Chapter 4
Long-term memory and the medial temporal lobe
Long-term memory refers to the retrieval of previously experienced information, but can also refer to the encoding of information or a stored representation. It is widely believed that retrieval from long-term memory relies on either the process of recollection, memory with specific detail, or familiarity, memory without any specific detail. To illustrate, if you were asked to recall where you had breakfast this morning, you might have a detailed memory that you ate while seated on your couch, which would reflect recollection, or you might be confident that you ate on the couch without retrieving any specific details, which would reflect familiarity. In the laboratory, context memory refers to memory for the context of a previously presented item and is assumed to reflect detailed recollection, while item memory refers to memory for the previously presented item itself and is assumed to be based on non-detailed familiarity.

There has been intense debate regarding two hypotheses of medial temporal lobe function that will be referred to as the sub-region processing hypothesis and the system processing hypothesis. The sub-region processing hypothesis, the majority view, assumes the medial temporal lobe sub-regions -- the perirhinal cortex, the parahippocampal cortex, and the hippocampus -- have separate functions during recollection and familiarity, where the perirhinal cortex mediates item processing, the parahippocampal cortex mediates context processing, and the hippocampus binds item and context information (Figure 4.1, left; Diana, Yonelinas, and Ranganath, 2007; Ranganath, 2010). As such, this hypothesis predicts that medial temporal lobe sub-regions will be differentially active during context memory/recollection and item memory/familiarity.

Figure 4.1. Left, the sub-region processing hypothesis specifies that the medial temporal lobe sub-regions -- the perirhinal cortex (PRC), the parahippocampal cortex (PHC) and the hippocampus (HC) -- have separate functions where the PRC processes item information, the PHC processes context information, and the HC binds item and context information (arrows illustrate the flow of information from the cortex to the medial temporal lobe sub-regions). This hypothesis predicts that the
medial temporal lobe sub-regions will be differentially active during recollection and familiarity. Right, the system processing hypothesis specifies that the medial temporal lobe sub-regions operate together (indicated by the circular arrow) and predicts that each medial temporal lobe sub-region will be active to a similar degree during recollection and familiarity.

By contrast, the system processing hypothesis, the minority view, assumes the medial temporal lobe sub-regions operate together (as a system) during both context memory/recollection and item memory/familiarity (Figure 4.1, right; Squire, Stark, and Clark, 2004; Squire, Wixted, and Clark, 2007). This hypothesis predicts that if a medial temporal lobe sub-region is active, the magnitude of activity within that sub-region should be the same or similar during context memory and item memory (although the magnitude of activity can vary across sub-regions). Distinguishing between these hypotheses fits within a central aim of cognitive neuroscience to identify the functional role(s) of particular brain regions.

Evaluating these hypotheses depends on the specific anatomic location of the relevant medial temporal lobe sub-regions. Figure 4.2 shows the hippocampus in addition to the perirhinal cortex within the parahippocampal gyrus (Bernasconi, Bernasconi, Caramanos, Antel, Andermann, and Arnold, 2003). The hippocampus runs in the anterior-posterior direction (into the page on the coronal view) and is flanked by the parahippocampal gyrus that also runs in the anterior-posterior direction. The parahippocampal gyrus contains the perirhinal cortex more anteriorly (toward the front of the brain) and the parahippocampal cortex more posteriorly (toward the back of the brain).

Figure 4.2. The temporal lobes with the left hippocampus body (HB) and the perirhinal cortex (PC, within the parahippocampal gyrus) outlined (partial coronal view). The parahippocampal cortex (not shown) is located more posteriorly within the parahippocampal gyrus (Bernasconi et al., Mesial temporal damage in temporal lobe epilepsy: A volumetric MRI study of the hippocampus, amygdala and parahippocampal region, Brain, 2003, 126, Pt 2, 462-469, by permission of Oxford University Press).
In an effort to increase the amount of relevant evidence in this chapter, activity in the parahippocampal gyrus is assumed to reflect activity in the parahippocampal cortex if the anterior-posterior spatial coordinate of parahippocampal gyrus activation falls within the range of parahippocampal cortex activation coordinates reported previously (Davachi, Mitchell, and Wagner, 2003; Woodruff, Johnson, Uncapher, and Rugg, 2005; Ross and Slotnick, 2008; Yonelinas, Otten, Shaw, and Rugg, 2005).

MAJORITY VIEW

**Context memory-item memory activation evidence**

Unless otherwise specified, all of the evidence supporting the sub-region processing hypothesis has been obtained using fMRI. It should be mentioned that memory studies often employ very different stimuli and tasks, and that the term context is used very broadly to refer to an item's previous spatial location, its color, or the task associated with an item during encoding. Of importance, despite the substantial differences in experimental protocols, memory findings have proven to be highly consistent across studies.

Cansino, Maquet, Dolan, and Rugg (2002) presented colored objects in 1 of 4 quadrants during the encoding/study phase and then participants classified each stimulus as artificial or natural during the retrieval/test phase (Figure 4.3).

![Figure 4.3](image.png)

Figure 4.3. Left, example object. Top right, during the encoding/study study phase, each object was presented in 1 quadrant. Bottom right, during the retrieval/test phase, objects were presented at fixation (Cansino et al., Brain activity underlying encoding and retrieval of source memory, Cerebral Cortex, 2002, 12, 10, 1048-1056, by permission of Oxford University Press).
During the retrieval phase, old and new objects were presented at fixation and participants classified each item as old and previously in the “upper left”, old and previously in the “upper right”, old and previously in the “lower left”, old and previously in the “lower right”, or “new”. The comparison of accurate item memory and spatial location/context memory versus accurate item memory with inaccurate context memory (i.e., item memory alone) produced activity in the right hippocampus and the left parahippocampal cortex. This differential activation, produced by contrasting accurate item and context memory versus accurate item memory, supports the sub-region processing hypothesis of medial temporal lobe function. Note that studies in which the results could not be attributed to either recollection or familiarity were not considered in this chapter as such findings cannot be used to distinguish between the hypotheses of medial temporal lobe function. For instance, accurate item and context memory is often contrasted with completely forgotten items (i.e., responding “new” to a previously presented item and context), but activity associated with this contrast may be attributed to item memory, context memory, or both processes, making the interpretation of such results unclear. Davachi, Mitchell, and Wagner (2003) investigated the role of medial temporal lobe sub-regions during memory encoding. During the study phase, words were presented and participants either generated a corresponding mental image or covertly (mentally, rather than aloud) read the word backwards. During the test phase, old and new words were presented and participants first classified each word as “old” or “new”, and then “old” words were classified as previously in the “image” or “read” condition (based on memory for context). It should be highlighted that activity was measured during the study phase, before participants had produced responses during the test phase, such that study items were classified according to the subsequent response at test. For example, a particular item and its context at study may later be accurately remembered, and thus associated with subsequent accurate item and context memory. As will be illustrated repeatedly below, subsequent memory paradigms that measure memory activity during encoding have produced the same pattern of results as paradigms that measure memory activity during retrieval, thus encoding and retrieval results are considered together. Davachi et al. found that the left perirhinal cortex was associated with greater activity during subsequent accurate item memory as compared to subsequent forgotten items (Figure 4.4, left panel). In addition, subsequent accurate item and context memory (context memory is synonymous with the term source memory) as compared to subsequent accurate item memory produced activity in the left and right hippocampus and the left parahippocampal cortex (Figure 4.4, middle and right panels).
Ranganath, Yonelinas, Cohen, Dy, Tom, and D'Esposito (2004) used words as stimuli and manipulated source by varying stimulus color (and a corresponding task) at encoding. Subsequent accurate item and context memory versus subsequent accurate item memory produced activity in the right hippocampus and the right parahippocampal cortex. Weis, Specht, Klaver, Tendolkar, Willmes, Ruhlmann, Elger, and Fernández (2004) varied color to manipulate the context of photos and observed that accurate item and context memory versus accurate item memory produced activity in the left hippocampus. Kensinger and Schacter (2006) used words and pictures as stimuli and varied context by manipulating the encoding task by asking participants to make an animate-inanimate judgment or a common-uncommon judgment. They found that subsequent accurate item and context memory versus subsequent accurate item memory was associated with activity in the left and right hippocampus and the right parahippocampal cortex. Ross and Slotnick (2008) presented abstract shapes in the left or right visual field during encoding, and found that accurate item and spatial location/context memory versus accurate item memory produced activity in the left and right hippocampus and the left parahippocampal cortex. Moreover, within the left perirhinal cortex there was a decrease in activity during accurate item memory as compared to forgotten items. Such item memory decreases in activation within perirhinal cortex during retrieval and item memory increases in activation within this region during encoding (Figure 4.4, left panel) have been consistently observed, although the reason behind this perirhinal polarity reversal is currently a mystery. Staresina and Davachi (2008) presented words with colored backgrounds (context 1) and manipulated task (context 2), while Tendolkar, Arnold, Petersson, Weis, Brockhaus-Dumke, van Eijndhoven, Buitelaar, and Fernández (2008) presented photos of landscapes with varied color (context 1) and shade (context 2). In both
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studies, the left hippocampus produced a graded response during memorial encoding and retrieval, respectively, with the greatest magnitude of activity during accurate memory for 2 contexts, a lower magnitude of activity during accurate memory for 1 context, and the smallest magnitude of activity during accurate item memory. These findings of progressively increasing activity in the hippocampus with increasing amounts of information supports the view that this region binds information together, as a greater degree of binding would be required when more information is encoded or retrieved. Like Ross and Slotnick, Tendolkar et al. also reported that accurate item memory versus forgotten items produced a decrease in activity within the perirhinal cortex, which suggests that this region is involved in processing familiarity.

“Remember”-“know” activation evidence

The studies thus far have isolated the medial temporal lobe sub-regions associated with recollection by contrasting accurate item and context memory with accurate item memory and have isolated the sub-regions associated with familiarity by contrasting accurate item memory with forgotten items. This type of procedure can be described as objective, as it is based on behavioral accuracy. A subjective procedure has also been employed to investigate recollection and familiarity where, at test, a “remember” response corresponds to a memory associated with the subjective experience of specific detail while a “know” response corresponds to a memory that an item is familiar (i.e., associated with high confidence) but without any subjective experience of specific detail. The key distinction between “remember” and “know” responses is whether the participant has the subjective experience of detail or does not have the subjective experience of detail. Even if a single detail is retrieved, participants are instructed to make a “remember” response. Of relevance, objective accuracy can be dissociated from subjective experience, as illustrated by accurate objective responses that are accompanied by the subjective experience of guessing. Eldridge, Knowlton, Furmanski, Bookheimer, and Engle (2000) presented words in the study phase and then presented old and new words during the test phase. Participants first classified each item as “old” or “new”, and then for “old” items made a “remember” or “know” response. The “remember” versus “know” contrast revealed activity in the left hippocampus and the right parahippocampal cortex. Woodruff, Johnson, Uncapher, and Rugg (2005) presented pictures or picture names during the study phase. During the test phase, old and new names were presented during the test phase and participants made a “remember”, “know”, or “new” response to each item. The “remember” greater than “know” contrast produced activity in the right hippocampus and the right parahippocampal cortex. Yonelinas, Otten, Shaw, and Rugg (2005) presented words at study and then presented old and new
words at test. Participants made a “remember” response or, if an item was not associated with specific detail, made an old-new confidence judgment ranging from 1 to 4 (where 1 meant they were sure the item was “new” and 4 meant they were sure the item was “old”). The introduction of high confidence old responses in this study was an important aspect of the experimental design, as these items could be assumed to reflect familiarity based responses with relatively high memory strength (as compared to “know” responses that can reflect a broader range of memory strength), and thus were a more appropriate condition for comparison with the high memory strength “remember” responses. The contrast between “remember” responses versus the highest confidence familiarity responses produced activity in the left and right hippocampus and the left parahippocampal cortex. Montaldi, Spencer, Roberts, and Mayes (2006) used a similar procedure as in the previous study, where pictures of colored scenes were shown during the study phase and old and new pictures were shown during the test phase. Participants made a “remember” response (which in this study was defined as memory for contextual detail that occurred without effortful retrieval), made a confidence judgment from 1 to 3 to convey very weak familiarity to strong familiarity, or responded “new”. “Remember” responses versus the highest confidence familiarity responses produced activity in the left and right hippocampus. Consistent with previous findings, familiarity confidence rating increases (from 1 to 3) were also associated with decreases in activity within the left and right perirhinal cortex.

The hippocampus, objective binding, and subjective experience

All of the previous studies reported activity in the hippocampus by contrasting accurate item and context memory versus accurate item memory (to objectively isolate memory for context) or by contrasting “remember” responses versus “know”/high confidence familiarity responses (to isolate the subjective experience of memory for context). Objective memory for context, however, would be expected to correlate with the subjective experience of memory for context, as more accurate context memory responses should be associated with a higher rate of “remember” responses and less accurate context memory responses should be associated with a lower rate of “remember” responses. As such, the preceding evidence cannot be used to determine whether the hippocampus is associated with objective memory for context, the subjective experience of memory for context, or both aspects of memory. To distinguish between possibilities, Slotnick (2010a) conducted an experiment that employed both objective and subjective measures of item memory and context memory. During the study phase colored or gray abstract shapes were presented (Figure 4.5, top). During the test phase old and new gray shapes were presented and participants classified each item as old and previously in “color”, old and
previously in “gray”, or “new”, and then for “old” items made a “remember” or “know” response. Accurate item and context memory (item memory-hits and context memory-hits, HH) produced greater activity than accurate item memory (item memory-hits and a context memory-misses, HM) in the left and right hippocampus (Figure 4.5, bottom left), and the hit-hit versus hit-miss difference in activity was greater than the “remember” (R) versus “know” (K) difference in activity (Figure 4.5, bottom right). In fact, “know” activity was greater than “remember” activity, in direct opposition to the pattern of activity predicted if the subjective experience of remembering was driving the response in the hippocampus. By comparison, the “remember” versus “know” contrast did not produce any activity in the hippocampus, but did produce activity in the left inferior parietal cortex. These results, along with previous findings, suggest that the hippocampus is associated with objective binding, while subjective aspects of memory depend on cortical regions outside of the medial temporal lobe such as the parietal cortex (Wheeler and Buckner, 2004; Montaldi et al., 2006) and the prefrontal cortex (Chua, Rand-Giovannetti, Schacter, Albert, and Sperling, 2004; Kao, Davis, and Gabrieli, 2005).

Figure 4.5. Top, illustration of colored or gray abstract shapes shown during the study phase (color not shown). Bottom left, activity (in black) in the left hippocampus identified by contrasting accurate item and context memory (item memory-hits and context memory-hits, HH) versus accurate item memory (item memory-hits and context memory-misses, HM)
misses, HM; coronal view). Bottom right, magnitude of activity 
associated with HH, HM, “remember” (R), and “know” (K) responses 
(percent signal change) in the hippocampal region to the left (Reprinted 
from NeuroImage, 49/2, Slotnick, 2010a, Does the hippocampus 
mediate objective binding or subjective remembering?, Copyright 2010, 
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Lesion evidence
The results of the preceding fMRI studies provide compelling 
evidence that the hippocampus and parahippocampal cortex are 
associated with recollection, and that the perirhinal cortex is associated 
with familiarity. Further support for recollection based processing in the 
hippocampus has been provided by measuring behavioral performance 
in human patients with relatively selective damage to this region. 
Yonelinas, Kroll, Quamme, Lazzara, Sauvé, Widaman, and Knight 
(2002) evaluated 56 patients who had a brief episode of hypoxia (a lack 
of oxygen) that is thought to produce severe atrophy of the 
hippocampus but largely spare the parahippocampal gyrus. Memory for 
a list of words was tested using both recall, where participants produce 
as many words from a previously studied list as possible without any 
retrieval cues, and word recognition, where retrieval cues (old and new 
words) are provided. Patients were more impaired during the recall task 
than the recognition task (Figure 4.6, top). Given that recall is thought to 
rely on recollection to a greater degree than recognition, these results 
support the view that the hippocampus preferentially supports 
recollection. Yonelinas et al. conducted another experiment with 4 
hypoxic patients with relatively selective damage to the hippocampus 
(H participants), 5 patients with relatively selective damage to the 
hippocampus and parahippocampal gyrus (H+ participants), and control 
participants with no medial temporal lobe damage (C participants). 
Participants studied words and then at test were shown old and new 
words and made “remember”, “familiar/know”, or “new” responses. An 
estimate of recollection was computed as the proportion of old items 
that received “remember” responses minus the proportion of new items 
that received “remember” responses (which corrects for guessing). An 
estimate of familiarity was computed as the proportion of old items that 
were not remembered and received “know” responses minus the same 
estimate for new items (which corrects for guessing and assumes 
recollection and familiarity are independent processes). Compared to 
control participants, H+ patients had deficits in familiarity and 
recollection, but H patients only had a deficit in recollection (Figure 4.6, 
bottom). The results of these hypoxia patient experiments suggest that 
the hippocampus is specifically associated with recollection. However, it 
is tenuous to assume that recall taps into recollection to a greater 
degree than recognition. While it is reasonable to argue that recall 
(which does not involve retrieval cues) is relatively more difficult than
recognition, difficulty does not necessarily correspond to the amount of details that are retrieved (for instance, detailed memories are often retrieved with little effort). Furthermore, as discussed in more detail below, recognition may be associated with retrieval of detailed item or contextual information (recollection), thus recognition should not necessarily be assumed to rely on familiarity alone. As such, patient studies that only considered recall and recognition results were not considered.

Figure 4.6. Top, recall and recognition performance of hypoxia patients measured in z-scores (standard deviation units from control participant performance), with negative values of greater magnitude corresponding to more impaired performance. Bottom, familiarity and recollection estimates computed from “remember”-“know” responses for control participants (C), 5 patients with damage to the hippocampus and parahippocampal gyrus (H+), and 4 patients with damage to the hippocampus (H). (Yonelinas et al., 2002, DOI: 10.1038/nn961; reprinted with permission of the Nature Publishing Group).

Bowles, Crupi, Mirsattari, Pigott, Parrent, Pruessner, Yonelinas, and Köhler (2007) presented a case study of a patient with a left anterior temporal lobe lesion, due to surgical removal of a tumor in the amygdala that included the perirhinal cortex but spared the hippocampus and parahippocampal cortex. Memory for words was tested with a “remember”-“know” protocol. Estimates of recollection and familiarity indicated that this patient had a greater degree of recollection
and a lower degree of familiarity than control participants. The lesion evidence from both of the preceding studies suggests that the hippocampus (but not the perirhinal cortex) is necessary for recollection and the perirhinal cortex (but not the hippocampus) is necessary for familiarity. This double dissociation provides support for the sub-region processing hypothesis that complements the previous fMRI results.

MINORITY VIEW

There are those that believe the medial temporal lobe sub-regions are similarly engaged during recollection and familiarity. This position has been championed by Larry Squire. When considering the following findings, it is important to keep in mind that if a medial temporal lobe sub-region was similarly active during item memory and context memory, the contrast between these event types should not produce any differential activity in that sub-region. This line of research has focused on the role of the hippocampus, with the results taken to suggest that this region is similarly activated by recollection and familiarity. Gold, Smith, Bayley, Shrager, Brewer, Stark, Hopkins, and Squire (2006) conducted a subsequent memory fMRI experiment and a patient experiment. During the study phase of the fMRI experiment, words were each followed by a cue, ‘indoor’ or ‘outdoor’, and the participant imagined a corresponding scene associated with the word. During the test phase, old and new words were presented and participants classified each word as “old” or “new” and provided an item confidence rating ranging from 1 to 3 (where 1 meant “not sure”, 2 meant “somewhat sure”, and 3 meant “very sure”). For “old” words participants also classified the previous context (“indoor” or “outdoor”) and provided a source confidence rating ranging from 1 to 3. The contrast of subsequent accurate item and context memory versus subsequent accurate item memory did not produce any activity in the hippocampus, the parahippocampal cortex, or the perirhinal cortex. The contrast of subsequent accurate item memory with inaccurate source memory versus subsequent forgotten items did not produce any activity in the hippocampus either. However, the contrast of subsequent accurate item memory regardless of source accuracy versus subsequent forgotten items did produce activity in the left hippocampus and the right perirhinal cortex. Furthermore, subsequent accurate item and source memory and subsequent accurate item memory were associated with similar magnitudes of activity within each of these sub-regions (Figure 4.7, top). Of theoretical importance, this finding suggests that the hippocampus is involved during item memory/familiarity.
The second experiment included 5 amnesic patients: 1 following a cardiac arrest, 2 following respiratory failure following a drug overdose, 1 following kidney failure and toxic shock syndrome, and 1 with no known cause. Relatively selective hippocampal lesions were confirmed using MRI, with reductions in the hippocampal volume of both hemispheres ranging from 33 to 49 percent, which was more than 3 standard deviations smaller than the average volume of the control participants. The patients had little or no reduction in the volume of the parahippocampal gyrus, which was within 2 standard deviations from the average volume of the control participants. The patients with selective hippocampal lesions (H) and the first set of control participants (CON-1) studied 25 words 3 times. A second set of control participants (CON-2) studied 100 words 1 time to match the memory performance.
with the patients. Item memory performance was computed as the hit rate (the probability of responding “old” to an old item) minus the false alarm rate (the probability of responding “old” to a new item, which corrected for guessing). Source memory performance was computed from the probability of an accurate source response for items correctly classified as “old”. Figure 4.7 (bottom) shows that the patients performed worse than the first control group and had similar performance levels as the second control group during both the item memory task and the context memory task. These results suggest that the hippocampus is similarly involved during recollection and familiarity. Manns, Hopkins, Reed, Kitchener, and Squire (2003) investigated 7 patients with relatively selective lesions to the hippocampus and sparing of the parahippocampal gyrus, including 4 of the 5 patients from the previous study. The patients had a similar impairment during recall as compared to recognition, although as mentioned previously it is uncertain whether these tasks should be assumed to reflect recollection and familiarity. Of greater importance, patient responses in a “remember”-“know” task were compared to the responses of two groups of control participants. One control group completed the same task as the patients and the other control group completed the test phase after a 1 week delay (to match memory performance with the patients). The patients had a similar degree of impairment in “remember” and “know” responses relative to control participant performance (Figure 4.8; if anything, for patients, “know” responses were relatively more impaired than “remember” responses). These findings failed to replicate the previously reported preferential deficit in recollection (Yonelinas et al., 2002), and suggest that that hippocampus is associated with both recollection and familiarity.

Figure 4.8. Memory strength (d’) associated with “remember” and “know” responses for patients with selective hippocampal lesions (H), control (CON) participants, and control participants with an additional 1 week delay (1-WK CON; key to the upper right). (Reprinted from Neuron, 37/1, Manns et al., Recognition memory and the human
Song, Wixted, Hopkins, and Squire (2011) also reported impaired “remember” and “know” responses in the 5 patients with relatively selective hippocampal damage that participated in the Gold et al. (2006) study. The lesion evidence from the previous 3 studies support the view that the hippocampus is similarly involved in recollection and familiarity. To investigate why Yonelinas et al. (2002) might have previously observed greater impairment in recall as compared to recognition (Figure 4.6, top), Wixted and Squire (2004) reanalyzed the Yonelinas et al. data and found that the differential recall versus recollection results were due to inclusion of 1 aberrant recognition score of a control participant. When this score was removed from the analysis, patient recall performance and recognition performance were similarly impaired. This reanalysis indicates that the patient results of Yonelinas et al. were due to a control participant data outlier that should not have been included in the analysis, and had nothing to do with impaired patient performance.

Kirwan, Wixted, and Squire (2008) conducted a subsequent memory fMRI study where words were presented during the study phase and participants either made an animacy judgment (for green words) or a size judgment (for red words). During the test phase, old and new words were presented and participants made an item confidence rating ranging from 1 to 6 (where 1 meant “sure new”, 2 meant “probably new”, 3 meant “guess new”, 4 meant “guess old”, 5 meant “probably old”, and 6 meant “sure old”) and for words classified as “old” made a source confidence rating ranging from 1 to 6. Regions associated with subsequent accurate item memory were identified where activity linearly increased with progressively higher item confidence ratings. Analysis was restricted to items where source memory performance was at chance levels (i.e., source confidence “guess” ratings of 3 or 4) to avoid a source memory strength confound. Kirwan et al. argued that the contrasts employed in previous studies did not adequately isolate these processes (which will be discussed in more detail below). The analysis revealed that activity in the left and right hippocampus and the right perirhinal cortex tracked subsequent item memory confidence ratings (Figure 4.9), suggesting that these regions were associated with item memory. A subsequent source memory analysis was conducted to identify activity that increased linearly with increasing source confidence ratings, with item memory ratings maintained at a confidence level of 6 to avoid an item memory strength confound. This analysis did not reveal any subsequent accurate context memory activity in the medial temporal lobe. However, activity in the prefrontal cortex tracked subsequent source memory confidence suggesting that this region, rather than the hippocampus, was involved in source memory.
COUNTERPOINTS

Table 4.1 illustrates the medial temporal lobe regions associated with recollection and familiarity that were identified using fMRI. Recollection was associated with the hippocampus in the large majority of studies, was associated with the parahippocampal cortex in approximately half of the studies, and was never associated with the perirhinal cortex. By contrast, familiarity was associated with the perirhinal cortex a third of the studies, and was almost never associated with the hippocampus or the parahippocampal cortex.
Table 4.1 Medial temporal lobe sub-regions (the hippocampus, HC, the perirhinal cortex, PRC, and the parahippocampal cortex, PHC) associated with recollection and familiarity

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The empirical evidence reported by proponents of the minority view has provided little support for the system processing hypothesis. Again, this hypothesis predicts that medial temporal lobe sub-regions will be similarly involved during recollection and familiarity. Kirwan et al. (2008) aimed to avoid a memory strength confound by keeping item memory or source memory confidence constant, based on the assumptions that accurate item memory and context memory reflect strong memory while accurate item memory alone reflects weak memory. Activity in the hippocampus and perirhinal cortex tracked item memory confidence, while no medial temporal lobe regions tracked source memory confidence. These distinct item memory and context memory results are at odds with the system processing hypothesis prediction of similar sub-region activation magnitudes. The fMRI evidence reported by Gold et al. (2006) also failed to support the system processing hypothesis as no medial temporal lobe sub-region activity was associated accurate item memory. Although the comparison between subsequent accurate item and context memory versus forgotten items did produce activity in the hippocampus and perirhinal cortex, this result can be discounted as this contrast confounds context memory and item memory (which is ironic because this is a major fault proponents of the minority view have found with the work of others). That the item memory contrast, which did not suffer from this confound, produced a null result indicates the procedures employed in this study had limited sensitivity.

While the fMRI evidence provides strong support for the sub-region processing hypothesis, patient results cannot convincingly distinguish between the system processing hypothesis and the sub-
region processing hypothesis. The major problem with the patient data is that the lesions were almost all caused by an event that impacted the entire brain, such as a transient loss of oxygen due to cardiac arrest. If the brain outside of the medial temporal lobe is ignored, as it was by proponents of both the majority and minority views, the lesions might appear to selectively impact the hippocampus. However, the patient results reported could just as well have been caused by a lesion or lesions that occurred outside of this region. With this in mind, the patient results of Yonelinas et al. (2002), where recollection was impaired and familiarity was relatively spared (Figure 4.6), might have been due to a hippocampal lesion as was assumed, but could have been due to a prefrontal cortex lesion given that this region has been associated with memory confidence (Chua et al., 2004; Kao et al., 2005). The same reasoning can be used to question the patient evidence that has been taken to support the minority view. Furthermore, it is unclear whether a similar impairment in context memory and item memory in patients with selective hippocampal lesions actually supports the system processing hypothesis. Such a null finding may be due to any factor that limits sensitivity such as a relatively low number of trials, employment of a particular task, or the use of a particular analysis procedure. Of importance, null medial temporal lobe findings, whether based on lesion evidence or fMRI evidence, are not inconsistent with the sub-region processing hypothesis. By contrast, the differential medial temporal lobe evidence that has been consistently observed directly contradicts the system processing hypothesis. Thus, the empirical fMRI findings that have been taken to support the system processing hypothesis do not actually support this hypothesis, but are consistent with the sub-region processing hypothesis.

There are also theoretical reasons to question the system processing hypothesis. The memory strength explanation of differential medial temporal lobe results is a valid concern and should be taken seriously. However, there are a number of major problems with this explanation. First, contrary to the claim of minority view proponents, all of the studies considered in this chapter that supported the majority view did isolate item memory by maintaining context memory at chance levels, like Kirwan et al. (2008). Specifically, accurate item memory and inaccurate context memory were contrasted with inaccurate item memory and inaccurate context memory (forgotten items), such that source memory remained constant (i.e., inaccurate). Moreover, context memory was always isolated by comparing accurate item memory and accurate context memory versus accurate item memory and inaccurate context memory, such that item memory was maintained at a high level of performance, again like Kirwan et al. Thus, the critique that previous studies confounded item memory and context memory strength is not supported by the actual contrasts that were used. Second, the
statement that context memory is stronger than item memory is not justified. The contrast of accurate item and context memory versus accurate item memory alone is employed to isolate the process of context memory, as item memory is subtracted out, thus context memory strength could be weaker than item memory strength. That is, while it is possible that context memory strength is greater than item memory strength under certain conditions, the opposite may also occur. It would seem prudent for future studies to include measures of context memory strength and item memory strength so that this factor can be taken into account when interpreting results. Third, proponents of the minority view often claim that item memory activity in the hippocampus can be taken as evidence against the sub-region processing hypothesis. However, item memory activity in the hippocampus is actually compatible with the sub-region processing hypothesis if the hippocampus serves a general binding function. From this perspective, the hippocampus can bind item and contextual information or this region can bind individual features that comprise an individual item, such as an item’s color and its shape. Such a general binding function deviates from an emphasis by proponents of the majority view on the role of the hippocampus in binding item and context information. However, of primary importance, this description still maintains that the hippocampus mediates binding of memorial information.

Although not directly related to the cognitive neuroscience debate, it is notable that neural evidence is often inappropriately taken to support a particular side of a separate debate in cognitive psychology. Specifically, most cognitive psychologists and cognitive neuroscientists believe recollection is a threshold process, where this process is engaged if memory strength is above a certain threshold and otherwise one has no memory and guesses. Others believe recollection is a continuous process, where there is no internal threshold and recollection reflects a range of memory strength from very weak to intermediate to very strong. Critically, brain evidence cannot distinguish between the threshold model and the continuous model of recollection, as recollection in both cases refers to detailed memories that are constructed by binding information. Thus, assuming the hippocampus mediates binding, both accounts predict that contrasting recollection versus familiarity will activate this region. Although neural evidence cannot be used to distinguish between the threshold and continuous models of recollection, these models make distinct predictions with regard to behavioral performance. A growing body of behavioral evidence indicates recollection is a continuous process (Wixted, 2007). For instance, the shape of the receiver operating characteristic (ROC), a plot of the hit rate as a function of the false alarm rate (generated from confidence ratings), has provided some of the most compelling behavioral results. Specifically, the threshold recollection model predicts the ROC will be linear while the continuous recollection model
predicts the ROC will be curved. Slotnick (2010b) found that ROCs generated from context memory-“remember” responses, which are based on recollection by any account, were curved (Figure 4.10), providing strong support for the continuous model of recollection. This related but separate debate is still playing out in cognitive psychology, and was touched on merely to emphasize that caution should be taken when it is claimed that neural evidence can distinguish between models of cognitive function.

![Figure 4.10. Recollection based receiver operating characteristic (ROC) associated with context memory-“remember” responses ("Remember" source memory ROCs indicate recollection is a continuous process, Slotnick, Memory, 2010b, reprinted by permission of Taylor & Francis Ltd, http://www.tandf.co.uk/journals).](image)

CONCLUSION

The current body of evidence provides strong support for the sub-region processing hypothesis and directly contradicts the system processing hypothesis. Proponents of the minority view have made the valid argument that differential medial temporal lobe findings may be due to a strength confound; however, this argument does not account for the empirical results and it is not theoretically justified. It is anticipated that the strength confound argument will be discounted by future evidence, and that support for the sub-region processing hypothesis will continue to accumulate.
SUGGESTED READINGS

Majority view


Minority view

REFERENCES


