

Semantic versus perceptual priming in fusiform cortex

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What is the nature of the representations of visual objects in the human brain? How abstract are these representations? Recently, Koustaal *et al.* have reported evidence of neural correlates of semantic priming in the left fusiform gyrus¹. They showed that when subjects see repeated presentations of pictures previously seen, or new pictures from object categories previously seen, there is a reduced fMRI signal in the left fusiform gyrus. Several other recent neuroimaging studies using fMRI have shown that repeated presentation of identical stimuli results in a reduced activation compared with that elicited by similar but non-repeated stimuli. This reduction in the fMRI signal is observed in higher-level cortices such as occipito-temporal and prefrontal regions and is thought to be related to priming (the behavioral phenomenon that responses are typically faster and more accurate for repeated than for novel stimuli). A possible explanation for the reduction is the suppressed response of neurons with repetitive stimulus presentation, a phenomenon termed ‘mnemonic filtering’, which has been well documented in physiological studies in the macaque². Because the suppression is specific, it can be used to investigate the nature of the representations of the underlying neuronal populations.

Before the scan (study phase) in Koustaal *et al.*'s experiment, they showed subjects four repetitions of several pictures. These pictures served as the primed pictures. During the scan subjects saw either novel stimuli from object categories not seen before the scan, identical pictures from the study phase or pictures of different exemplars from the same categories seen before the scan (e.g. two different pictures of umbrellas). Koustaal *et al.* report bilateral reduction in fMRI activation in occipito-temporal and prefrontal cortex for presentation of primed identical stimuli compared with novel stimuli. Moreover, they report that there is also a reduction in activation (adaptation) in the left fusiform gyrus when subjects saw new pictures of objects

from the same semantic categories as those seen prior to the scan, though this reduction is smaller than that found with identical stimuli.

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The novelty of their findings is twofold: they are the first to report semantic adaptation in occipito-temporal regions, and they find that semantic adaptation occurs in left but not right fusiform regions. Previous publications have reported reduced activation in left inferior prefrontal cortex during repeated semantic processing of both words and pictures (e.g. Ref. 3), and several studies have shown reduced activation in occipital regions after repeated presentations of identical object stimuli^{4,5}.

One of the implicit assumptions in the Koustaal *et al.* study is that objects from different categories are represented within the same strip of cortex, and the goal of this study was to determine the abstractness of these representations. However, there are several reports that indicate that there might be specialized regions within the fusiform gyrus that are specific to certain object categories, such as faces⁶. As the new pictures are from different object categories from the primed objects, there is a possibility that the smaller signal that is attributed to priming might be lower because of the use of a different and potentially non-optimal stimulus set. Thus, it is important in fMR-adaptation studies to control the parameters that might affect the strength of the measured fMR signal, such as the choice of object categories and the variability in the image sets across different trial types.

The findings of Koustaal *et al.* imply that the representation of objects in the left and right occipito-temporal regions differs in some respects. There are two very different hypotheses that might account for semantic adaptation in left occipito-temporal regions. One possibility is that the representation in the left

hemisphere is more semantic compared with the representation in the right hemisphere. Furthermore, these left fusiform regions are close to regions that were also found to be engaged in visual encoding of visually presented words. Thus, the activation of these regions might be related to lexical/semantic processing of concepts and not just visual object-form processing. One problem with this interpretation is that it does not account well for the greater reduction seen in the left fusiform for identical stimuli compared with different stimuli from the same semantic category.

An alternative hypothesis is that the representation in the left hemisphere is feature-based, whereas the representation in the right hemisphere is holistic or class-based. If this is the case, presenting subjects with objects from many categories containing a large variety of object features would be an ‘optimal’ stimulus for left-fusiform regions, because it would activate many different neural populations. As objects from the same basic category tend to share common visual features, there is a smaller variability in the number of features of these stimuli compared with pictures of images from different categories, resulting in a lower signal. Identical pictures, which are most similar, would activate the smallest neuronal populations, hence giving rise to the lowest signal. Therefore, the differential response elicited by identical pictures, pictures of objects from the same semantic category, and non-repeated pictures of objects from different categories could be explained by the differences in the perceptual similarity between the stimuli rather than the semantic content.

Although the results of this latest research are indeed intriguing, further studies controlling for both the semantic and perceptual similarity between the stimuli in the different conditions are necessary to elucidate the mechanisms underlying the differences in the representation of objects in the left and right occipito-temporal regions.

References

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The hippocampal complex and long-term memory revisited

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A recent report by Cipolotti *et al.* demonstrates that the hippocampus and perhaps the parahippocampal area are essential for retrieval of remote episodic memory and important for remote semantic memory. This report, along with other recent findings, re-opens the debate about the role of these medial temporal lobe structures, indicating that their role extends much further than traditional theory had suggested.

Although involvement of the hippocampal formation and related structures (entorhinal, perirhinal and parahippocampal cortices) in memory has been known for more than 50 years, the exact nature of this involvement remains a hotly debated subject. In the 1960s the outlines of the central debates were already clearly crystallized in work with amnesic patients such as H.M., which reflected the assumption that it was damage in the medial temporal lobes that was primarily responsible for the amnesia. The focus of attention shifted quickly from the medial temporal lobes to the hippocampal formation, and then to the hippocampus itself. Three major questions emerged: (1) is amnesia a problem of memory storage or memory retrieval?; (2) does the hippocampus play a role in recent or remote memories, or both?; and (3) is the hippocampus important for all, or only some, kinds of memory?

Of these three issues only the last appears to be resolved – most investigators now agree that the hippocampal formation is critical for only some kinds of learning and memory

(e.g. Refs 1,2, but see Ref. 3). The issues of storage versus retrieval, and recent versus remote memory must be discussed within this constraint, even though lively disagreements persist about how to characterize the kinds of memory that are, and are not, dependent on the hippocampal formation.

Recent versus remote memory

The initial report on H.M., and subsequent studies with temporal lobe patients, were taken to show that the hippocampal formation was involved neither in processing short-term memories nor in storing long-term memories. Although they lacked substantial portions of the hippocampus, these individuals had a normal short-term memory as measured by a number of tests, including digit-span performance, which involves repeating back a series of numbers. Similarly, it was reported that deficits in remote memory were limited to retrieval of events within the past few years, suggesting that older memories were stored, and could be retrieved readily, without the hippocampal formation^{4,5}.

Storage versus retrieval

However, reports of quite extensive retrograde amnesia, sometimes extending throughout the patient's remaining lifetime, complicated the picture. Warrington and her colleagues argued that the medial temporal lobe was essential to the retrieval of all remote memories, no matter how old, and that amnesia must reflect the lack of access to memory rather than the loss of the

memories themselves⁶. One concern in this debate (to which we return later) was the extent of damage underlying the amnesic defect. At first it was believed that the damage needed to be restricted to the medial temporal lobes but when reports of extensive retrograde amnesia came to light, the structure viewed as crucial became the hippocampal formation. When such damage was thought to be limited to the hippocampal formation itself, it appeared that the remote memory loss might be restricted (but see Ref. 7 for qualification). Thus, the view emerged that the hippocampus was critical for encoding of memories, and for consolidating memory for a limited period afterwards, but not for storage of memory itself. Over the years, this view became the accepted wisdom.

Recently, this view has come under renewed attack, and the paper by Cipolotti and her colleagues⁸ adds weight to the evidence suggesting that matters are a good deal more complex than many thought. Two lines of evidence have re-opened the debate. First, several studies have shown that activation in the hippocampus, as detected by fMRI studies, is as robust when remote memories are being retrieved as when recent ones are retrieved^{9,10}. This finding would not have been predicted by the traditional theory. Second, the period of retrograde amnesia, even in patients with damage restricted to the hippocampal formation, is now known to extend for years, and possibly decades. This is true also of H.M., whose retrograde amnesia on retesting grew from 3 to 11 years. Even in the case of