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Interfacing mind and brain: A neurocognitive model of recognition memory

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Abstract

A variety of processes contribute to successful recognition memory, some of which can be associated with spatiotemporally distinct event-related potential old/new effects. An early frontal and a subsequent parietal old/new effect are correlated with the familiarity and recollection subcomponents of recognition memory, respectively, whereas a late, postretrieval old/new effect seems to reflect an ensemble of evaluation processes that are set by the task context in which retrieval occurs. Both the early frontal and the parietal old/new effects are differentially modulated by the informational content (e.g., object forms and spatial locations) of recognition and seem to rely on brain systems damaged in amnesia. The late frontal effect appears to reflect prefrontal cortex activation. A neurophysiologically based model of recognition memory retrieval is presented and it is shown that coupling recognition memory subprocesses with distinct old/new effects allow examination of the time course of the processes that contribute to correct and to illusory memories. In conjunction with event-related functional magnetic resonance imaging activation patterns the brain systems recruited by various aspects of episodic memory retrieval can be identified.

Descriptors: Event-related potentials, Recognition memory, Recollection, Familiarity, Old/new effects, Memory retrieval

Everyone knows the experience of seeing a face that looks familiar but not being able to retrieve the person's name or the context in which the face was seen before. Alternatively, an individual could meet the same person, immediately recognize him or her and remember his or her name as well as the several experiences that were shared with this person. These two apparently different forms of recognition underlie so-called dual-process theories of recognition memory that assume recognition memory to be comprised of two components: familiarity and recollection. *Recollection* refers to the consciously controlled retrieval of information from a prior study episode. In contrast, the term *familiarity* does not refer to a specific process but rather to the phenomenal experience that a particular item "reminds one of something." The processes, however, that lead to this phenomenal experience are still a matter of debate. In the following discussion, the term familiarity will be used to refer to processes by which linked information in long-term memory is assessed without forming larger representational units that allow recollection processes to occur.

Cognitive psychologists have developed a variety of techniques to dissociate the recollection and familiarity components of recognition memory. Jacoby (1991) introduced the process dissociation procedure in which subjects are presented with two classes of items for study. At test they are instructed to respond with an old response to items belonging to one class of study stimuli (exclusion task) or to respond old to all items that have been studied (inclusion task). The exclusion task can only be performed when the two classes of study items can be discriminated, whereas recognition based on familiarity is assumed to be sufficient to discriminate old from new items in the inclusion task. Based on these assumptions separate values for recollection and familiarity can be calculated (Jacoby, 1991). Hintzman and Curran (1994) applied the response-signal technique (Dosher, 1984) to dissociate the contribution of familiarity and recollection processes to recognition judgments. In this method the test item is followed after a variable delay by a signal that requires an immediate response. Recognition accuracy typically increases as a function of delay. The authors examined response functions for false-alarm response evoked by items that were similar with studied items. They found a higher proportion of false-alarm response to these items at short delays than at long delays and took these biphasic response functions to suggest that familiarity rises earlier during retrieval than recollection. Another way of dissociating familiarity and recollection is the

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"Remember/Know" procedure proposed by Tulving (1985). Subjects are instructed to accompany old recognition decisions by a judgment of whether the item was old because they explicitly remembered it or because it felt familiar. Remember responses are identified with recollection and Know responses are assumed to reflect recognition based on familiarity. Although there is an ongoing debate to what extent the various approaches to define and measure recollection and familiarity are convergent (cf. Rugg, Schloerscheidt, & Mark, 1998) dual-process models are successful in explaining many basic recognition memory phenomena.

Another important contribution to our understanding of the mechanisms that lead to recognition memory judgments comes from neuropsychology. Neuropsychological research is concerned with the localization of cognitive functions in the brain and with the brain systems and processes that are recruited by specific information processing functions. Neuropsychological findings have had an important impact on our understanding of memory systems and processes in general (Milner, Squire, & Kandel, 1998) and have also added to our understanding of how the familiarity and recollection components of recognition memory are realized in the human brain (Volpe, Holtzman, & Hirst, 1986). Another important implication of neuropsychological studies of memory is that impairments in recognition memory can be content specific. That is, brain lesions can attenuate recognition memory performance for some contents while the ability to recognize other contents is spared (cf. Shallice & Warrington, 1970). Pigott and Milner (1993) examined recognition memory for figurative details and spatial locations in line drawings of complex scenes in a group of temporal lobectomy patients. While all patients were impaired in object-based recognition judgments, a selective impairment in recognizing spatial locations was found in patients with partial to complete removal of the right hippocampus. A selective recognition memory deficit for spatial materials after right medial temporal lobectomy (including the hippocampus) was reported by Owen, Sahakian, Semple, Polkey, and Robbins (1995), confirming the relevance of the hippocampus for spatial recognition memory judgments. It is important to note that it is unknown how these content-specific impairments in recognition memory map onto the proposed recollection and familiarity subcomponents of recognition memory. They can be orthogonal to these subcomponents or, alternatively, reflect the fact that the familiarity and the recollection subcomponent are differentially recruited by different recognition memory contents.

These studies suggest that different processes underlie recognition memory for object forms and spatial locations. However, they do not allow unambiguous inferences on the functional architecture of recognition memory in the nonlesioned brain for the following three reasons. First, functional deficits after brain lesions can either reflect that a particular, unimpaired processing system does not receive the appropriate input, or that the processing system itself is damaged. Second, selective impairments can reflect a compensatory strategy characteristic for the lesioned brain that is of no relevance for the understanding of the nonlesioned brain (Shallice, 1988). Third, neuropsychological studies of recognition memory in most instances require particular testing conditions adapted to the patients' needs and therefore do not allow fine-grained analyses of the subcomponents underlying recognition memory. Therefore, an important question is whether a similar segregation of object-based and spatial-based recognition memory is also characteristic of the nonlesioned human brain.

This report is structured as follows: The first section includes an examination of whether there is a content-specific organization of recognition memory in the nonlesioned human brain. To this end, a series of studies are reviewed that used event-related potentials (ERPs) to examine the neurocognitive systems underlying recognition memory for object forms and spatial locations. Next, the issue is addressed whether a content-specific brain organization of recognition memory processes is orthogonal to the dual-processes account of a familiarity and recollection subcomponent of recognition memory. ERP evidence is provided for the view that content-specific organization of recognition memory for object forms and spatial locations reflects the differential contribution of recollection and familiarity processes. The second section concerns the brain systems underlying recognition memory and the more detailed functional characteristics of its subcomponents. In the third section, ERP correlates of recognition memory subprocesses are used for a fine-grained analysis of illusory memories. Brain activation patterns from a functional magnetic resonance imaging (fMRI) study are used to identify the brain regions recruited by illusory memories. In the final section a neurocognitive model of recognition memory retrieval is developed.

CONTENT-SPECIFIC ORGANIZATION OF RECOGNITION MEMORY

ERP Measures of Recognition Memory

ERPs are small voltage oscillations measured at the scalp that are time-locked to the processing of external events. ERPs have been examined in a large number of recognition memory studies using both direct and indirect tests of memory (for an overview, see Rugg, 1995). In direct tests of memory, correctly classified old items elicit more positive-going waveforms than new items. These effects are labeled old/new effects and are assumed to be comprised of a N400 component, which is reduced with repetition, and a late positive component, which is enhanced by repetitions (Besson, Kutas, & Van Petten, 1992; Joyce, Paller, McIsaac, & Kutas, 1998; Rugg, 1990; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). Old/new effects in direct tests of memory are not elicited by erroneously rejected old items (misses) or by false alarms to new items (Neville, Kutas, Chesney, & Schmidt, 1986). Therefore, they are not simply a consequence of item repetition nor do they reflect the execution of an old response. Rather the old/new effects are considered to be associated with the successful retrieval of events from a prior study episode.

Different spatiotemporal patterns of the old/new effects have been associated with different subcomponents of recognition memory. For example, differences between old and new items in the range from 300 to 500 ms at frontal recording sites have been found to be insensitive to a depth of processing manipulation and consequently this aspect of the old/new effect was associated with familiarity (Rugg et al., 1998). Conversely old/new effects in the range between 400 and 600 ms that are most pronounced at parietal recording sites, that is, parietal old/new effects, have been found to be correlated with the hit rate and decision confidence during recognition judgments (Johnson, Kreiter, Russo, & Zhu, 1998; Johnson, Pfefferbaum, & Kopell, 1985). They also were more pronounced for items given a Remember response than for those given a Know response (Smith, 1993; but see Spencer, Abad, & Donchin, in press) and were sensitive to a depth of processing manipulation at study (Paller & Kutas, 1992). These results were taken to support the view that the parietal old/new effects are closely tied to the recollection component of recognition memory (Allan, Wilding, & Rugg, 1998). Another spatiotemporally distinct aspect of the old/new effect is observable in a late time window, sometimes even beyond the execution of responses with a maximum over right frontal recording sites. It is associated with the successful retrieval of contextual information from the study episode (Wilding & Rugg, 1996) and is assumed to reflect various strategic processes that operate on the products of the retrieval process (Allan et al., 1998; Mecklinger & Meinshausen, 1998; Trott et al., 1999).

Recognition Memory for Object Forms and Spatial Locations

In a series of studies we used the ERP technique to disentangle the subcomponents of recognition memory for object forms and spatial locations (Mecklinger, 1998; Mecklinger & Bosch, 1999; Mecklinger & Meinshausen, 1998). Basically, we asked subjects to make recognition judgments for the two information types and we tried to identify both types of judgments with distinct spatiotemporal voltage patterns. To ensure that these spatiotemporal ERP signatures could indeed be identified with the retrieval of a specific information type, two conditions had to be satisfied: First, ERPs elicited during recognition tests for both information kinds could not be affected by differential encoding operations. Second, given that even late ERP components such as the P300 are modulated by physical stimulus characteristics (Roth, Blowers, Doyle, & Kopell, 1982), we had to ensure that both recognition memory tests used physically identical stimulus materials.

The basic experimental paradigm is illustrated in Figure 1. The subjects were instructed to memorize four abstract object forms and their respective spatial locations in a two-dimensional spatial matrix. The subjects were instructed to maintain an image of the objects and their spatial locations. To minimize verbal rehearsal strategies, an articulatory suppression task had to be performed between study and test. Prior to the subsequent test phases, each including eight judgments, a cue was presented that indicated whether recognition judgments for object forms or spatial locations would be required. Subjects responded faster and also more accurately for spatial locations than for object forms. The ERP waveforms elicited by correct old and new responses at two representative electrode sites are illustrated in Figure 2a.

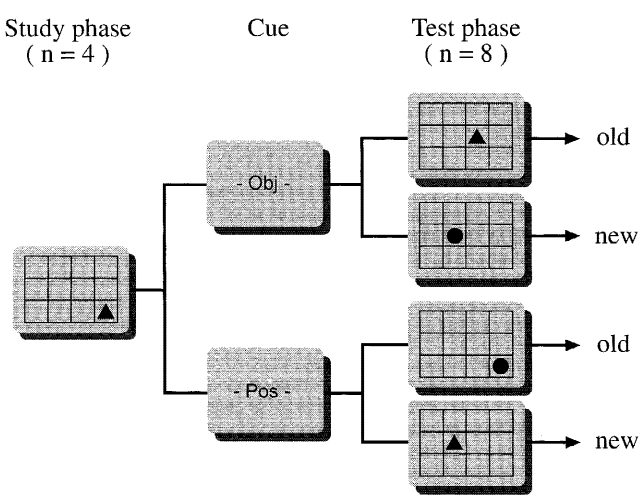

Figure 1. Schematic illustration of the experimental task used to examine recognition memory for object forms and spatial locations.

Both recognition tasks elicited old/new effects with a broad temporal distribution. Several aspects are noteworthy. First, there was a pronounced anterior/posterior dissociation in the magnitude of the old/new effects elicited in both tasks. The spatial task showed a posteriorly focused distribution whereas the object task showed a frontally focused topography. Second, as apparent from the effect sizes of the old/new effects illustrated in Figure 2b, between 1,200 and 1,800 ms pronounced old/new effects emerged at frontal recordings that were most pronounced over the right frontal cortex in the object task, whereas parietally focused effects were obtained in the spatial task during this time interval. To ensure that these topographic effects were not confounded with differences in absolute amplitude, a series of topographical profile analyses (Johnson, 1993) was performed. These analyses revealed reliable anterior/posterior differences for the early effects and a reliable difference between the late and early frontal effects in the object task.

Prior to relating these distinct spatiotemporal ERP signatures obtained in recognition memory tests for object forms and spatial locations to subcomponents of recognition memory, alternative interpretations for the differential ERP pattern were considered. It is conceivable that the between-task ERP differences arise from the intrinsic properties of the stimulus materials. The aforementioned studies used geometric forms (e.g., circle, cross, ellipse) that share a variety of basic features such as lines, angles, and textures and by this similarity might have required more demanding discrimination processes as compared with the easy-to-discriminate spatial locations. We tested this hypothesis in an experiment in which the geometric forms were replaced by line drawings of highly familiar everyday objects (e.g., glasses, pipe, hammer, etc.). According to Snodgrass and Vanderwart (1980), all 12 objects had high rankings on a familiarity scale and low rankings on a complexity scale. All other experimental details were identical to those of the first two experiments; however, to enable a more fine-grained analysis of the spatiotemporal ERP pattern, high density electroencephalogram recordings (61 electrodes) were applied. Figure 3a shows a clear anterior/posterior dissociation of the early old/new effects evoked in both tasks. Closer visual inspection of the waveforms elicited by old and new items in both tasks suggests that the frontally focused effects in the object task arise from the attenuation of a frontally focused N400-like negative component to old objects,[1] whereas the parietal maximal effects reflect an enhanced late positive component to old spatial locations. In fact, in the object task at frontal recordings the mean voltages were 11.2 μV for old responses and 9.7 μV for new responses. In the spatial task at parietal recordings the mean voltages were 15.8 μV for old judgments and 14.7 μV for new judgments. This pattern of results supports the view of a content-specific brain organization for object-based and spatially based recognition memory.

As mentioned earlier, an important issue is whether this content-specific organization of recognition memory is orthogonal to the dual-process account of recognition memory. Frontally focused old/new effects of similar kinds have been found recently in a variety of explicit memory tasks (Curran, in press; Penney, Mecklinger, Hilton, & Cooper, 2000; Rugg et al., 1998) and several lines of evidence suggest that these effects are related to the familiarity component of recognition memory (cf. Rugg et al., 1998). Curran

[1] Note that the term “frontal N400-like negative component” was chosen to distinguish the present negative component from the centroparietally focused N400 initially reported by Kutas and Hillyard (1980).

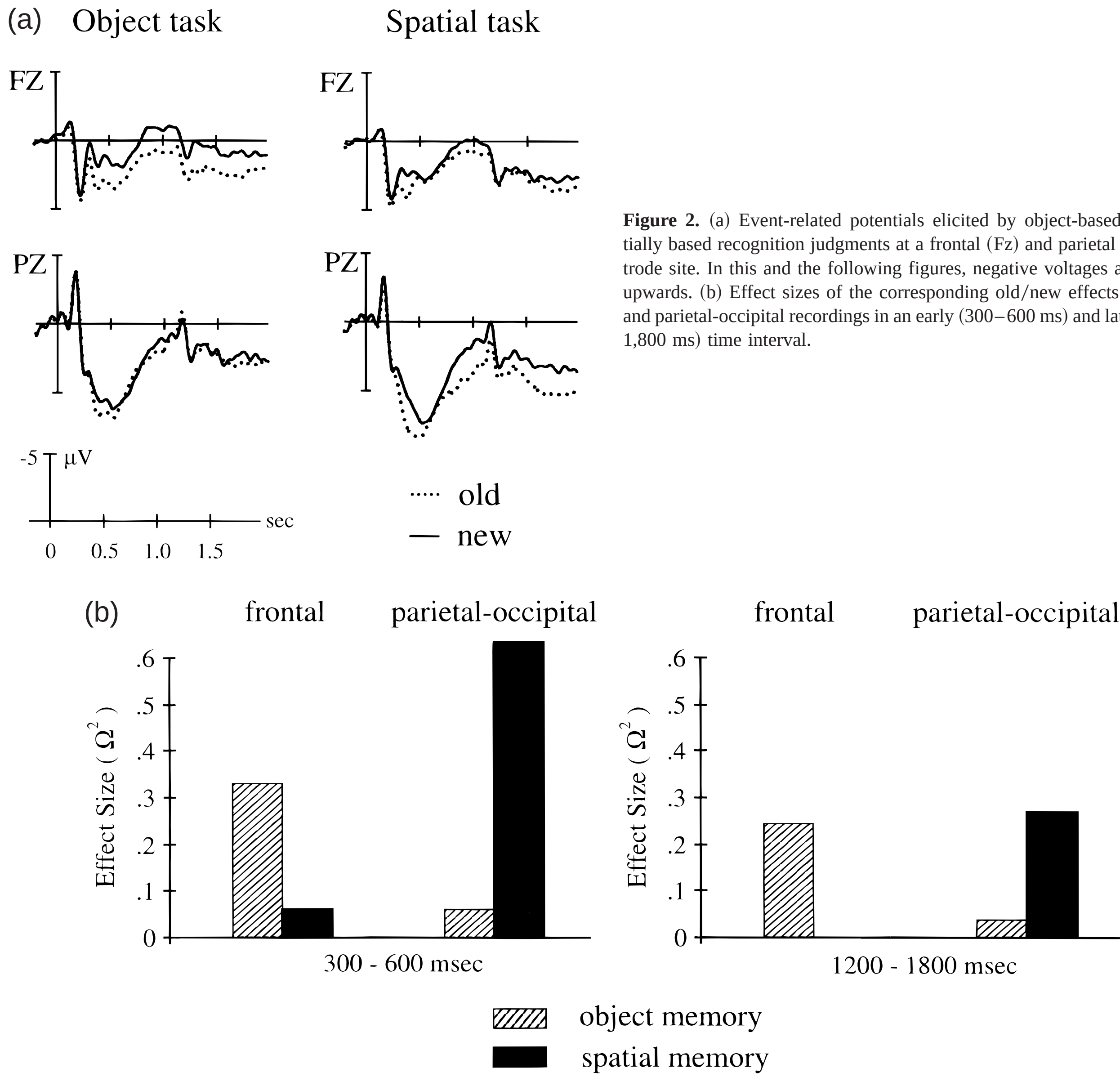

Figure 2. (a) Event-related potentials elicited by object-based and spatially based recognition judgments at a frontal (Fz) and parietal (Pz) electrode site. In this and the following figures, negative voltages are plotted upwards. (b) Effect sizes of the corresponding old/new effects at frontal and parietal-occipital recordings in an early (300–600 ms) and late (1,200–1,800 ms) time interval.

(in press) found that a frontal N400-like component (the FN400) was attenuated for words that were similar (i.e., singular/plural ambiguities) to studied words. Frontally focused old/new effects have also been reported in a series of ERP studies on memory for three-dimensional (3D) possible and impossible line drawings. Penney et al. (2000) examined explicit and implicit memory for 3D possible and impossible objects (Schacter & Cooper, 1993) and found an attenuated negative component over frontal scalp sites for 3D possible objects in an explicit but not in an implicit retrieval task, a finding that supports the view that familiarity as indexed by frontally focused old/new effects is an explicit memory phenomenon. Given these lines of evidence, we are inclined to associate the frontal old/new effects with increased processing fluency by which items are experienced as being more familiar.

Why was a frontal effect not obtained in the recognition memory tasks for spatial locations? It has been suggested recently that the N400 component is elicited by items that can be represented in a unitized code, a format that represents an item within a particular domain of processing and by which it can be integrated in a task context (Mecklinger, 1998; Rugg, 1995; Rugg & Doyle, 1994). This format might include different forms of relationships established by prior experience and activation of these relationships might be critical for recognition (Weiskrantz, 1997). We assume that a spatial location is not represented by a semantic code but rather is coded into a visual-structural representation format that mainly comprises surface descriptions of the visual input (Penney et al., 2000; Schacter, Cooper, Delaney, Peterson, & Tharan, 1991). Only the semantic code representation format includes conceptual factors that modulate familiarity when recognition is tested explicitly and gives rise to frontally focused old/new effects. The visual-structural representation format entails structural descriptions that cannot be represented on a conceptual level and thus do not allow contextual integration. These descriptions enable recollection but no other forms of recognition memory. In this vein, the parietally focused old/new effects elicited by spatial locations can be considered as correlates of the recollection component of recognition

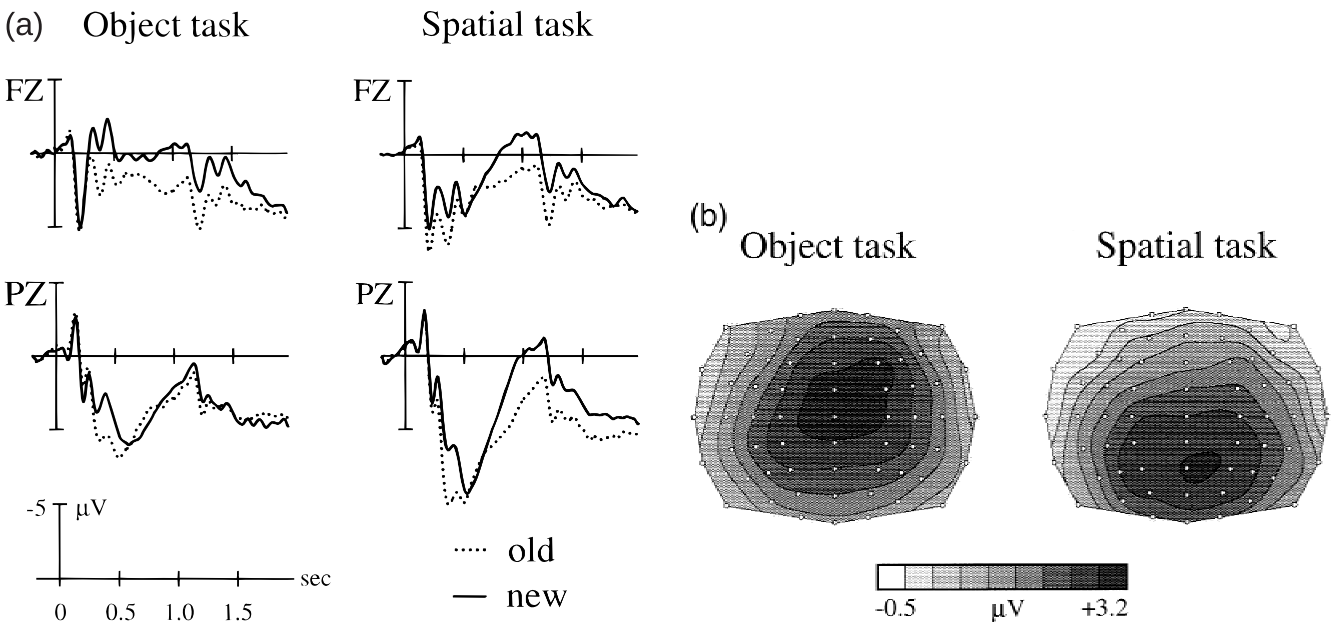

Figure 3. (a) Event-related potentials elicited by object-based and spatially based recognition judgments using familiar and low complexity stimuli at a frontal (Fz) and parietal (Pz) electrode site. (b) Topographic distribution of the early old/new effects (300–600 ms) in both tasks. These and all following topographic maps were calculated with a two-dimensional spherical spline interpolation algorithm using a radial projection from Cz, which respects the length of the median arcs (Perrin, Pernier, Bertrand, & Echallier, 1989).

memory. We take this pattern of results to suggest that object form recognition and spatial recognition rely differentially on recollection and familiarity. In other words, there is a distinction between a conceptually based representation system, accessible by object forms and enabling increased processing fluency in a recognition memory test, and a perceptually based, less flexible format that mainly enables recollection. As only recognition memory for object forms but not for spatial locations gives rise to late-occurring old/new effects maximal over the frontal scalp, it is conceivable that the postretrieval operations reflected in these effects are contingent upon conceptual semantic representations.

SUBCOMPONENTS OF RECOGNITION MEMORY: BRAIN SYSTEMS AND FUNCTIONAL SIGNIFICANCE

Familiarity and Recollection in Amnesic Patients

An important issue concerns the brain systems underlying the familiarity and recollection components of recognition memory. In some models the distinction between familiarity and recollection appears similar to the distinction between implicit and explicit memory. In fact, dual-process models differentiate between an explicit recollection component and a more perceptually based familiarity component (Jacoby & Dallas, 1981). This view, that familiarity and recollection are implicit and explicit memory phenomena and by this depend on different brain structures, is build on dissociations in amnesic patients between impaired performance on recall tasks and intact performance in recognition memory tasks. To illustrate this point, Volpe et al. (1986) found that recognition memory performance in amnesic patients was comparable to controls, whereas there was a pronounced decline in the patients' recall performance even when the patients were given extra study time. This dissociation has been taken to suggest that recognition unlike recall depends on perceptual priming processes (an implicit memory phenomenon) that are not reliant on medial temporal lobe structures, whereas recall, an explicit memory phenomenon, is reliant on the integrity of medial temporal lobe structures.

Other models, however, assume that familiarity and recollection are both part of an explicit memory system that is damaged after amnesia. This view is based on results showing that amnesic patients were similarly impaired in Remember and in Know recognition responses (Knowlton & Squire, 1995) and on other studies that revealed highly similar impairments in recall and recognition in amnesic patients (Haist, Shimamura, & Squire, 1992). These results support the view that familiarity and recollection recruit the same brain mechanisms (Zola & Squire, 1999).

Under the abovementioned assumption that the two subcomponents of recognition memory are explicit and implicit memory phenomena and by this depend on different brain structures, recognition memory for spatial locations that is more reliant on recollection should be more degraded in amnesic patients as compared with recognition memory for object forms for which an additional familiarity component can be assumed. In this case the parietal old/new effects should be attenuated whereas the frontal old/new effects should be spared in the amnesic patients.

We tested these predictions by performing an recognition memory experiment with a group of patients who had transient global ischemia (TGI) due to cardiac arrest (Mecklinger, von Cramon, & Matthes-von Cramon, 1998). Although TGI leads to a variety of neuropathological changes, some brain regions such as the medial basal temporal lobes (including the hippocampal formation) are selectively vulnerable to a lack of blood and oxygen supply (Cervós-Navarro & Diemer, 1991). Consequently, six of the eight patients studied were amnesic according to a criterion of scoring well on IQ tests of non-mnemonic abilities and performing poorly on tests of mnemonic abilities like the Wechsler Memory Scale-Revised (Wechsler, 1987). The patients and a group of 24 age-matched controls performed the object and spatial recognition memory tasks (without mirror-based judgments) using a blocked presentation of both conditions.

As expected, task performance was poorer for the patients than for the controls. The mean proportion of correct responses was 72% in the object task (controls 94%) and 74% in the spatial task (controls 95%). Even though the patients' performance level was low, it was significantly different from chance for seven patients in the object task and for six patients in the spatial task. The ERP waveforms evoked by correctly classified old and new responses for patients and controls in both tasks are shown in Figure 4 (object task) and Figure 5 (spatial task).

In showing frontally focused old/new effects in the object task and parietal maximal old/new effects in the spatial task, the control group data resemble those obtained in previous experiments using the same experimental paradigm with randomized task presentation (Mecklinger, 1998). Interestingly, neither task evoked any old/new effects in the patient group. This result is further illustrated in Figure 6, which shows the mean amplitude measures of the old/new effects in the 300–600-ms time interval for those patients who performed above chance in the respective memory task. The mean old/new effects in the control group were around 3 μV, whereas no corresponding effects were obtained for either patients.

This pattern of results implies that under the assumption that object-based and spatial-based recognition judgments differentially rely on familiarity and recollection, both processes depend on brain structures damaged after TGI. Therefore, these results add to the increasing evidence that the recollection and familiarity components of recognition memory are related functions of declarative memory and depend on the brain systems damaged in amnesia (Gabrieli, 1999; Haist et al., 1992; Knowlton & Squire, 1995).

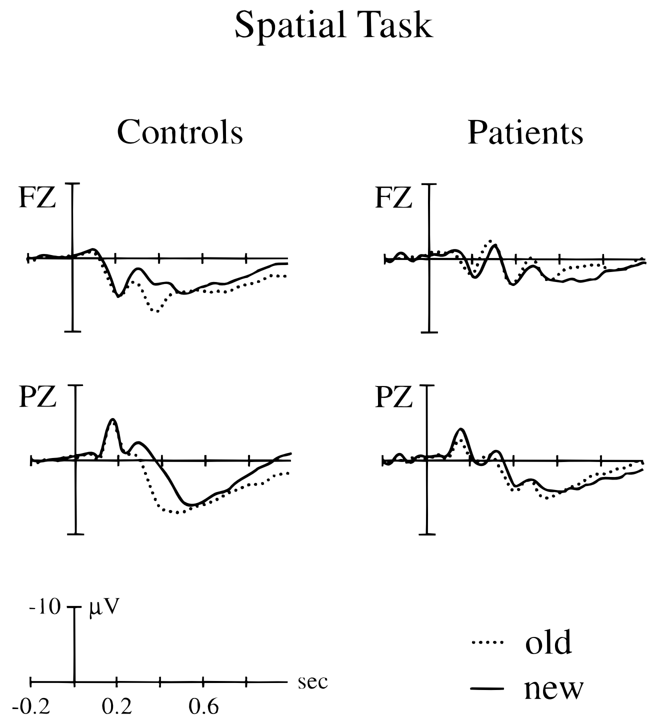

Figure 5. Event-related potentials elicited by spatially based recognition judgments in patients with transient global ischemia (TGI) (right) and matched controls (left).

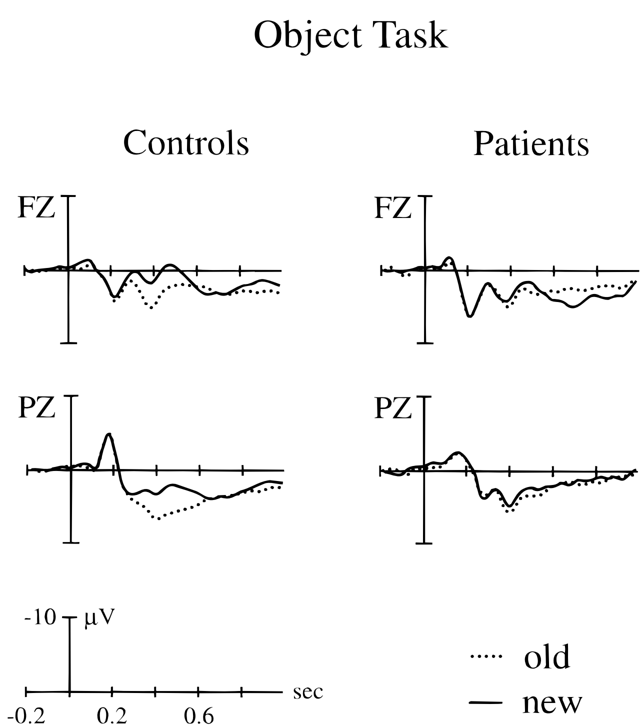

Figure 4. Event-related potentials elicited by object-based recognition judgments in patients with transient global ischemia (TGI) (right) and matched controls (left).

Given that the patients showed neither a familiarity-related ERP effect nor a recollection-related ERP effect, the issue arises as to how the patients performed the task. The fact that most patients performed above chance suggests that some form of nondeclarative memory is spared after TGI and must have contributed to recognition performance. A likely candidate could be perceptual priming, a form of nondeclarative memory that is spared in amnesic patients (Cermak, Verfaellie, & Chase, 1995). However, in the present experiment a fixed set of items was used interchangeably as old and new items in different task blocks such that increased processing fluency could not build up across the experiment. We rather assume that another form of nondeclarative memory, which is learning skills for accessing and retrieving memory information, is spared after TGI. Because skills learning of similar kinds has been found in amnesic patients for unique and nonrepeated items (e.g., Cohen & Squire, 1980) it is not unlikely that such skills were acquired and applied to multiple objects and locations in the present study. In support of this view we found performance improvements between the first and the last test block in both recognition tasks in the patients that were of similar magnitude to those obtained for controls (Mecklinger, von Cramon, et al., 1998). To summarize, the combined behavioral and ERP data suggest that both components underlying recognition memory in explicit tasks are affected similarly by TGI. This finding implies that declarative memory functions, even though they are reflected by ERP components, are not necessarily required for recognition

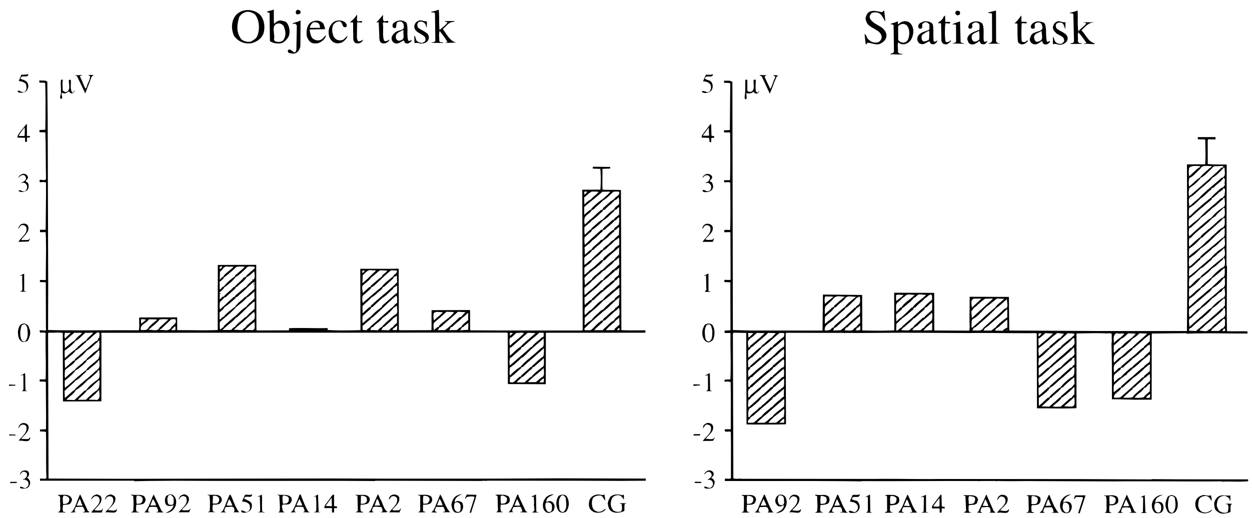

Figure 6. Magnitude of the early old/new effects of transient global ischemia (TGI) patients that performed above chance in the recognition tasks and the mean old/new effects of the corresponding controls in the object (left) and spatial (left) recognition task.

memory performance. Rather, in the present study it may be a form of nondeclarative memory, that is, skill learning and acquisition, that guides recognition judgments without giving rise to ERP modulations.

Probing the Functional Characteristics of the Different Old/New Effects

The studies reviewed so far suggest that different spatiotemporal patterns of the old/new effects can be associated with the familiarity and recollection subcomponents of recognition memory in direct tests of memory. An additional ERP effect, which onsets at the time the response is executed at right frontal recording sites, seems to be associated with postdecision evaluation and monitoring processes. Both the frontal and the parietal old/new effects are differentially modulated by the informational content (object forms and spatial locations) of recognition and can be considered as declarative memory functions that rely on the brain systems damaged in amnesia. To allow more detailed proposals about the functional significance of the different old/new effects, that is, the subprocesses of recognition memory they are associated with, it is important to examine how these effects are modulated by task variables usually used in direct tests of memory and to examine how the subprocesses underlying these effects operate in concert to enable adequate recognition judgments.

The task variable we manipulated was *directed forgetting* (Ullsperger, Mecklinger, & Müller, in press). A well-established but also poorly understood phenomenon in experimental memory research is that study items that are followed by an instruction to forget are more poorly remembered than items instructed to be remembered. At least three different mechanisms have been proposed to explain this directed forgetting effect: differential encoding (Bjork, 1972), formation of separate storage sets for both remember and forget items (Epstein, 1972), and an inhibition mechanism that blocks the retrieval of forget items (MacLeod, 1989).

We assumed that if an instruction to forget initiates a process by which the access to that item is inhibited during retrieval this additional process at the time of retrieval should be reflected by a qualitatively different spatiotemporal pattern of old/new effects elicited by forget and remember items. In detail the predictions were as follows: If a remember/forget instruction is delayed with respect to item presentation it should not render forget words less familiar than remember items. Consequently there should be no differences in the frontal old/new effect as a function of remember/forget instruction. Second, an instruction to forget should result in reduced retrieval of aspects of the study episode, that is, a lower proportion of trials with conscious recollection, and therefore the parietal old/new effects should be attenuated. Finally, given that the right frontal effect is related to retrieval success, that is, evaluation or monitoring effects contingent on successful retrieval, it should be smaller for forget items for which fewer retrieval products are available. These predictions were tested using a directed forgetting paradigm. The study phase consisted of an equal number of remember and forget words (180 words in total), presented in random order. Each word was followed by a remember or forget instruction after a delay of 2.5 s. The subsequent test phase in which the subjects were instructed to respond old to all previously seen words, irrespective of the remember/forget instruction, comprised all study words and an equal number of new words (see Ullsperger et al., in press).

Reaction times were faster and error rates were lower for remember words than for forget words, indicating that the forget instruction was effective. Figure 7a shows the ERP waveforms for correctly classified new and old words associated with either a remember or forget instruction. There are pronounced spatiotemporal differences between the old/new effects for both word types. Figure 7b shows the topographic distribution of the old/new effects in three successive time windows. Consistent with our prediction, both forget and remember words elicited a topographically similar frontal old/new effect between 350 and 550 ms, which, however, was larger in magnitude for remember than for forget words. Second, a parietal effect in the 550–850-ms time interval was obtained for remember words but not for forget words. A late right frontally focused old/new effect arises at around 800 ms and reaches its maximum between 900 and 1,200 ms. Most interestingly the right frontal effect was larger for forget words than for remember words and also displayed a somewhat different scalp distribution. This latter result, together with the poorer memory

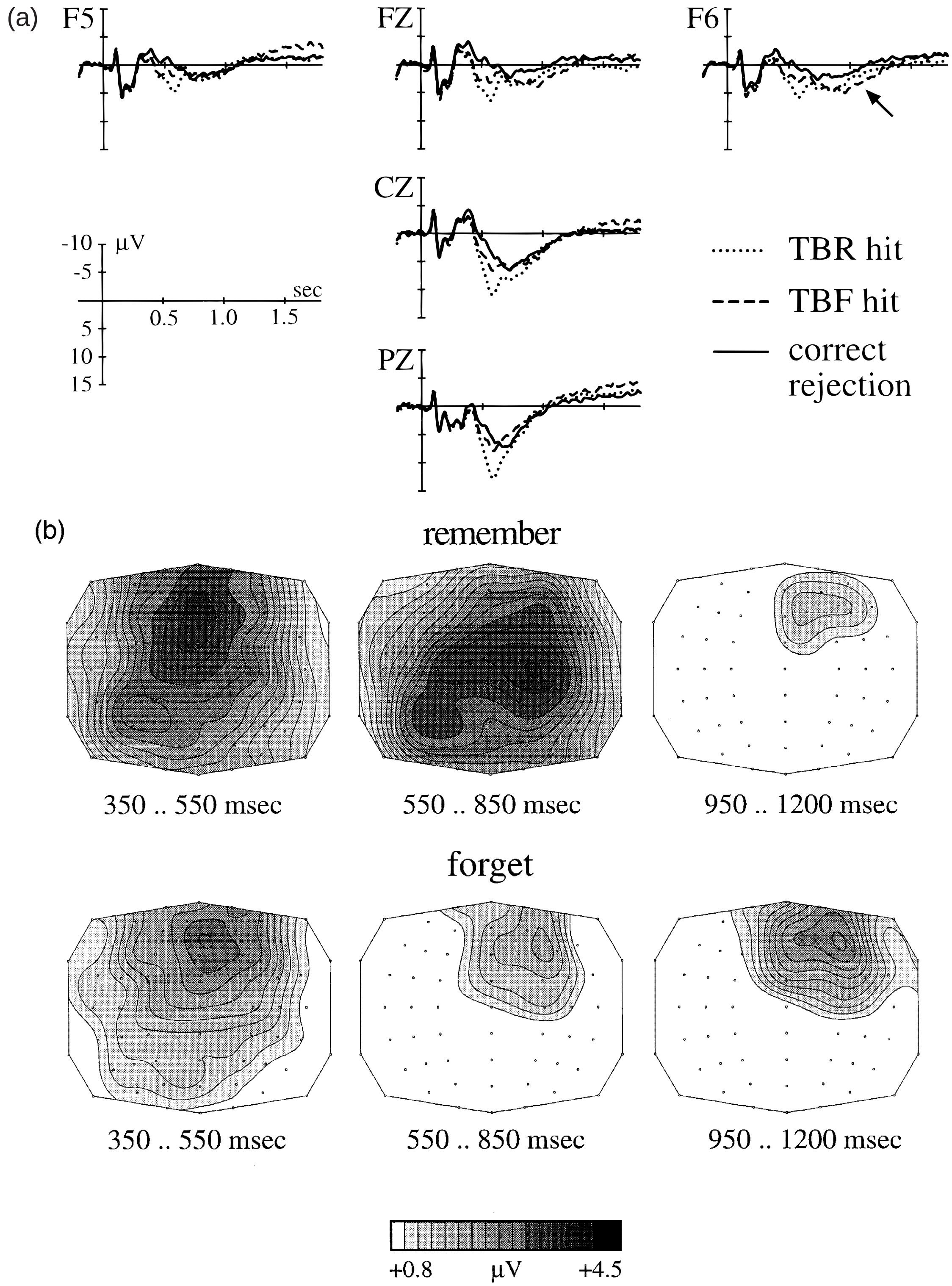

Figure 7. (a) Event-related potentials elicited by correctly recognized to-be-remembered words (TBR-hit), correctly recognized to-be-forgotten words (TBF-hit) and by correct rejections in a directed forgetting task. (b) Topographic distribution of the corresponding old/new effects for remember and forget words in the three consecutive time intervals.

performance for forget items, is at odds with the retrieval success account of the late right frontal effect (Donaldson & Rugg, 1998; Wilding & Rugg, 1996). The present result is more consistent with the view that an ensemble of evaluation or monitoring processes are engaged, some of which are context dependent, for example, higher evaluation demands when few retrieval products are available or when the valence of items are changed from irrelevant (study) to relevant (test) (cf. Henson, Rugg, Shallice, Josephs, &

Dolan, 1999; Wagner, Desmond, Glover, & Gabrieli, 1998) as was the case for the forget words but not for remember words in the present study.

The implications of these results for the understanding of the mechanisms involved in directed forgetting are twofold: First, the presence of qualitatively different old/new effects at parietal and right frontal recordings sites argues against the view that directed forgetting effects arise solely from the modulation of an unidimensional variable such as elaboration during encoding (see Paller, 1990, for similar arguments). They do, however, suggest that recognition judgments for words associated with a forget instruction are based mainly on familiarity followed by more extensive post-decision evaluation demands. Judgments for remember words are based on a combination of recollection and familiarity and require fewer evaluation processes (see Ullsperger et al., in press, for a detailed discussion of implications for models of directed forgetting).

ILLUSORY MEMORIES

The purpose of a final set of experiments was to examine the subprocesses contributing to illusory recognition memory. In a typical experimental setting, illusory or false recognition can be inferred from old responses to new words that are on some level related or similar to previously studied words, be it phonologically (Rubin, Van Petten, Glisky, & Newberg, 1999), semantically (Roedinger & McDermott, 1995), or episodically (Miller & Gazzaniga, 1998). For related new words this false-alarm rate is usually higher than the false-alarm rate to new unrelated items. Various accounts have been proposed to explain false recognition: For example, false recognition is assumed to reflect encoding failures, because subjects generate similar items during study of associated items. By this, false recognitions result from source confusions during recognition because it cannot be inferred whether an item was studied or generated. The role of such an associative process is also emphasized in more retrieval-oriented models of false memories (cf. Schacter, Norman, & Koutstaal, 1998). Pattern separation failures during encoding lead to good memories for what items have in common (e.g., categorical relatedness) but to poor memory for distinctive, item-specific information. This view is similar to a distinction proposed by Conway and Rubin (1993), who referred to different forms of memory based on general event knowledge and event-specific knowledge. The view that false memories arise mainly from familiarity-based recognition judgments was, however, challenged by a study by Roedinger and McDermott (1995). Using the Remember/Know procedure they showed that false recognition responses were accompanied by remember judgments as frequently as correct recognitions, indicating that under some circumstances recollection (or at least the feeling of recollection) occurs for similar but new items.

Neurophysiological Aspects

Words that are categorically related to studied words presumable are more prone to feelings of familiarity than words for which no such relationship exists and therefore should show a unique ERP signature. Measuring ERPs evoked by old words and categorically related new words should allow estimations of the contribution of recollection and familiarity to true and false recognition judgments. Most of the ERP studies of false memories used the so-called Deese paradigm (Deese, 1959) in which participants study sets of words that are all semantically associated with nonstudied (lure) words. At test, false recognitions are examined for the non-studied lure words. However, lure words by definition are highly associated with a large number of studied words, whereas old words are selected based on their relationship with the lure words but not for their relationship with each other. This asymmetric relationship between old and lure words can lead to different response criterions for lure and old words (Miller & Wolford, 1999) and can also assert differential effects on the ERPs evoked by lure and old words when these are presented intermixed in a test phase (cf. Rubin et al., 1999). To overcome these limitations we used semantic categories as stimulus materials and selected old words and similar words from the same semantic category (Nessler, Mecklinger, & Penney, submitted).

In a first experiment, we examined old/new effects to old words and categorically related (similar) words. If false recognition of similar words relies on general familiarity and true recognition of old words results from recollection of item-specific information from the study episode, false recognition should evoke a frontal old/new effect whereas true recognition should evoke frontal and parietal effects. Conversely, if, as suggested by Roedinger and McDermott (1995), false memories can be the result of conscious recollection there should be no qualitative differences between the old/new effects evoked by true and false recognition.

To prevent perceptual fluency for old words in the test phase a cross-modal recognition memory task was used. In the study phase the subjects listened to 150 words (6 exemplars selected from 25 categories) and in the subsequent test phase a total of 300 words (150 old words, 100 similar words drawn from the study categories, and 50 new words drawn from new categories). The hit rate was 73% and the false-alarm rate to similar words amounted to 30% and thus was considerably higher than the basic false-alarm rate (12%). Figure 8a shows the ERPs evoked by correctly rejected new words and by old responses to similar and old items. The topographic distribution of the old/new effects in an early (400–600 ms) and a late (1,200–16,00 ms) time interval evoked by true and false recognitions is illustrated in Figure 8b. Notably, there were reliable frontal, parietal, and right frontal old/new effects for old items, whereas for lure words there was a small but statistically reliable, slightly right lateralized frontal old/new effect in the 400–600-ms time interval, and at parietal sites starting around 600 ms old responses to lure words gave rise to a negative slow wave with a duration of about 1,000 ms. Interestingly, the late right frontal old/new effect, starting around 1,200 ms, was indistinguishable for true and false recognition judgments.

Given that the frontal old/new effect though significant, was small, we considered alternative measures of familiarity. We directly contrasted old and new responses for lure items because lure words that attract an old response should be more familiar than those that are rejected. In fact, as can be seen in Figure 9, new responses to lure words evoked a pronounced frontal negative component that was attenuated for old responses to lure words. The negative component might reflect search in episodic memory by which recollected information about the specific study words allows rejection of semantically related lure words. A similar view has been proposed by the “recall-to-reject account” (Clark, 1992; Hintzman & Curran, 1994). The absence of this component reflects a failure in accessing item-specific, within-category information that can be best described as “illusory familiarity.” The lure words may remind the participants of the studied words. In support of the view that false recognition is based on illusory familiarity rather than recollection, there were no statistically reliable ERP differences between correct and erroneously classified lure words at parietal recording sites in this time interval.

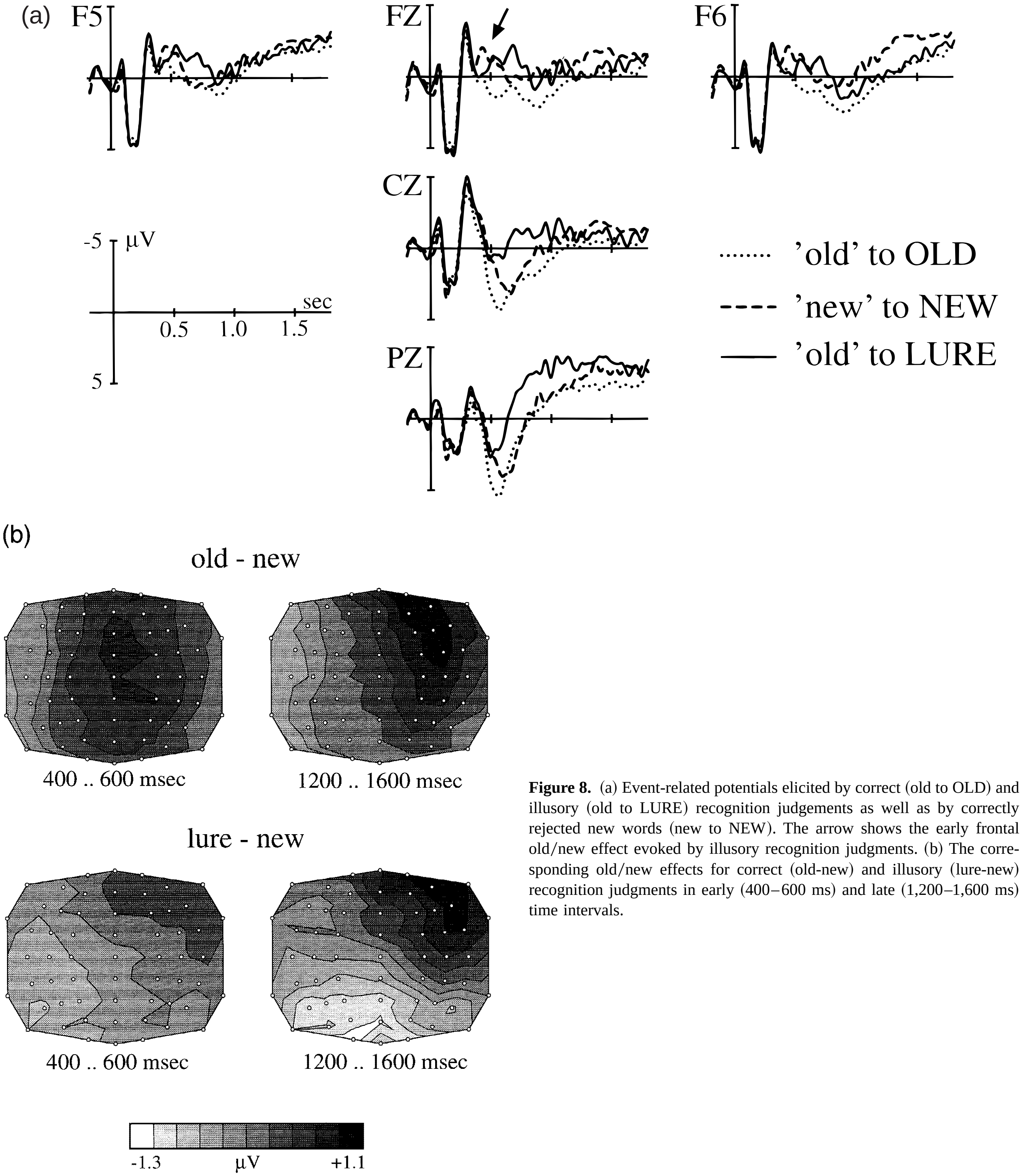

Figure 8. (a) Event-related potentials elicited by correct (old to OLD) and illusory (old to LURE) recognition judgements as well as by correctly rejected new words (new to NEW). The arrow shows the early frontal old/new effect evoked by illusory recognition judgments. (b) The corresponding old/new effects for correct (old-new) and illusory (lure-new) recognition judgments in early (400–600 ms) and late (1,200–1,600 ms) time intervals.

Interestingly, both illusory and correct old judgments evoked late right frontal old/new effects. Moreover, the effects were also present though less pronounced for correctly rejected lure words. The absence of a parietal old/new effect for lure words suggests that familiarity assessment may have been the basis for false recognitions, so that this pattern of results again argues against a unitary functional account of the right frontal effects. Rather, these results suggest that it is the retrieval context and not the further processing of recollection products that drives these effects. In the present study a low proportion of new words appeared among a sequence of categorically related words and subjects might have adapted a retrieval strategy of attempting to recover information

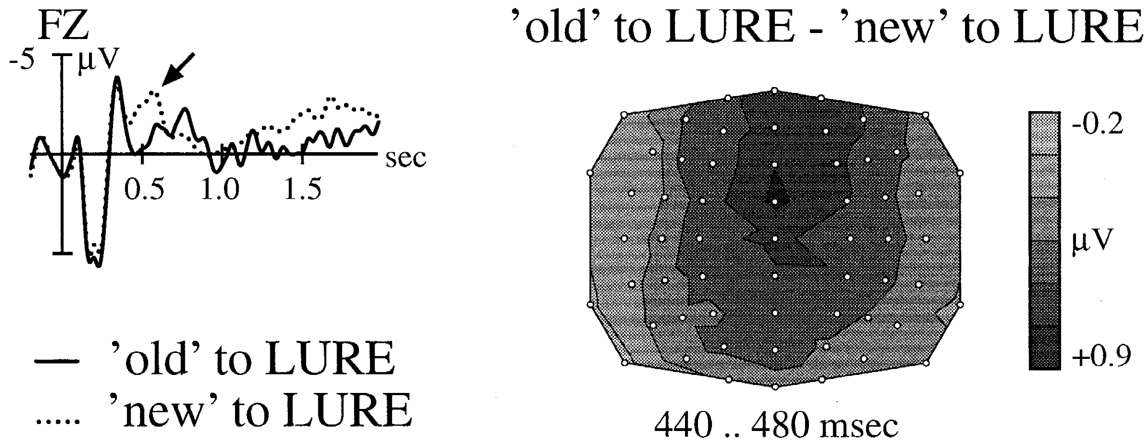

Figure 9. Event-related potentials to correct rejections and false alarms to lure words at Fz (left) and the topographic distribution of the corresponding difference wave in an early (440–480 ms) time interval (right).

from the study phase whenever an familiar item was presented. Conversely, the cross-modal character of the task (study: visual; test: auditory) may have caused a change in retrieval context that led to a more careful evaluation of familiar words.

The old/new effects were not the only features that distinguished old responses to old and categorically related words. As shown in Figure 8a, only old responses to lure words evoked a negative slow wave over parietal recording sites. Moreover, old response times to lure words were about 200 ms longer than new responses to new words and the slow wave differences were largest between these two conditions, suggesting that the negative slow wave apparently is related to response times. Slow waves with similar timing, functional, and topographical characteristics have been elicited by false-alarm response in an exclusion/inclusion recognition memory task (Wilding & Rugg, 1997).

The present results show that the spatiotemporal fractionation of ERP old/new effects allow some important insights in the nature of illusory memories. The study differed from other false memory studies (Düzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Johnson, Nolde, Mather, Kounios, Schacter, & Curran, 1997) by the low false-alarm rate and the control for bidirectional semantic relationships. The results indicate that false recognitions of categorically related words arise from illusory familiarity that gives rise to increased evaluation demands, whereas correct recognitions rely on both familiarity and recollection and in the present retrieval context evoke similar postdecision evaluation processes.

Hemodynamic Brain Activity

ERP measures provide excellent temporal resolution for studying the subprocesses contributing to recognition memory, but inferences about the neuronal generators of these effects are problematic. Our discussion of the old/new effects so far implies that different aspects of the retrieval process are associated with a characteristic pattern of neuronal activity that gives rise to a particular ERP old/new effect. However, determining the location, strength, and orientation of the neuronal sources that contribute to the scalp-recorded ERP components is an ill-posed problem. That is, in principle there are an infinite number of dipole configurations inside the brain that can produce a given voltage pattern on the scalp. Several ways to overcome this ambiguity in estimating the neuronal generators of a scalp recorded voltage pattern have been proposed (see Kutas & Dale, 1997; Nunez, 1981). A particularly promising approach is to constrain the dipole configurations by means of fMRI recordings. Such fMRI recordings allow identification of the brain regions recruited by information processing activities with a relatively high spatial resolution and it seems reasonable to assume that the neuronal activity that produces scalp-recordable voltage patterns also causes changes in hemodynamic processes that can be visualized by means of fMRI (cf. Opitz, Mecklinger, Friederici, & von Cramon, 1999).

To examine the neuronal mechanisms that contribute to the aforementioned recognition-related ERP effects, we conducted the above-described, illusory recognition experiment with fMRI recordings. The functional imaging data were then used as "soft" constraints (Dale & Sereno, 1993) in estimating the dipole configurations of some of the recognition-related ERP effects. The fMRI experiment was identical to the ERP study with the exception that the interval between two words in the test phase was increased from 3.6 to 6.75 s. Sixteen subjects were tested and imaging was performed with a Bruker 3T scanner. The blood oxygen level dependent (BOLD) response was acquired from 16 axial slices parallel to the AC-PC line (Slice thickness: 5 mm, interslice distance: 2 mm). Image acquisition was synchronized with the onset of the test phase stimuli, allowing an event-related analysis of the BOLD signal (for details of signal analysis see Mecklinger, Nessler, Penney, & von Cramon, 1999). Based on the outcome of the ERP experiment our fMRI analysis focused on the following two aspects: the early frontal negative component elicited by correct rejections but not by false alarms to lures and the bilateral parietal slow wave elicited by false alarms to categorically related words.[2]

[2]It should be noted that the soft-constrained dipole analysis approach was also applied to other effects, that is, the old/new differences in the middle and the late time intervals. However no biologically and statistically reasonable results were obtained, suggesting that multiple sources, not all of them visible in the BOLD response might have contributed to these ERP effects. Conversely, the regions showing increased hemodynamic responses do not necessarily lead to enhanced electrical responses at the scalp (see Opitz et al., 1999).

As is apparent from Figure 9, the early difference between old and new responses to lure words was restricted to medial-frontal recording sites. As outlined above, the negativity might be related to some sort of recollection required to reject similar words (Hintzman & Curran, 1994; Rotello & Heit, 1999). Thus, contrasting the BOLD response for new and old responses to lure words should enable us to identify brain regions that are required for the retrieval of this event-specific episodic information. Figure 10 shows brain regions for which significantly larger ($p < .001$) brain activations were found (averaged across 16 subjects) for correct rejections of lure words than for false alarms to lure words. This right hemisphere activation is located in the pars orbitalis of the inferior frontal gyrus (IFG) (Talairach coordinates: 39, 35, 1) (see Talairach & Tournoux, 1988).

A similar though smaller activation pattern was obtained for the corresponding left hemisphere region. In a second step we performed a dipole analysis of the medial frontal old/new effect for lure words. A realistically shaped head model with three volumes (brain, skull, scalp) was developed using the boundary element method (Zanow, 1997). Dipole locations were kept fixed at the left and right IFG regions activated in the fMRI study (cf. Figure 11). With these constraints dipole orientations and strength were fitted using the grand-average ERP data. This two-dipole model accounted for 86% of the old/new effect for lure words in the 440–480-ms time interval in which the effect was most pronounced. Echoing the right hemisphere preponderance of the fMRI data, the estimated dipole strength was considerable higher in the right than in the left hemisphere.

The second ERP finding of particular interest was the pronounced bilateral negative slow wave elicited by false alarms to lure words. Given its co-occurrence with prolonged response times it is conceivable that the pronounced bilateral negative slow wave reflects motor-related processes related to prolonged false alarm responses. As shown in Figure 12, contrasting old responses to lure words with new responses to new words revealed significant activation in the anterior cingulate cortex (ACC) (Talairach coordinates: −9, 8, 40). A similar frontomedial cortex activation, though slightly more anterior (Talairach coordinates: 3, 21, 38) was obtained when old responses to lure words were contrasted with old responses to old words. A single dipole model that constrained the dipole location to the medial-frontal cortex fMRI activation focus accounted for 86.4% for the variance in the grand-average ERP data in the 640–800-ms time interval in which the slow wave was most pronounced (cf. Figure 13).

The combined analyses of ERP and fMRI data revealed some important insights into the brain mechanisms recruited by the recollection and familiarity subcomponents of recognition memory. The right IFG activation for correctly rejected lure words relative to false alarms to these words is consistent with results from previous neuropsychological and neuroimaging studies showing that the right IFG (i.e., BA 10/11) is recruited by episodic retrieval (McDermott, Buckner, Petersen, Kelley, & Sanders, 1999; Wagner et al., 1998) or when event-specific retrieval of prior study information is required (Schacter, Curran, Galluccio, Milberg, & Bates, 1996). The ACC is considered to be part of an anterior attention network, activated under conditions of response competition. Response competition occurs whenever response selection requirements are demanding and the likelihood of committing an error is high, as, for example, when a competing response has to be suppressed (Awh & Gehring, 1999; Carter, Braver, Barch, Botvinick, Noll, & Cohen, 1998; Turken & Swick, 1999). It is conceivable that the ACC activation reflects an enhanced response conflict or its attentional modulation, caused by the requirement to classify categorically familiar words as "new."

MODELING MEMORY RETRIEVAL

In this section I will summarize the electrophysiological evidence for the multicomponent view of recognition memory and present a model of the facets of episodic memory retrieval. Recent neuropsychological findings on the brain mechanisms mediating the subcomponents of recognition memory will be reviewed and finally the role of working memory in episodic retrieval will be considered.

Facets of Recognition Memory Retrieval

The experiments discussed so far support the view that recognition memory is a multicomponent process the aspects of which can be

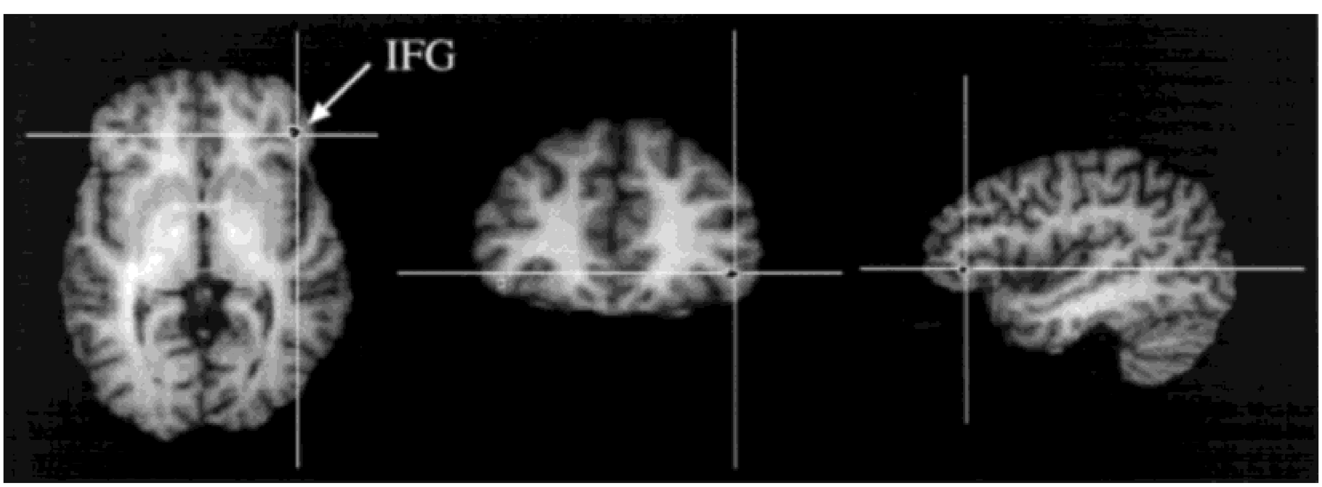

Figure 10. A sagittal, coronal, and lateral view of functional magnetic resonance imaging (fMRI) activation patterns in the pars orbitalis of the inferior frontal gyrus (IFG). This brain region was stronger activated by correctly rejected than by falsely classified lure words.

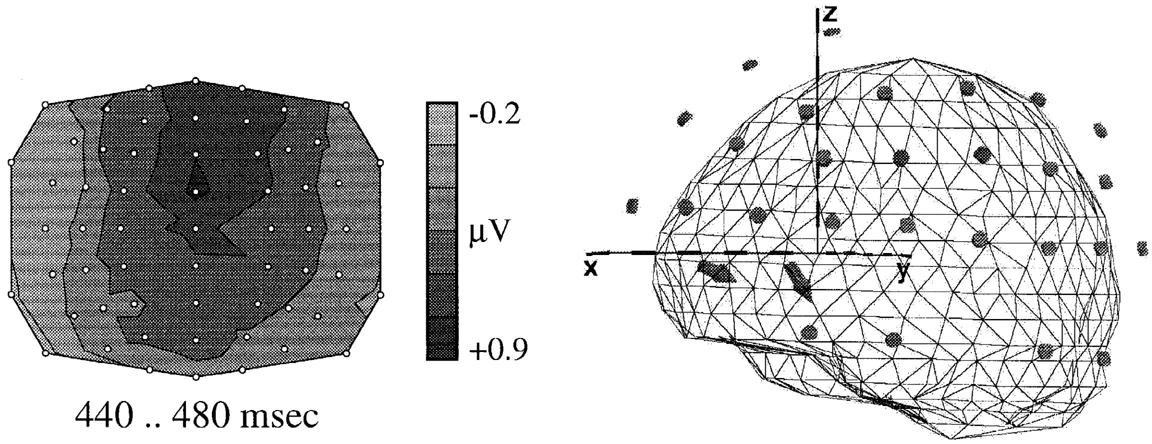

Figure 11. Location and orientation of the two inferior frontal gyrus (IFG) dipoles that accounted for 86% of the variance in the "old" to lure minus "new" to lure difference wave in the event-related potential experiment.

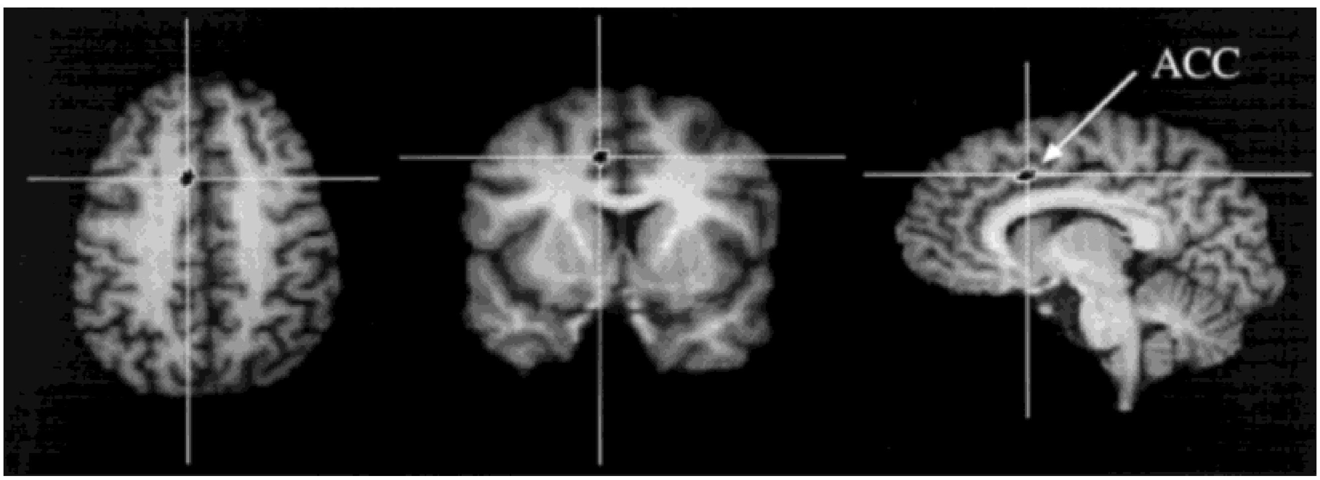

Figure 12. A sagittal, coronal, and lateral view of the functional magnetic resonance imaging (fMRI) activation in the anterior cingulate cortex (ACC). This brain region was stronger activated by falsely classified lure words ("old" to lures) than by correctly rejected new words ("new" to new).

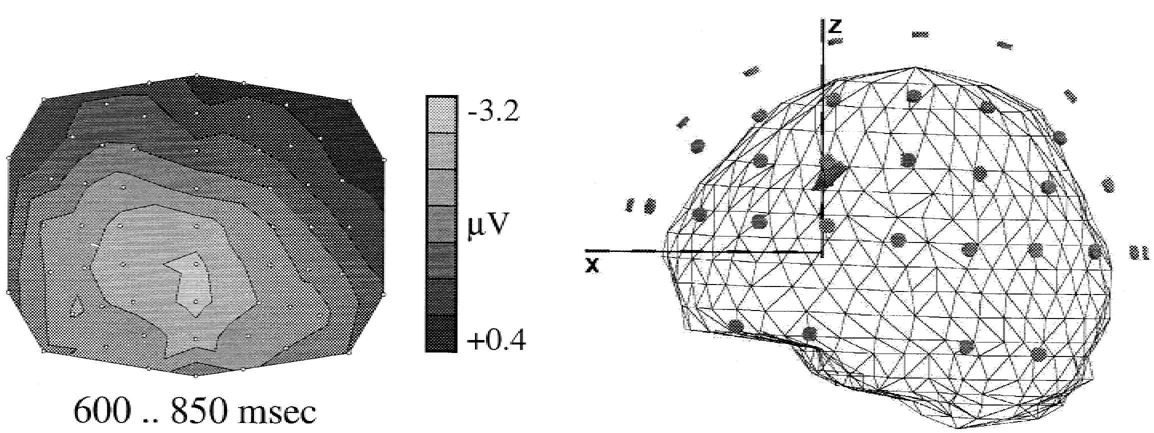

Figure 13. A single dipole constrained to the functional magnetic resonance imaging (fMRI) activation pattern in the anterior cingulate cortex (ACC) accounted for 86% of the variance in the "old" to lure minus "new" to new event-related potential difference waves.

A Neurocognitive Model of Recognition Memory

Processes	Familarity assessment	Recollection	Post-retrieval evaluation
ERP-correlate	frontal old/new effect	parietal old/new effect	late right frontal old/new effect
Timing	300 .. 500 msec	400 .. 700 msec	800 msec...
Exp. Manipulation	• Object recognition • TBR and TBF words • False and correct recognitions	• Spatial recognition • TBR words • Correct recognitions	• Object recognition • larger for TBF than for TBR words • False and correct recognitions
Brain Systems	MBTL Perirhinal cortex (?)	MBTL EHDC (?)	Right PFC

Figure 14. A neurocognitive model of recognition memory. Note that "Exp. Manipulations" is not a survey of studies in which event-related potential old/new effects have been reported. Rather, for reasons of simplicity only those experiment reported in the present paper are illustrated. TBR = to-be-remembered; TBF = to-be-forgotten; MBTL = medial-basal temporal lobes; PFC = Prefrontal cortex; EHDC = extended hippocampal-diencephalic complex.

associated with spatiotemporally distinct aspects of the ERP old/new effects. The main features of the episodic memory retrieval model are illustrated in Figure 14. In the temporal domain we were able to distinguish three effects: First, familiarity assessment in intentional retrieval tasks is associated with a frontal old/new effect between 300 and 500 ms. It is the first electrophysiological sign of differential processing of old and new information and its elicitation presupposes some form of representation format that allows integration of an item into the context in which it was presented. Even though this frontal effect in some instances overlaps temporally with the parietal old/new effect, it is topographically distinctive from the parietal effect and reflects different memory processes. This frontal effect is elicited by line drawings of objects but not by spatial locations that cannot be represented at a conceptual level (Mecklinger, 1998). It is found for words that subjects were instructed to forget during encoding (Ullsperger et al., in press) and it is insensitive to levels of processing instructions (Rugg et al., 1998). It is similar for words that share similarities with studied words and for studied words proper (Curran, in press). This frontal old/new effect is also found when words that are categorically related to studied words are classified erroneously as old but not when these words are correctly rejected. One aspect that all these stimuli eliciting the frontal old/new effect have in common may be that they "remind one of something"[3] because their unitized representation formats allow this. The line drawings of objects remind one of similar drawings, the forget words remind one of studied remember words, or the semantically similar lure words remind one of their studied associates. From a processing point of view this frontal old/new effect may reflect the assessment of links in long memory that associate a particular item with other long-term memory information without necessarily forming larger representational units that allow recollection processes to occur.

Even though this empirical evidence together with its unique frontal scalp distribution and its timing characteristics suggests that this effect reflects a unique, familiarity contribution to recognition memory, it is still conceivable that recollection contributes to this effect. An interesting hint about the functional significance of the early frontal old/new effects was provided recently by Curran (in press). He showed that in one of two experiments there was a frontal positive difference between correctly rejected new and lure words, a comparison that excludes a contribution of recollection. Further research along these lines will be required to obtain a more detailed picture of the processes reflected in the frontal old/new effect.

The second effect in the temporal domain is a clear correlation between recollection and the parietal old/new effect. The parietal old/new effect is temporally delayed and, depending on stimulus materials and testing conditions, reaches its maximum between 400 and 700 ms. It is sensitive to levels of processing during study (Rugg et al., 1998) and other manipulations that enhance recollective experience (Paller & Kutas, 1992; Paller, Kutas, & McIsaac, 1995; Ullsperger et. al., in press). In addition the parietal old/new effect appears to be correlated with the subjective experience of recollection (Düzel et al., 1997; Smith, 1993) and it clearly separates correctly classified studied items from erroneously classified categorically related words (Curran, in press; Nessler et al., submitted) or words that shared syllables with studied words (Rubin et al., 1999). Based on topography, timing, and sensitivity to experimental manipulation, at a component level this effect presum-

[3] I want to thank Cyma van Petten for bringing my attention to this aspect.

ably reflects modulations of the P300 component, which is assumed to be associated with context updating processes (Donchin & Coles, 1988, Spencer et al., in press).

A third electrophysiological aspect contributing to recognition judgments was a late old/new effect that in all studies reported above onset at the time the response was executed, extended for several hundred milliseconds, and was dominant at right frontal recording sites. This late right frontal effect was larger for words associated with a forget instruction for which no parietal effect occurred and was indistinguishable for correct and illusory recognitions. Senkfor and Van Petten (1998) reported a (bilateral) frontal effect beginning at about 700 ms that did not distinguish trials with accurate and inaccurate source judgments (see Penney, Mecklinger, Hilton, & Cooper, 1999, for similar results). Notably the reaction times were around 1,650 ms in the study by Senkfor and Van Petten. These findings argue against a unitary functional account of long duration frontal old/new effects (i.e., retrieval success or retrieval effort) and rather suggest that it reflects more global aspects of the context in which retrieval takes place. It is conceivable that these late right frontal effects reflect a tonically maintained state entered by the participants in episodic retrieval tasks. In support of this view, Ranganath and Paller (1999) found that ERPs to correctly rejected new items for which contributions from episodic memory can be excluded differed as a function of the retrieval context, that is, the specificity of information that had to be recovered from memory, at left frontal recording sites. This finding suggests that these late-onsetting effects reflect the engagement of cognitive operations that are set by the retrieval context and successful recollection seems not to be necessary for their elicitation.

In light of the partial temporal and spatial overlap of the three old/new effects, from a methodological point of view, new techniques that allow a more fine-grained decomposition of spatiotemporal sources of variance such as spatiotemporal principal components analysis (Spencer, Dien, & Donchin, 1999), analyses of source current distributions (Knösche, Maess, & Friederici, 1999; Kutas & Dale, 1997), or the application of methods with higher spatial resolutions as the magnetoencephalogram (Mecklinger, Maess, Opitz, Pfeifer, Cheyne, & Weinberg, 1998) are desirable.

Neuropsychological Evidence

Another way that may help to distinguish different subprocesses of recognition memory is the neuropsychological approach. The absence of frontal and parietal old/new effects in the object and spatial recognition tasks performed by amnesic patients who had TGI due to cardiac arrest supports at first glance the view that both subcomponents of recognition memory depend on the medial-basal temporal lobe memory system (Squire & Zola-Morgan, 1992). Recent neuropsychological studies and results from animal research, however, provide some indirect support for a double dissociation of familiarity and recollection after lesions of the perirhinal cortex and the hippocampus proper (Aggleton & Brown, 1999), suggesting an important functional segregation with the medial-basal temporal lobe system. These studies suggest that familiarity is reliant on the perirhinal cortex inferior to the hippocampus proper, whereas recollection presupposes the integrity of the extended hippocampal-diencephalic system, a system that links the hippocampus proper with the anterior thalamic nuclei. In animals, lesions to the fornix (a fiber bundle carrying hippocampal efferents and afferents) impaired spatial working memory (Ennaceur & Aggleton, 1997; Ennaceur, Neave, & Aggleton, 1996), whereas lesions in perirhinal cortex, which also houses a large number of visually responsive neurons, had no disrupting effect.

Neuropsychological studies show that lesions to the perirhinal cortex that spare the hippocampus can impair some forms of memory but do not lead to anterograde amnesia. A patient described by Kapur et al. (1994) with extensive bilateral damage to the temporal lobes mainly sparing the hippocampus showed no anterograde amnesia but a retrograde amnesia with deficits in semantic and factual knowledge. Conversely, Vargha-Khadem, Gadian, Watkins, Connelly, Van Paesschen, and Mishkin (1997) reported the reversed dissociation after hippocampal pathology that spared the adjacent temporal cortices. These patients, who had had a perinatal hypoxia, showed intact factual knowledge and reading comprehension but a pronounced amnesia for everyday autobiographic events. Although the retrieval of autobiographic information presupposes conscious recollection, impairments in semantic and factual knowledge cannot necessarily be equated with a degradation of familiarity-based recognition. Nevertheless the aforementioned results point to a neuroanatomical separation of familiarity and recollection within the medial-basal temporal lobes. More convincing support for a neuroanatomical dissociation of both subcomponents of recognition memory needs to be provided by double dissociations within the same experiment and using the same stimulus materials. The fact that both aspects of recognition memory can be mapped onto spatiotemporally distinctive ERP effects adds a new methodological tool to this endeavor.

Role of Working Memory

A final aspect to be considered is the role of working memory in intentional retrieval tasks. Previous neuropsychological studies have shown that patients with media-basal temporal lobe lesions perform well in recognition tasks with retention intervals < 15 s (Cave & Squire, 1992; Chao & Knight, 1995). This finding indicates that for retention intervals < 15 s, study phase items are maintainable in a short-term working memory store. Therefore old/new effects obtained with intervals of that duration cannot necessarily be related to episodic memory retrieval but have to take into account a working memory contribution. Many studies examining old/new effects as a function of repetition lag used incidental rather than explicit recognition tasks. The few studies, however, that explicitly tested old/new effects under different retention intervals (cf. Rugg & Nagy, 1989) found that with retention intervals of more than 45 min the early and frontally distributed old/new effects disappeared, whereas later parietally focused effects were still present. In the studies discussed in the present report the mean retention delay ranged from a minimum of 20 s in the patient study (Mecklinger, von Cramon, et al., 1998) to a maximum of 15 min in the directed forgetting study (Ullsperger et al., in press). Within this time range there were no apparent differences in the timing and scalp topography of the old/new effects. Nevertheless we examined the extent to which working memory contributes to ERP old/new effects within an experiment. Therefore the ERP data in one study (Mecklinger, 1998) was analyzed post hoc for good and poor performers, with the assumption being that good performers would have higher working memory capacity than low performers. This analyses revealed that neither the frontal nor the parietal old/new effects were statistically different for the two groups (cf. Mecklinger, 1998, Figure 10). At present, the absence of any differential ERP old/new effects as a function of working memory variables in explicit recognition memory tasks is most consistent with the view that the main contribution of working memory comes from rehearsal process in the study–test interval by which study phase information enters long-term memory.

In conclusion, the identification of subprocesses of recognition memory with three distinct spatiotemporal old/new effects—an early frontal effect related to familiarity assessment, a second parietal effect related to recollection, and a third process that is tied to the task context in which retrieval occurs—provides a useful and promising tool for studying the neurocognition of recognition memory. This holds in particular when the traditional ERP approach is integrated with other approaches such as the examination of ERPs in brain-injured patients or with functional brain imaging techniques that allow the identification of functionally relevant neuronal structures. Important issues to be solved in further research concern the interdependence of the three patterns of old/new effects. Additional experimental manipulations are required that allow an adequate separation of familiarity and recollection and by this separation minimize a potential confound of both variables. Similarly, a related important issue is whether conscious familiarity and increased perceptual fluency that occurs without awareness show distinguishable ERP correlates (Badgaiyan & Posner, 1997).

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