Neuroimaging

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The advent of neuroimaging technology (including functional Magnetic Resonance Imaging, or "fMRI", which is the focus of this review) has revolutionized cognitive neuroscience. Cognitive neuroscience is the study of the neural and biological bases of cognition. This review considers how fMRI works and some important caveats that cognitive neuroscientists must take into consideration.

Cognitive neuroscience. "Cognition" is defined in *Oxford American Dictionaries* as "the mental action or process of acquiring knowledge and understanding through thought, experience and the senses." The ultimate goal of cognitive neuroscience is to explain the link between cognition and the activity of the brain. The field is guided by the principle that all behaviour is the result of neural activity. Cognitive neuroscience is an interdisciplinary field and relies on the convergence of several techniques, including the methods of the cognitive psychologist, along with physiological methods like single neuron recording, electroencephalography (EEG) and of course fMRI, which helped to catalyze the growth of the field.

The basics of fMRI. Basically, fMRI is a technique that allows the user to map activity in the living brain. The spatial resolution of fMRI is rather coarse relative to multi-unit and single-unit recording, as fMRI cannot resolve details much smaller than cortical columns. Functional neuroimaging takes a broader look, mapping activity in large swathes of neural tissue ("population activity"). The temporal resolution of neuroimaging is on the order of seconds and minutes. Neuroimaging is particularly useful as it exploits the functional segregation of the brain. Different brain regions are active during the execution of different cognitive tasks. Neuroimaging allows scientists to view where and when brain activity is taking place.

How fMRI works. The scanner used for magnetic resonance imaging is essentially a giant magnet with a bore (an empty tube) running through the middle. In an fMRI experiment, a subject lies motionless in the bore of the magnet. The subject is placed in a powerful magnetic field, causing an alignment of bodily molecules along an axis. Radio waves are then transmitted into the subject. The subject re-transmits the radio waves, which are received and analyzed by the experimenter. The pattern of radio wave reception over time varies in different tissues of the body. This allows for construction of an image, in which different tissues appear as different shades in the visible spectrum.

The magnetic properties of deoxygenated blood and oxygenated blood are different. The pattern of radio wave reception is not the same for these two types of blood. This forms the basis of fMRI. As these two types of blood re-transmit radio waves in slightly different ways, the experimenter is able to map the location of oxygenated blood and deoxygenated blood. The significance of this is considered next.

The Blood Oxygenation Level Dependent (BOLD) signal. The ability to map the location of oxygenated and deoxygenated blood in the brain is what allows scientists to map where activity in the brain is taking place. Presumably, neurons that become increasingly active require more oxygen to satisfy their growing metabolic requirements. A relatively quiescent neuron is thought to be less metabolically active and therefore require less oxygen than a neuron that is firing vigourously.

Active neurons likely draw more oxygen from the blood than quiescent neurons. The capillaries surrounding active neurons become transiently deficient in oxygen. This is in theory followed by a compensatory shunt of oxygenated blood to the vasculature serving the active neurons. As fMRI can distinguish between oxygenated and deoxygenated blood (each produces a different BOLD signal), the location of the active neurons can be discovered by virtue of their increased dependence on oxygenated blood.

The basics of an fMRI experiment. An fMRI researcher is interested in measuring activity in the brain during a cognitive task. In a typical fMRI study, a subject is placed in the bore of the magnet and then completes a cognitive task. Brain activity is measured during execution of the task. This activation is compared with activation that occurs during a control condition(s), which is designed to mimic all features of the task aside from a key manipulation, which is thought to result in the activity pattern of interest. The experimenter then performs a subtraction. Brain activity during the experimental condition is subtracted from brain activity during the control condition. The difference in brain activity is the pattern of brain activity that is associated with the experimental manipulation.

Important caveats. Functional MRI is certainly powerful, but a number of valid criticisms have been leveled at the technique. First, consider the BOLD signal. The hematological event that most closely follows neural activity is the initial dip in the BOLD signal, which pertains to the transient deoxygenation of blood supplying active neurons. This is a subtle change in the BOLD signal and much more difficult to detect than the compensatory increase in oxygenated blood (and the accompanying BOLD signal) that follows. Thus, fMRI measures an event that is much slower than neural transmission and not quite coincident with neural firing. This is akin to watching a baseball game from the great height of a hot air balloon. Imagine that an individual in the balloon wants to observe players hitting home runs. Of course, the observer can see neither the players nor the ball. Instead, the observer measures the larger, wave-like frisson of excitement that ripples through the crowd of spectators after a home run is hit.

The link between neural activity and the hemodynamic response is poorly understood. The metabolic signal that leads to a shunt of oxygenated blood to active neural tissue is unknown. This is another important caveat to consider. Scientists must also take care to image the brain and not its vasculature (this is the so-called "brain versus vein" debate).

Recent examinations of the BOLD signal suggest that brain activity is more closely tied to blood flow and glucose consumption than it is to oxygen consumption. Accordingly, it is possible that the BOLD signal is produced by the activity of astrocytes, relying on glycolysis to handle an increase in glutamate (released from neurons), which must be converted by the astrocytes into glutamine before reuptake.

As fMRI measures gross activity, it cannot easily be used to elucidate the neural circuitry that underlies a pattern of brain activation. Neuroimaging cannot distinguish between action potentials, excitatory postsynaptic potentials, inhibitory postsynaptic potentials, feedforward projections, or feedback projections. Accordingly, patterns of activity measured by fMRI do not exactly match the patterns revealed by local field potentials, multi-unit recording or single-unit recording.

The measurement of activity of populations of neurons makes fMRI most sensitive to universal changes in neural activity across broad expanses of the brain. In contrast, fMRI does not easily detect localized changes in small expanses of neural tissue. This makes fMRI particularly sensitive to the effects of attention on brain activity, as attention leads to changes in activity across large areas of the brain.

The value of fMRI. Localization of brain activity on its own is of limited value. The value of fMRI lies in its ability to reveal fundamental principles of brain organization and their relation to cognition. A consideration of the types of experiments one can conduct using fMRI provides insight into the value of the technique.

Major Themes/Questions

- What are the strengths and weaknesses of neuroimaging?
- How can neuroimaging be used to explain the link between the brain and cognition?
- How is functional segregation relevant to neuroimaging?
- In studying the neural basis of a particular behaviour, what advantages does fMRI provide when compared to other techniques such as ____ ?
- How would one design an fMRI experiment to examine the relationship between ____ and ____ ?
- Why is metabolism relevant to neuroimaging?
- Among the techniques available to cognitive neuroscientists, which are most suitable to the study of ____ and why?