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Introduction to the Special Section: 20 Years of fMRI—What Has It Done for Understanding Cognition?

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Understanding the human brain is one of the greatest scientific quests of all time. Although this endeavor has engaged generations of scientists, the available methods were very limited until recently. Investigators could examine people with brain injuries, measure brain structure post mortem, make inferences from behavior, or extrapolate from invasive work in animals. Even the tools used to examine the brain in action in healthy people in the latter part of the 20th century had major limitations. Electrophysiological measurements of brain activity on the scalp could record rapid fluctuations but could not pinpoint the source of these signals. Positron emission tomography (PET) allowed scientists to measure blood flow as an index of local brain activity, and to trace molecules that bind to specific receptors, but it requires injecting people with a radioactive isotope, thus limiting the temporal and spatial resolution according to the decay properties of the isotope. Techniques that captured activity in the human brain with high spatial and temporal resolution were lacking (Churchland & Sejnowski, 1988). Thus, the development of functional magnetic resonance imaging (fMRI), which offered temporal resolution on the order of seconds and spatial resolution on the order of millimeters, opened up an exciting new landscape for exploration.

The first fMRI study was published in 1992 (Kwong et al., 1992), and multiple others were presented that year at meetings (for review, see Frahm, Merboldt, & Hanicke, 1993). The excitement around this new method was explosive. After validating the method by finding known basic sensory and motor regions, scientists quickly moved on to use fMRI to accomplish stunning new feats, including mapping the human retinotopic cortex (Engel et al., 1994), demonstrating the neural correlates of visual motion aftereffects in humans (Tootell et al., 1995), and demonstrating attentional modulation of basic perceptual processing (O'Craven, Rosen, Kwong, Treisman, & Savoy, 1997).

Few events are as thrilling to scientists as the arrival of a novel method that enables them to see the previously invisible. Neuroimagers raced in to aim their new telescope in many different directions and discovered all kinds of things—some predicted by prior work and some not. Cognitive psychologists grappling with the emerging fMRI findings focused on trying to link cognitive theories to brain activity to see how the latter might constrain or inform the former. It is the usefulness of this enterprise that we consider in the current special section.

Despite the many new methods and results derived from fMRI research, some have argued that fMRI has done very little to advance knowledge about cognition and, in particular, has done little to advance theories about cognitive processes. For instance, one argument is that "the huge investment of time and money that has accompanied this trend [the explosion of use of fMRI] has not resulted in a corresponding theoretical advancement, at least with respect to cognitive psychological theory" (Page, 2006, p. 428). Likewise, the claim has been made that "no functional neuroimaging research to date has yielded data that can be used to distinguish between competing psychological theories" (Coltheart, 2006, p. 323). Others have criticized fMRI research as being the "new phrenology" (Diener, 2010; Dobbs, 2005; Kennedy, 2005; Uttal, 2001).

In this special section, we invited submissions to tackle the question of how fMRI results have (or have not) changed the way we think about human psychology and the brain. Specifically, we asked authors to describe findings that illustrate how fMRI can or cannot inform cognitive theories. We are happy to have 12 provocative articles in this collection and have also contributed a commentary ourselves.

Several authors discuss fMRI's contributions to the longstanding debate about whether cognitive operations are modular or distributed across domains. Blumstein (2013, this issue) used evidence from studies of language to argue that fMRI provides evidence against notions of a "fixed neural architecture." Cabeza and Moscovitch (2013, this issue) tackled this issue in the domain of memory, and they argue that there are numerous processing components that are recruited in different combinations by memory tasks. In their article, Chiao and Immordino-Yang (2013, this issue) argued that, even in brain regions that appear to be modular, culture shapes processing.

Two articles argue that one domain in which fMRI research has fundamentally changed the way that researchers think is in

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terms of the aging mind (Park & McDonough, 2013, this issue; Reuter-Lorenz, 2013, this issue). fMRI findings indicate that although the aging brain does less of what the young brain does, it also compensates for structural decline. Previous theories of aging, such as speed of processing and resource theory, cannot account for findings showing that older adults show more brain activation in task-relevant regions when performing the same task as younger adults.

Other authors address specific ways in which fMRI data can speak to cognitive theories. For instance, Levy and Wagner (2013, this issue) discuss how the reactivation of memories can be measured using fMRI and how this ability provides a means to tackle questions that have proven difficult to answer with just behavioral data. White and Poldrack (2013, this issue) point out that some of the core debates in cognition are difficult to resolve with behavioral data because similar behavioral predictions can be made by models with different assumptions. They argue that functional neuroimaging provides additional dependent measures that help constrain model testing. Rugg and Thompson-Schill (2013, this issue) discuss some of the inferential challenges faced when employing fMRI and argue that one way in which fMRI data informs cognitive theory is the finding that color knowledge retrieval activates slightly different regions than viewing colors—a finding that is inconsistent with a strong form of embodied cognition theory.

When considering how fMRI contributes to cognitive theory, one question is whether neuroimaging data are typically judged by different criterion than are other types of data. Farah and Hook (2013, this issue) examine the recent claim that fMRI data have a "seductive allure" that makes them more convincing than other types of data; they also come to the conclusion that there is little empirical support for that claim. Another relevant question is when (if ever) fMRI might be able contribute more to cognitive theories than other measures. In their article, Wager and Atlas (2013, this issue) argue that neuroimaging provides a more direct measure of pain experience than do behavioral or autonomic measures, and they review ways in which fMRI findings have informed theories about the nature of placebo effects.

Two articles highlight the importance of considering the two-way street aspect of fMRI and cognitive theories (Coltheart, 2013, this issue; Wixted and Mickes, 2013, this issue). Wixted and Mickes point out that many fMRI studies depend on cognitive theories to interpret their results in such a way that the interpretation of the fMRI results would be entirely different without the corresponding theoretical framework. Coltheart also provides a critique of the other articles in the special section, pointing out the importance of avoiding the "consistency fallacy" in which the data are consistent with a particular theory, but the researchers offer no plausible alternative outcomes of the experiment that are inconsistent with that theory.

Finally, in our closing commentary (Mather, Cacioppo, & Kanwisher, 2013, this issue), we discuss some of the issues raised in this special section and suggest that fMRI can inform cognitive theories by answering at least four different types of questions.

Editor's Note

APS notes with sadness the passing of Edward E. Smith, APS Fellow, APS Board Member (2009–2012), recipient of the William James Fellow Award (1999), and Member of the National Academy of Sciences, who did much to make fMRI a part of the toolbox for psychological science.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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