0.000	3.88	-46	32	-10
MFG & precentral gyrus	8/9	R	181	0.011	3.92	40	18	40
ITG & MTG	21	L	171	0.015	4.10	-60	-6	-18

Note: IFG = inferior frontal gyrus; SFG = superior frontal gyrus; MFG = middle frontal gyrus; ITG = inferior temporal gyrus; MTG = middle temporal gyrus; STG = superior temporal gyrus

hemisphere (e.g. the right IFG; cf. Mason & Just, 2004). The activated situational knowledge may then become integrated in the left IFG (cf. Hagoort et al. 2004). This hypothesis is empirically supported by the *Control > Explicit* and *Control > Paraphrase* contrasts which show these specific brain areas. In the explicit and paraphrase conditions such construction processes are not required because of the autonomous memory resonance process which achieves the linkage in a more economic way.

Overall, the current results provide a means for differentiating the role of a more passive memory process (O'Brien et al., 1998) and a more active construction process (Graesser et al., 1994) in relating a statement to a previously read text. The passive memory process may be termed memory resonance because it establishes a relation on the basis of local information. A related ERP-experiment has furthermore shown when these processes occur by N200, P300 and N400 components (Yang et al., submitted). The current study characterizes these two types of coherence formation processes according to where they occur in the brain by fMRI data.

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