Retrieval processing and episodic memory

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The emergence of brain imaging has had a major impact on research into the cognitive and neural bases of human memory. An area in which this impact has been particularly strong is retrieval processing – the processes engaged when attempting to retrieve information during a memory test. Several different classes of retrieval process – such as 'mode', 'effort' and 'success' – have been invoked to account for findings from neuroimaging studies of episodic retrieval. In this article we discuss how these different kinds of process, along with a fourth kind associated with 'retrieval orientation', can be investigated in brain imaging experiments. We then review studies of retrieval processing, and assess how well their designs match up to our proposed criteria for dissociating the neural correlates of different classes of retrieval process. We conclude that few studies have used designs that permit these different kinds of process to be independently identified, and that presently there is little evidence to indicate which kinds of processing can be fractionated in terms of their neural correlates.

To remember a past event, information must be retrieved from episodic memory. Episodic retrieval is thought to involve an interaction between a 'retrieval cue' (self-generated or provided by the environment) and a memory trace, leading to the reconstruction of some or all aspects of the episode represented by the trace. This interaction and its sequelae were termed 'ecphory' by Semon[1–3]. Whether an episodic retrieval attempt is successful or not is influenced by numerous factors, not least of which is the way the event was initially 'encoded' into memory[4]. Also important are the cues available, and the processes engaged, during the retrieval attempt. The importance of retrieval cues and the nature of their processing is emphasized in the principle of 'transfer appropriate processing'[5], according to which memory performance is a function of the degree to which cognitive operations engaged at encoding are recapitulated at retrieval. A similar notion is enshrined in the principle of 'encoding specificity'[6].

In his 1983 book, Tulving[7] proposed that a further prerequisite for successful episodic retrieval is that the rememberer is in the appropriate cognitive state, which he termed 'retrieval mode'. According to this proposal, only when a rememberer is in retrieval mode will a stimulus event be treated as an episodic retrieval cue. More recently, it has been proposed[8] that retrieval mode is also necessary for retrieval to be accompanied by the experience of 'reliving the past' or 'autonoetic' remembering[9]. These two conceptions of retrieval mode share the notion that mode is manifest as a 'tonically' maintained cognitive state.

Although Tulving first discussed retrieval mode more than 15 years ago, it is only in the past five or so years that much attention has been paid to the concept. This is largely because it is not easy to investigate cognitive states using behavioural measures alone. Thus, the rise of interest in the concept of retrieval mode has been most marked among researchers using functional neuroimaging methods to study memory, methods which allow the neural correlates of different cognitive states and processes to be investigated (see Box 1).

In the literature on the functional imaging of memory, retrieval mode has frequently been discussed along with two other kinds of process: 'retrieval success' and 'retrieval effort'. Retrieval success is a term used to denote processes that are associated with, or depend upon, ecphory. Retrieval effort is a more nebulous concept, which, broadly speaking, refers to the level of processing resource deployed in service of a retrieval attempt. We would add 'retrieval orientation' to this taxonomy of retrieval-related processes, although it has not received so much attention to date (but see Ref. 10). Retrieval orientation[11,12] determines the specific form of the processing that is applied to a retrieval cue. For example, orientation would differ according to whether a task required retrieval of phonological or spatial information.

The aims of the present article are threefold. First, to discuss how neural activity associated with processing retrieval cues can, in principle, be fractionated using current brain imaging methods (see Box 1). Second, to assess, in light of this discussion, findings from studies that have employed these methods to identify the neural correlates of retrieval processing. Third, to comment on the adequacy of the fourfold classification of retrieval processes described above, and discuss how it might be refined. We are concerned only with retrieval processing in 'direct' memory tests, when there is an intention to retrieve. We do not consider processing related to the 'involuntary' or 'unintentional' episodic retrieval that can be elicited in indirect tests[13], processing that may differ from that engaged during intentional retrieval[14].

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Box 1. Brain imaging methods used to study retrieval processing

Methods for the non-invasive measurement of brain activity fall into two principal categories, depending on whether they measure electrophysiological or haemodynamic variables (Ref. a). These methods can be used to detect the transient activity that follows a specific event such as the presentation of a stimulus (event- or item-related activity), as well as the more sustained activity that may accompany engagement in a specific task (state-related activity). As discussed below, methods vary in their capacity to separate these two classes of neural activity. For the reasons noted in the main article, this capacity is highly desirable in studies of retrieval processing.

Electrophysiological methods

Electrophysiological methods detect the time-varying electric (EEG) and magnetic (MEG) fields at the scalp surface generated by synchronously active populations of neurons (Ref. b). Currently, the electrophysiological measure most commonly used in studies of memory is the event-related potential (ERP). An ERP waveform represents the average time-locked electrical activity elicited by a particular class of experimental items (e.g. 'new' as opposed to 'old' items in a recognition memory task). Because the temporal resolution of ERPs is in the order of milliseconds, they are well suited to addressing questions about the time course of the neural correlates of stimulus-locked cognitive processes. Furthermore, the method imposes few constraints on the range of experimental designs that can be employed. A major drawback of the method, however, is that there are no general solutions for the localization of the sources of ERP activity (or, indeed, for any other scalp electrophysiological measure). Although this drawback does not compromise the assessment of whether stimuli from different experimental conditions engage distinct neural populations (Ref. c), it limits the strength of the neuroanatomical conclusions that can be drawn.

In addition to the measurement of item-related neural activity, electrophysiological methods can be used to investigate state-related activity extending across experimental trials. This can be achieved by analysis of the frequency characteristics of inter-trial epochs of the 'background' EEG (Ref. d). State-related changes in activity can also be investigated by recording ERPs in direct current (DC) mode, which allows temporally extended, low-frequency components of the ERP waveform to be measured. Such recordings can be time-locked to the onset of a specific experimental task, and used to investigate state- and item-related activity concurrently (see Fig. 1 of main article).

Haemodynamic methods

Haemodynamic methods measure neural activity indirectly, relying on coupling between changes in neural activity and local changes in variables such as regional cerebral blood flow (rCBF) and blood oxygenation. The methods employ image reconstruction techniques to localize changes in these variables to within a spatial resolution of a few millimetres.

Until relatively recently, the haemodynamic method of choice was PET, which measures rCBF by imaging the distribution of a short-half-life radiotracer such as $H_2{}^{15}O$. From the perspective of experimental design, the major drawbacks of PET stem from the fact that data must be acquired over a period of several tens of seconds. This constraint necessitates the use of blocked rather than randomized experimental designs, and leads to the inability to separate item- and state-related activity. Although attempts have been made with PET to identify item-related activity specifically, the possibility that such measures are confounded with state-related changes cannot easily be discounted (Ref. e).

At present, the dominant haemodynamic imaging method is functional MRI, which detects changes in regional blood oxygenation. The majority of published fMRI studies of memory processing have employed blocked designs, and their findings therefore suffer from problems of interpretation similar to those noted above for PET. However, more studies are now using the method of event-related fMRI, which, like the ERP method described above, permits data to be obtained in response to individual items (Ref. f). Event-related fMRI has the dual advantages of allowing randomized experimental designs to be used, and of allowing item-related condition effects to be identified unequivocally. With careful attention to design, it is possible to use fMRI to measure state- and item-related effects concurrently (Ref. g).

A major limitation of haemodynamic methods stems from their limited temporal resolution. Because of the sluggish nature of haemodynamic responses, item-related activity is generally difficult to resolve at a temporal resolution of much below 1 s (although see Ref. h). This compares unfavourably with the resolution that can be achieved with electrophysiological methods, and acts a spur to efforts to integrate the two kinds of measure.

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Investigating retrieval processing

To investigate the neural correlates of any cognitive process, that process must first be operationally defined in the context of an experimental design suitable for investigation with brain imaging methods. In this section, we outline how this might be achieved for the retrieval processes introduced in the preceding section, using the electrophysiological and haemodynamic imaging methods outlined in Box 1. As already noted, we do not mean to imply that these four categories of process exhaust the possible forms that retrieval processing can take, or that each of these categories is equally valid. Nor are we assuming that the experimental designs we discuss are the only, or indeed the optimal, designs for investigating retrieval processing; we have no doubt that other designs will supersede those proposed here and lead to changes in how retrieval processes are defined both operationally and conceptually. Nonetheless, the operational definitions offered below are useful for two reasons: they provide a yardstick against which studies claiming to have identified or dissociated different kinds of retrieval processing can be evaluated, and they offer a basis for more rigorous attempts to dissociate the neural correlates of these different putative processes than those typically undertaken to date.

Mode

Retrieval mode is held to constitute a tonically maintained state (or 'set') entered when there is need to engage in episodic retrieval. The neural correlates of retrieval mode should (1) be time-locked to the onset of engagement in an episodic retrieval task, and maintained for the duration of the task;

(2) be revealed by contrasts between classes of task (episodic versus non-episodic) rather than classes of retrieval cue (e.g. old versus new words in a recognition memory test); and (3) demonstrate task invariance – in principle, any pair of tasks, so long as one of them requires episodic retrieval and the other does not, should differentially activate the brain systems supporting retrieval mode.

Orientation

Retrieval orientation can be thought of as a further fractionation of mode, in that orientation determines the specific form of the processing that is applied to a retrieval cue. The neural correlates of different retrieval orientations are revealed when physically identical retrieval cues are used in memory tests that differ either in their task requirements (e.g. recognition versus 'source' judgments), or with respect to the information encoded at study (e.g. pictures versus words). By performing separate contrasts for cues associated with retrieval failure and retrieval success (e.g. correctly classified 'new' and 'old' items in a test of recognition memory), the effects of orientation on the processing of retrieval cues can be distinguished from its effects on the processing of retrieved information.

If the disposition to process a retrieval cue in a particular way is tonically maintained, different retrieval orientations should also be manifest as different states. Unlike retrieval mode, however, the neural correlates of these states should be task dependent, and revealed not by contrasting episodic and non-episodic tasks, but different episodic tasks.

Effort

Retrieval effort can be defined as the mobilization of processing resources in service of a retrieval attempt. The neural correlates of effort can be identified by comparing the activity elicited by retrieval cues that engage qualitatively equivalent retrieval processing (i.e. equivalent orientations), but that are presented in tasks that vary in difficulty, as measured by performance accuracy or reaction time. As with orientation, and for the same reason, the contrasts should be performed separately for cues associated with successful and unsuccessful retrieval.

Success

Retrieval success encompasses any process associated with, or contingent upon, ecphory. Thus, processes associated with success are necessarily item-related, and their neural correlates are revealed by contrasting the activity elicited by retrieval cues that engender veridical memories with that elicited by cues that either cannot, or which fail, to do so (e.g. 'hits' versus 'correct rejections' and 'misses' in a recognition memory test). Note that although these contrasts will reveal activity related to success, they could be contaminated by two other kinds of differential activity – related respectively to cessation of processes supporting orientation and effort, and to decision and response processes – that have nothing to do with the processing of retrieved information *per se*. The contrast between retrieval cues eliciting veridical versus non-veridical memory judgements (e.g. hits versus 'false alarms') provides one possible means of eliminating these potential confounds.

Selective review of ERP and neuroimaging studies of retrieval processing

The previous section shows how it is possible, at least in principle, to design experiments so that the effects of mode, orientation, effort and success might be dissociated. However, the majority of studies of episodic retrieval have employed designs in which different retrieval processes are likely to be confounded. We review studies concerned with retrieval mode, effort and orientation in turn. When possible, we have placed studies in different sections below according to their authors' interpretation of the findings, commenting on alternative interpretations as necessary. As the focus of this article is the processing of retrieval cues rather than retrieved information, retrieval success is referred to only when it could be confounded with one or more of the three other kinds of retrieval processing.

Mode

To our knowledge, no functional neuroimaging study has met all the criteria set out above for demonstrating a neural correlate of retrieval mode. On the basis of a series of individual PET studies[15–18], and a subsequent meta-analysis[19], Tulving and colleagues have proposed that activation of the right prefrontal cortex, especially in the vicinity of Brodmann's Area 10, represents the 'neural signature' of retrieval mode. This proposal is based principally on the findings that right prefrontal activation is invariant with respect to both task[15] and the nature of the retrieval cue, that is, whether the cue corresponds to a studied or unstudied item[16–19]. For example, Cabeza *et al.*[15] used PET to study the neural correlates of retrieval in two different tasks, cued recall and recognition, and found broadly equivalent levels of right prefrontal activity, relative to non-episodic 'baseline' conditions, in each. Kapur *et al.*[16] and Düzel *et al.*[17] compared the activity that was associated with recognition memory test lists containing low and high densities of old words, and found that the two lists gave rise to equivalent levels of right frontal activation relative to a common control task. In addition, Nyberg *et al.*[18] reported that the right frontal activation associated with performance of a recognition memory task did not differ according to whether the test lists contained mainly old or exclusively new items. Although the design of these studies leaves open the possibility that the findings reflect item- rather than state-related right prefrontal activity, the pattern of results suggests that this region is activated by engagement in an episodic retrieval task, but that the activation is insensitive to the nature of the task and the retrieval cue employed – two of the criteria for demonstrating a neural correlate of retrieval mode.

These results have not gone unchallenged. Rugg *et al.*[20] reported that right prefrontal activation during episodic retrieval was indeed task-sensitive in a study in which regional cerebral blood flow (rCBF) was measured during the performance of tests of recognition memory and word stem (e.g. STA__) cued recall. The critical portions of the test lists comprised retrieval cues that did not correspond to any studied item (a 'zero density' test list). Relative to a baseline task requiring stems to be completed with the first word to come to mind, engagement in cued recall was associated with right anterior prefrontal activation. No such effect was observed for the contrast between the zero density condition of the recognition memory task and a 'read only' baseline. Rather, in the recognition task, right prefrontal activation was found only when the test list contained a high (about 80%) density of old items. This pattern of task sensitivity for right prefrontal activity is difficult to reconcile with the idea that activation in this region reflects the adoption of a task-invariant retrieval mode.

The finding that right prefrontal activation in tests of recognition memory is insensitive to whether the retrieval cue represents an old or a new item has also not been invariable[20,21]. In these studies, blocked designs were used and the ratio of old and new test items was varied to manipulate the proportion of trials on which retrieval was successful. In one study, already mentioned[20], the density of old items was either zero or approximately 80%. Relative to the zero-density condition, performance on the high-density lists gave rise to activation in right anterior prefrontal cortex, a finding in direct contradiction to that of Nyberg *et al.*[18] (see Ref. 22 for discussion of possible reasons for this contradiction). In an earlier study[21] test lists contained one of three different densities, zero, low (20%) or high (80%), and right prefrontal activation was also found to increase according to target density, albeit in a highly non-linear fashion. These findings (replicated in a subsequent fMRI study[23]), together with the findings of task-dependency described earlier, were taken as evidence that activation of right anterior prefrontal cortex during episodic retrieval reflects item-related, memory 'monitoring' operations[20].

The claim that right prefrontal activity during recognition memory varies according to the density of old items has itself been challenged[24]. Using fMRI, Wagner *et al.*[24] found that the right prefrontal cortex was activated more during test blocks containing a high as opposed to a low density of old items only when subjects were informed in advance about the blocks' composition. Wagner *et al.* argued that right prefrontal activation during recognition memory was a function of 'retrieval attempt' rather than retrieval success (no specification of the processes engaged during a retrieval attempt was offered). They further argued that whether a test item was used to instigate a retrieval attempt was under strategic control. According to this argument, findings of an association between right prefrontal activity and density of old items[20,21,23] reflect changes in retrieval strategy consequential upon identification of the structure of the test lists.

Whether or not Wagner *et al.*[24] are correct (it is worth noting that in at least one study[21] subjects' introspective reports were inconsistent with Wagner *et al.*'s account), the results of these studies are difficult to reconcile with the notion that right prefrontal activation during tests of recognition memory reflects a state maintained for the duration of the task. Rather, it would appear that the activity in this region can vary during task performance according to the 'local structure' of the test list.

The study by Düzel *et al.*[17] warrants additional mention, as part of it fulfills many of the criteria outlined previously for the identification of a neural correlate of retrieval mode. Düzel *et al.* recorded DC ERPs (see Box 1) while subjects undertook a recognition memory or a semantic classification task on a series of short word lists, wherein half of the words had recently been studied, and half were new. Subjects were cued before each list as to which task they should perform.

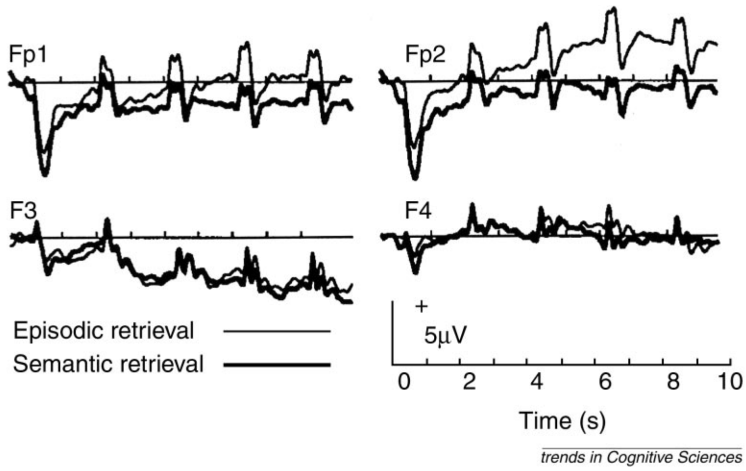

Fig. 1. DC ERPs (averaged over 11 subjects) recorded over left and right frontopolar (Fp1, Fp2) and lateral frontal (F3, F4) scalp regions during tasks of episodic (recognition memory) and semantic retrieval (living/nonliving classification). The recording period began prior to the onset of a cue informing subjects of the task associated with the upcoming word list, and continued during the presentation of the four words comprising the list. Item-related responses can be seen 'riding' on more sustained potentials, which exhibit prominent task-related differences at the right frontopolar site. (Reproduced, with permission, from Ref. 17.)

As is illustrated in Fig. 1, right frontopolar waveforms elicited during the recognition task showed a prominent positive-going shift. The onset of this shift was in response to the task cue, following which it was present for the remainder of the stimulus series. The authors interpreted this effect as the electrophysiological correlate of the right anterior prefrontal activation they observed in a broadly analogous PET study reported in the same paper, arguing that the effect supported the conception of episodic retrieval mode as a tonically maintained, item-independent state.

The ERP findings of Düzel *et al.*[17] provide perhaps the strongest evidence linking retrieval mode to activation of right anterior prefrontal cortex, and suggest that further work along similar lines would be very worthwhile. Three questions in particular stand out. First, do the findings extend to tasks other than recognition memory, as would be predicted if they signify the adoption of a generic retrieval mode? Second, the difficulties that are involved in localizing the generators of ERP waveforms (e.g. see Ref. 25) raise the question of whether these task-related ERP effects truly reflect differential activity within the right prefrontal cortex. Although this question does not impinge on the functional interpretation of the effects, it is crucial for the interpretation of the right frontal activations reported in neuroimaging studies. Finally, what is the relationship between these task-related ERP effects and the right frontal, item-related effects that have been described in several ERP studies of episodic retrieval (e.g. Refs 26–28), and taken as evidence that activity in the right prefrontal cortex is sensitive to retrieval success?

Thus far, we have discussed retrieval mode in terms of whether it possesses a unique 'neural signature' rather than in terms of its effects on memory retrieval. As already noted, in his original formulation of the concept Tulving[7] emphasized that a key function of retrieval mode was to bias the cognitive system to treat external events as retrieval cues. The results of another aspect of the study by Düzel *et al.*[17] are relevant to this idea. The authors examined the ERPs elicited by old and

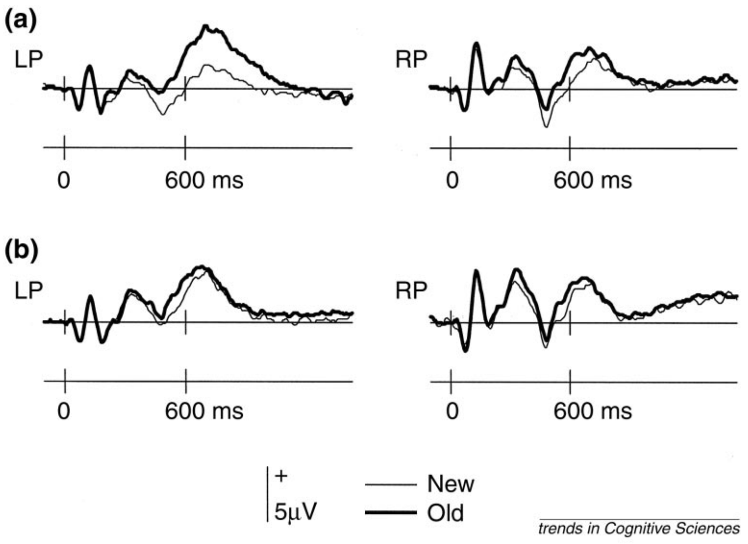

Fig. 2. ERP waveforms (averaged over 16 subjects) from left and right parietal sites (LP and RP) to new and old words during memory and classification tasks. The ERPs in the recognition memory task **(a)** have been collapsed over correct and incorrect judgements so as to permit a direct comparison with the waveforms obtained during the semantic classification task **(b)**, when no segregation according to recognition accuracy is possible. The prominent, left-lateralized difference between the ERPs elicited by old and new words in the recognition task is virtually absent in the semantic task, despite the use of equivalent encoding tasks, study-test intervals, and test items. The data are a subset of those reported originally by Rugg *et al.*[29]

new words separated according to task. In the recognition task old words elicited ERPs which, between about 400 and 800 ms post-stimulus, were more positive-going than the ERPs elicited by new items. This effect, which was maximal over the left temporo-parietal scalp, was virtually absent in the semantic classification task. Figure 2 illustrates data from another study[29] in which ERPs to old and new words were contrasted according to whether memory was tested 'directly' or 'indirectly'. As in Düzel *et al.*[17], 'old/new' ERP differences were markedly greater when the test demanded intentional retrieval. Several lines of evidence[26,29–32] converge to suggest that the 'old/new' ERP effect illustrated in Fig. 2 is a correlate of successful episodic retrieval. The finding that the magnitude of these effects can depend on whether the retrieval task is intentional or incidental is therefore a powerful demonstration of the influence of task instructions on the probability that a stimulus event will elicit episodic retrieval. According to Düzel *et al.*[17] these findings are a consequence of whether or not a test item is treated as a retrieval cue. According to an alternative interpretation, however, the results do not reflect differences in the potency of the test items as retrieval cues, but rather the failure to further process retrieved information when it is not task-relevant. Adjudicating between these interpretations will require more exact knowledge about the functional significance of ERP old/new effects than exists currently.

Effort

We know of no PET or fMRI study of retrieval effort where difficulty was manipulated while holding retrieval orientation constant. An early suggestion, contrasting with the 'mode hypothesis' of Tulving and colleagues, was that effortful retrieval was supported by the anterior prefrontal cortex[33]. This suggestion was based on a study of word-stem-cued recall in which words were studied either once in a 'shallow' encoding task, or four times in a 'deep' task. At test, anterior prefrontal activity was greater for stems that corresponded to the shallowly studied words. As recall was higher for the deeply encoded words, Schacter *et al.*[33] reasoned that the stems corresponding to the shallowly studied words engaged greater retrieval effort than did those corresponding to deeply studied words, and that it was this difference that underlay the observed differences in prefrontal activation.

Findings from three subsequent studies cast doubt on this interpretation. In one study[34], a design very similar to that of Schacter *et al.*[33] was employed, but with recognition rather than cued recall as the task. When blocks containing the test items from the 'deep' and 'shallow' encoding conditions were contrasted, greater right anterior prefrontal activation was seen for deeply studied items, the items putatively engaging less retrieval effort. Whatever its correct interpretation (compare Refs 20,34,35), this finding is inconsistent with the idea that anterior prefrontal activation is proportional to effort. By contrast, activity in left dorsolateral prefrontal cortex and bilateral insular was greater for the shallowly studied items. These latter findings might indicate a role for these regions in effortful retrieval, but the confounding of retrieval difficulty with probability of retrieval success and, in all likelihood, retrieval orientation, means that other interpretations cannot be ruled out. In the study of Wagner *et al.*[24], mentioned earlier, a similar design was adopted in one of the reported experiments. No prefrontal region could be identified in which activity discriminated between blocks of test items containing shallowly or deeply studied items, despite large differences in favour of the latter with respect to accuracy and speed of response. Finally, in the PET study of recognition memory and word-stem-cued recall already described, Rugg *et al.*[20] contrasted directly the high density conditions of each task. Although cued recall was very much the more difficult task, right anterior prefrontal cortex was less active in this task than it was during recognition, the opposite finding from that predicted by the effort hypothesis.

Together, these findings suggest that if retrieval effort (as operationalized by the variable of task difficulty) does have a distinct 'neural signature', it does not include right anterior prefrontal cortex. There are few clues as to which other regions, if any, might form part of such a signature.

Orientation

The investigation of retrieval orientation requires a comparison of neural activity elicited by identical retrieval cues, under conditions that vary the nature of the processing that the cues elicit. Such manipulations can be accomplished in two principal ways: by holding encoding conditions constant and varying which aspects of the encoded information are relevant to the retrieval task, or by holding the retrieval task constant and varying the nature of what is encoded. An additional requirement for studies of retrieval orientation is that they should be designed to allow effects on cue processing to be separated from effects on processes associated with retrieval success.

As far as we know, no PET or fMRI study has fulfilled this last requirement, and the majority of studies have also failed to avoid the potentially confounding effects of retrieval effort.

Three of the most relevant studies used fMRI and compared the neural correlates of yes/no recognition memory with memory for the 'source' (i.e. the encoding context) of studied items, while holding the encoding task and the nature of the retrieval cues constant[23,36,37]. In all three studies, activity in several regions of left prefrontal cortex was greater during the source memory task. Whereas the blocked experimental designs used by Henson *et al.*[37] and Rugg *et al.*[23] make it impossible to determine whether their findings reflect state- or item-related effects, the event-related design used by Nolde *et al.*[36] indicated that the effects in this study at least were item related. Nolde *et al.* interpreted their findings as evidence for a relationship between left prefrontal cortex and what they termed 'reflective' retrieval processes (see also Ref. 38). What is not clear from any of the studies, however, is whether the findings reflect differences in the processing of retrieval cues according to the task requirement, or whether they reflect instead differences in the nature of the information that is retrieved and its subsequent, 'post-retrieval', processing. Nor is it clear to what extent the findings were influenced by the fact that source memory is a more difficult task than recognition.

In two ERP studies, neural activity elicited by test items in recognition and source memory tasks was contrasted[39,40]. In both studies, task-related ERP differences predominated over frontal scalp regions. The differences onset around 400 ms and tended to be left lateralized, adding to the fMRI evidence noted above implicating the left prefrontal cortex in retrieval operations necessary for the recovery of source information[38]. Importantly, these ERP differences were evident in the waveforms elicited by correctly classified new items, suggesting that the retrieval operations supported by this region are not associated specifically with retrieval success.

Other ERP studies have investigated the consequences of varying the amount or type of information necessary for successful test performance. In Ranganath and Paller's study, the test items consisted of unstudied pictures dissimilar to any studied item, previously studied pictures, and unstudied pictures that were perceptually similar to studied items[41]. In one condition, subjects were instructed to classify both studied and similar items as 'old', responding 'new' only to dissimilar items. In a second condition, the task was to respond 'old' only to studied items, classifying both dissimilar and similar unstudied items as 'new'. ERPs over the left frontal scalp were more positive-going when elicited by items in the task requiring the more specific memory judgement, an effect found for both new and old items (see Fig. 3). Ranganath and Paller interpreted this finding (partially replicated in a subsequent study[42]) as a correlate of the differential engagement of memory search operations supported by the left prefrontal cortex, consistent with the ideas of Nolde and colleagues[36,38] noted above.

A similar finding was reported by Rugg *et al.*[11] In this study, task requirements were identical (yes/no recognition), but encoding conditions were varied, subjects performing either a semantically elaborate (sentence generation) or a low level (alphabetic judgement) study task. ERPs to correctly classified new items were more positive-going when presented at test among words from the 'shallow' study task, an effect that, as in Ranganath and Paller[41], tended to be greater over the left frontal scalp.

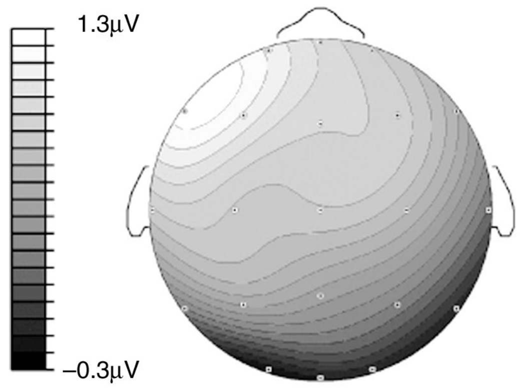

Fig. 3. Scalp distribution of ERPs to specific versus general memory judgements. The distribution over the scalp of the differences in voltage between 500 ms and 1200 ms in the ERPs (averaged over 12 subjects) elicited by all test items in the 'specific' and 'general' task conditions of Ranganath and Paller[41] (see text for details) illustrates the left frontal maximum of these differences. A similar pattern of results was obtained for the ERPs elicited specifically by new test items. (Reproduced, with permission, from Ref. 41.)

Unlike the fMRI studies discussed above, the ERP studies just described do not confound the effects of retrieval orientation with those of success, and their findings suggest that orientation does indeed influence how correctly-classified new test items are processed. In common with the fMRI findings, however, it is not possible to determine to what extent the ERP results reflect between-condition differences in difficulty rather than retrieval orientation as, in both studies, the task associated with the greater left frontal ERP positivity was also the more difficult one (although it is noteworthy that in the Ranganath and Paller study there were no between-task differences in RT and accuracy for new items[41]). Taken together, the findings suggest that item-related activity in the left prefrontal cortex is especially sensitive to retrieval manipulations that vary the nature or specificity of information to be retrieved.

Two studies have compared ERPs elicited in source memory tasks when retrieval demands were varied. In the first study[39] two groups of subjects performed different encoding tasks (encouraging visual versus semantic processing of words and pictures) prior to completing the same source memory task (determining whether a test word was new, studied as a picture, or studied as a word). From approximately 300 ms post-stimulus, the ERPs elicited by studied and unstudied test items in the two groups differed markedly at both frontal and posterior scalp sites. Johnson *et al.*[39] proposed that these ERP findings reflected the fact that the different encoding operations performed by the two groups resulted in differences in the 'evaluative operations' that were applied to retrieval cues. In the second study[12], items were presented initially in one of two voices and subjected to one of two encoding tasks. In a subsequent test of source memory, ERPs to correctly identified new test items varied according to whether subjects were directed to retrieve voice or task information, the waveforms diverging at frontal and central scalp locations. In line with the proposal of Johnson *et al.*[39], it was suggested[12] that these findings reflected processes that differed according to the content of the information to be retrieved.

Outstanding questions

- Can neural activity in the prefrontal cortex (or elsewhere) during episodic retrieval be fractionated into state- and item-related components? Does any brain region exhibit both kinds of activity?
- Is there a distinct neural system subserving retrieval effort (i.e. the allocation of processing resources to retrieval attempts)?
- Which of the cognitive operations (and their neural substrates) engaged during episodic retrieval tasks are domain-specific, and which also play a role in other processing domains (e.g. working memory)?
- What components of retrieval processing are influenced by retrieval orientation? For example, does orientation determine which aspects of an episode are retrieved from memory, or the way in which the products of retrieval are processed?

The studies of Johnson *et al.*[39] and Wilding[12] come nearest to meeting the criteria for the identification of a neural correlate of retrieval orientation. The findings suggest that neural activity is indeed modulated according to the nature of the information probed by a retrieval cue, even when retrieval cannot succeed. What remains to be determined is the nature of the cognitive operations reflected in the ERP effects. For example, to what extent do they reflect processes such as 'cue specification'[43], whereby a retrieval cue is targeted at a specific kind of memory representation, as opposed to processes involved in evaluating the products of a retrieval attempt? Another question, not well addressed by the ERP method, concerns the localization of the brain regions sensitive to retrieval orientation. Event-related fMRI studies along similar lines to those of Johnson *et al.*[39] and Wilding[12] are needed to investigate this issue.

In this section we have focused on neural correlates of retrieval orientation as revealed by item-related measures. As already noted, it is possible that different retrieval orientations could also be manifest as different tonically maintained states. However, we know of no studies that have employed designs that enable this issue to be addressed.

Concluding remarks

If nothing else, the foregoing review of the literature highlights the gap that exists between the experimental designs that could be adopted to investigate the neural correlates of retrieval processing, and the designs actually used in most studies of these processes. The development of more flexible imaging methods, together with an increasingly refined conceptual approach, should see a rapid closing of this gap.

An important general issue concerns the validity and completeness of the four-way classification of retrieval processing around which this article is based. Although this classification has proven heuristically useful, it seems unlikely that it will survive unmodified. The proposal that there exists a task-invariant state corresponding to retrieval mode remains to be demonstrated. Furthermore, the notion that additional processes are engaged specifically when retrieval is successful (e.g. Ref. 21) seems likely to be an oversimplification, with evidence accruing to suggest that some of the operations that are conducted on the products of successful retrieval are also engaged following retrieval attempts that do not result in a positive memory judgement[20]. A further issue concerns whether the neural correlates of retrieval effort can, in practice, be dissociated from the neural activity supporting a particular retrieval orientation. As already noted, studies ostensibly investigating one of these aspects of retrieval processing have invariably confounded it with the other, and there is a need for factorial studies that manipulate the two putative sets of processes independently. We suspect that such studies will reveal that the neural correlates of increasing effort will be manifest as increased activity of whatever brain regions are engaged by the retrieval task in question. In other words, it may turn out that retrieval effort does not have a distinct neural signature, and there will be no need to postulate cognitive operations that regulate or support the processing resources allocated to episodic retrieval.

Whatever the validity of present and future schemes for classifying retrieval processing, such schemes are most useful when they act as frameworks for the development of models that specify the component cognitive operations that subserve episodic retrieval (e.g. Refs 43,44). It is the neural correlates of these operations, rather than the more abstract and general concepts discussed in this article, which should ultimately be the focus of future research.

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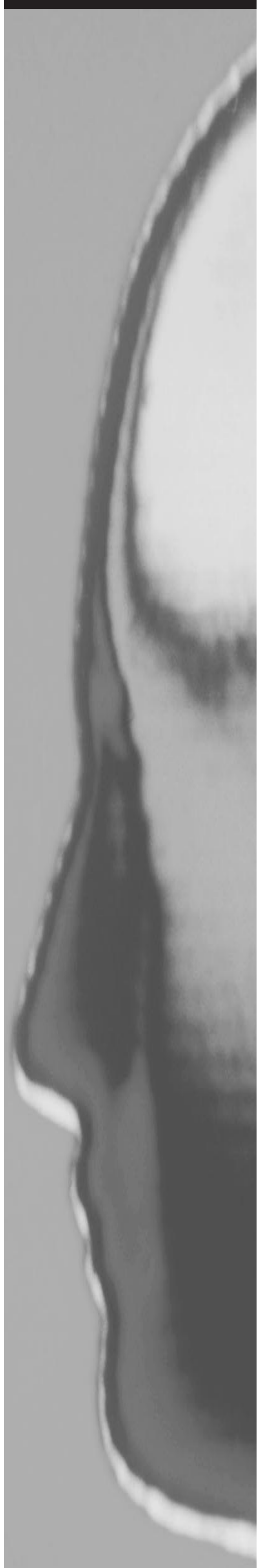

The Turing Test: the first 50 years

Robert M. French

The Turing Test, originally proposed as a simple operational definition of intelligence, has now been with us for exactly half a century. It is safe to say that no other single article in computer science, and few other articles in science in general, have generated so much discussion. The present article chronicles the comments and controversy surrounding Turing's classic article from its publication to the present. The changing perception of the Turing Test over the last 50 years has paralleled the changing attitudes in the scientific community towards artificial intelligence: from the unbridled optimism of 1960s to the current realization of the immense difficulties that still lie ahead. I conclude with the prediction that the Turing Test will remain important, not only as a landmark in the history of the development of intelligent machines, but also with real relevance to future generations of people living in a world in which the cognitive capacities of machines will be vastly greater than they are now.

The invention and development of the computer will undoubtedly rank as one of the twentieth century's most far-reaching achievements that will ultimately rival or even surpass that of the printing press. At the very heart of that development were three seminal contributions by Alan Mathison Turing. The first was theoretical in nature: in order to solve a major outstanding problem in mathematics, he developed a simple mathematical model for a universal computing machine (today referred to as a Turing Machine). The second was practical: he was actively involved in building

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