Studies yield insight into the numerical brain

Two studies in the January 18, 2007, issue of the journal *Neuron*, published by Cell Press, shed significant light on how the brain processes numerical information--both abstract quantities and their concrete representations as symbols. The researches said their findings will contribute to understanding how the brain processes quantitative information as well as lead to studies of how numerical representation in the brain develops in children. Such studies could aid in rehabilitating people who suffer from dyscalculia--an inability to understand, remember, and manipulate numbers. The researchers also said their findings offer insight into the mystery of how the brain learns to associate abstract symbols precisely with quantities.

Both studies reveal in unprecedented detail how structures in the parietal cortex--the region of higher cognitive processing just above the forehead--activates during perception of both abstract quantities and numerical symbols.

In one paper, Manuela Piazza and colleagues showed that regions of the parietal lobe activate in response to numbers, either when they are presented as patterns of dots or as Arabic numerals.

In their experiments, the researchers asked human volunteers to pay attention to the quantities conveyed by groups of dots or numeric digits presented to them. During the process, the subjects' brains were scanned using functional magnetic resonance imaging (fMRI), in which harmless magnetic fields and radio waves are used to measure blood flow in brain regions, which reflects activity.

The researchers found that the initial presentation of the numeric stimuli activated the parietal region of the subjects' brains, which subsided as they adapted to the stimulus. However, the activation rebounded when the subjects were presented with an abrupt change in the quantity, whether it was represented in the same (dots versus dots) or different (dots versus Arabic numerals) notation as the original. This rebound indicated that the region was processing numerical information.

However, to unambiguously establish that the subjects' brains were really reacting to numerical quantity, the researcher occasionally injected a "deviant stimulus" into the second presentation of a quantity as the brain was adapting to it. This deviant stimulus consisted of a different number that was either close to, or far from, the number being presented. The researchers found that this deviant quantity interrupted adaptation more if it was distant from the adaptation quantity than if it was closer--conclusive evidence that the subjects were processing numerical quantities.

The researchers concluded that their findings "indicate an important role for parietal cortex in the coding of symbolic and nonsymbolic quantities."

They also concluded that "crucially, we observed crossnotation adaptation and recovery, particularly in the right parietal cortex, supporting the idea that shared neural populations encode nonsymbolic quantities and symbolic stimuli." Piazza and colleagues also concluded that their findings shed light on how the brain learns to associate symbols with numbers.

"Our results show that, at least in the adult brain, numerical symbols and nonnumerical numerosities converge onto shared neural representations," they wrote. "Perhaps we attach meaning to symbols by physically linking populations of neurons sensitive to symbol shapes to preexisting neural populations holding a nonsymbolic representation of the corresponding preverbal domain (e.g., numerosity)."

In the other paper in Neuron, Roi Cohen Kadosh and colleagues conducted experiments demonstrating that the two hemispheres of the parietal lobe function differently in processing numbers. While the left lobe harbors abstract numerical representations, the right shows a dependence on the notation used for a number, they found. The researchers concluded that "results challenge the commonly held belief that numbers are represented solely in an abstract way in the human brain." The authors also concluded that their results "advocate the existence of distinct neuronal populations for numbers, which are notation dependent in the right parietal lobe."

In their experiments, the researchers also used the adaptation phenomenon, that the brain adapts to stimuli by reducing its initial activity--and that repeating the same quantity leads to reduced activation compared to changing the quantity. They asked subjects whose brains were being scanned using fMRI to view consecutive numbers presented on a screen that represented either the same or different quantities. Crucially, the numbers were also presented either as two words (e.g., two or eight), two digits (e.g., 2 or 8), or a mixed notation (two and 8).

They hypothesized "that if the assumption of an abstract representation of numbers in the [parietal cortex] held true, the adaptation effect would be observed within and across notations. In contrast, in the case of nonabstract numerical representation, we expected that the adaptation effect would be modulated by the notation type. This result would suggest that distinct neuronal populations for notation exist." This meant that if the brain region was purely representing an abstraction of a number (e.g., 8) then any notational representation of this number (e.g., 8 or eight) would cause an adaptation effect. Alternatively, if a brain region processed a specific nonabstract number (e.g., 8) then adaptation would only be seen for the same notation (e.g., 8 but not eight).

Their analysis revealed an effect of notation in the right parietal lobe, showing that this region appears to harbor neurons that process nonabstract numerical representations, in addition to neurons that code for abstract representations of numeric quantities.

The researchers said that exploring how the processing of numerical symbols develops could have clinical implications. "Developmental studies should focus on tracing the emergence of numerical representation in the brain, investigating in particular at which stage such a representational divergence appears. Such findings could contribute significantly both to the field of numerical cognition research and rehabilitation of people suffering from developmental dyscalculia," they wrote.

Source: Cell Press