Working Smarter, Not Harder

The ability to chunk, or to strategically organize, information is one of the most powerful ways people have to encode experience into memory. A functional brain imaging study by Bor and colleagues, in this issue of *Neuron*, provides evidence that prefrontal cortex contributes to this essential mnemonic process.

Imagine that you are about to win a large monetary prize if you can recall, with complete accuracy, a series of letters. The following letters are presented briefly: FBICB SNCAAPBS. You may be pessimistic about perfect recall, unless the same material is presented like this: FBI CBS NCAA PBS.

Psychologists have known for some time that people can encode material as "chunks," or integrated pieces of information, rather than representing items individually (Miller, 1956). Chunking thus offers a powerful mechanism for long-term memory processes to escape the shackles of severely limited short-term memory capacity. Typically, we can remember about seven random digits, but with the practice of a flexible chunking strategy, individuals have learned to recall over 80 random digits (Ericsson and Chase, 1982). The ability to integrate information into memorable chunks implies a psychological code that can represent items as elements of larger units of information.

In an elegant experiment, Bor and colleagues (Bor et al., 2003 [this issue of *Neuron*]) directly examined the brain basis of chunking for spatial material. They first developed a behavioral paradigm to measure the power of chunking for remembering visuospatial patterns. Over 400 volunteers at the London Science Museum were asked to memorize a sequence of locations presented on a 4×4 grid on a touch-sensitive monitor during an encoding phase. Then, in the subsequent retrieval phase, the volunteers had to touch the same locations in the same order. The critical manipulation was whether the sequence of locations followed a structured pattern or an unstructured pattern. Structured patterns were comprised of locations appearing in the same column, row, or diagonal from one location to the next and could be formed into spatial chunks because the patterns followed the outlines of familiar shapes. Memory was superior for structured versus unstructured patterns.

The neural substrates of such chunking were then examined via event-related functional magnetic resonance imaging (fMRI) that compared brain activation for structured relative to unstructured four-item sequences. Again, recall of structured sequences was superior to that of unstructured sequences. Critically, fMRI activation was greater for the encoding of structured versus unstructured patterns in a number of brain regions, including (bilateral) lateral prefrontal, parietal, and fusiform cortices. Presumably, these activations reflect the brain regions mediating the mental operations that exploit spatial structure to strengthen memory encoding. In contrast, during the brief pause separating the study and test phases (varying from 6 to 10 s), there was greater activation in parietal and occipital cortices for the unstructured relative to the structured patterns. Increased activation in these regions may represent the greater effort needed to maintain poorly structured information in the mind.

These results address a theoretically vexing issue that has challenged our understanding of the function of human prefrontal cortex. In almost every neuroimaging study, prefrontal activation increases as task demand increases (rare exceptions include Desmond et al., 1998, and Prabhakaran et al., 2000). Thus, prefrontal activation increases as reasoning tasks become more difficult (e.g., Christoff et al., 2001) or as more information must be maintained in working memory (e.g., Rypma et al., 1999). This correlation between brain activation and task difficulty makes it hard to characterize the precise psychological operation signified by prefrontal activation, because many mental resources must be recruited as a task takes longer to perform and is more prone to error. In this study, however, greater prefrontal activation was associated with the easier task of encoding structured versus unstructured patterns. Such a dissociation between difficulty and activation provides persuasive evidence that the lateral prefrontal cortex and other activated cortices are important for chunking processes per se.

These findings converge with those of Prabhakaran et al. (2000) to indicate that the prefrontal cortex plays a special role in the integration of information in working memory. Prabhakaran et al. (2000) found that prefrontal activation increased when letters and spatial locations could be integrated in working memory, a finding that corresponds with primate electrophysiological evidence that individual neurons in prefrontal cortex integrate object ("what") and spatial location ("where") information (Rao et al., 1997). In contrast, numerous posterior cortical areas were more activated in humans when an equal number of letters and spatial locations could not be integrated. These may reflect the additional memory demands that occur when prefrontal cortical mechanisms cannot encode information in an integrated, efficient fashion. Notably, the prefrontal activation observed by Prabhakaran et al. (2000) was anterior to that reported by Bor et al. (2003), raising the possibility of multiple chunking or integration mechanisms in prefrontal cortex.

These findings add to a growing literature showing that increased activation of lateral prefrontal cortex is associated with encoding that leads to superior memory for experience (Brewer et al., 1998; Wagner et al., 1998). Importantly, the study from Bor et al. (2003) associates prefrontal activation with the particular mental operation of chunking that leads to enhanced spatial working memory performance.

John D.E. Gabrieli and Alison R. Preston
Department of Psychology
Stanford University
Stanford, California 94305

Selected Reading

Bor, D., Duncan, J., Wiseman, R.J., and Owen, A.M. (2003). Neuron *37*, this issue, 361–367.

Brewer, J.B., Zhao, Z., Desmond, J.E., Glover, G.H., and Gabrieli, J.D.E. (1998). Science *281*, 1185–1187.

Christoff, K., Prabhakaran, V., Dorfman, J., Zhao, Z., Kroger, J.S., Holyoak, K.J., and Gabrieli, J.D.E. (2001). Neuroimage *14*, 1136–1149.

Desmond, J.E., Gabrieli, J.D.E., and Glover, G.H. (1998). Neuroimage *7*, 368–376.

Ericsson, K.A., and Chase, W.G. (1982). Am. Sci. *70*, 607–615.

Miller, G.A. (1956). Psychol. Rev. *63*, 81–97.

Prabhakaran, V., Narayanan, K., Zhao, Z., and Gabrieli, J.D.E. (2000). Nat. Neurosci. *3*, 85–90.

Rao, S.C., Rainer, G., and Miller, E.K. (1997). Science *276*, 821–824.

Rypma, B., Prabhakaran, V., Desmond, J.E., Glover, G.H., and Gabrieli, J.D.E. (1999). Neuroimage *9*, 216–226.

Wagner, A.D., Schacter, D.L., Rotte, M., Koutstaal, W., Maril, A., Dale, A.M., Rosen, B.R., and Buckner, R.L. (1998). Science *281*, 1188–1191.