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On the Relationship Between fMRI and Theories of Cognition: The Arrow Points in Both Directions

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Abstract

In this article, we ask about the contribution of fMRI data to our understanding of theories of cognition and about the contribution of theories of cognition to our understanding of fMRI data. Experiments using fMRI can contribute to our understanding of cognition when they are designed to test the predictions of a particular cognitive theory. Although not all cognitive theories make clear predictions about patterns of activity in the brain fMRI experiments are often well suited to testing the predictions of those that do. However, many fMRI studies that are concerned with cognitive functional neuroanatomy are not designed to test predictions of cognitive theories but are instead designed to investigate the role played by different regions of the brain in cognitive activity. These fMRI studies do not shed light on cognitive theories but instead depend on cognitive theories to interpret the data—an interpretation that is only as valid as the cognitive theory on which it is based. These considerations suggest that the relationship between fMRI and theories of cognition is a two-way street.

Keywords

fMRI, cognition, functional neuroanatomy, dual-process theory

This special section is concerned with the following question: What can brain activity measured by fMRI contribute to our understanding of cognition that goes beyond what can be learned using other methodologies? In this article, we address that question as well as a related question: What can theories of cognition contribute to our understanding of brain activity measured using fMRI that goes beyond what can be learned without the guidance of a cognitive theory? Both questions are worth asking because the arrow between the blood-oxygen-level-dependent (BOLD) signal and theories of cognition points in both directions.

fMRI Data → Cognitive Theory

It seems clear to us that fMRI can inform cognitive theories that make predictions about patterns of activity in the brain. Although not all cognitive theories fall into that category fMRI experiments can be designed to test the predictions of those that do. An example of a cognitive theory that has been informed in this manner by fMRI is the theory of *embodied cognition*, one version of which holds that cognition (e.g., episodic memory) is grounded in perception. This view is captured by the following quote from Wilson (2002):

Mental structures that originally evolved for perception or action appear to be co-opted and run “off-line,”

decoupled from the physical inputs and outputs that were their original purpose, to assist in thinking and knowing... Phenomenologically, recalling an episodic memory has a quality of “reliving,” with all the attendant visual, kinesthetic, and spatial impressions. (p. 633)

The embodied cognition theory of episodic memory predicts that the different perceptual areas of the brain that are active at encoding will be active again at retrieval. In agreement with this prediction, studies using fMRI have found that remembering the visual and auditory aspects of studied items elicits activity in the same regions of the visual and auditory cortex that were activated during the initial perception of those items (e.g., Wheeler, Petersen, & Buckner, 2000; see Gottfried, Smith, Rugg, & Dolan, 2004 for a related fMRI study involving the olfactory cortex). Note that the use of fMRI to test predictions like these involves capitalizing on what is already known about the brain’s perceptual processing regions.

In addition to testing predictions about neural activity using fMRI, other predictions made by the theory of embodied cognition have been tested using behavioral methods (e.g., Brunel,

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Labeye, Lesourd, & Versace, 2009) and lesion methods (see Squire & Wixted, 2011, for a review). However, whereas fMRI experiments can be designed to test predictions about real-time neural activity in the brain, behavioral and lesion studies necessarily test qualitatively different predictions. Thus, in our view, fMRI can uniquely contribute to the understanding of cognition when it is used to test predictions about neural activity that happen to be made by a theory of cognition and that cannot be tested using other methods. The neural predictions can be specific in that they refer to activity in regions of the brain with known function (as in the case of embodied cognition) or they can be more general in that they predict, for example, that Task A and Task B will be associated with activity in different (but unspecified) regions of the brain because the two tasks rely on different cognitive processes. Specific predictions seem more compelling than general ones, but, either way, fMRI can be used to test those predictions. When fMRI is used for that purpose, brain activity is treated as the known quantity (so to speak), and the validity of the cognitive theory is treated as the unknown quantity, with the former being used to shed light on the latter.

Cognitive Theory → fMRI Data

The arrow between fMRI and theories of cognition also points in the other direction. That is, just as fMRI can inform theories of cognition, theories of cognition can inform fMRI. This is particularly true of studies that use fMRI to elucidate the functional neuroanatomy of cognition. Instead of testing the predictions of a cognitive theory, these fMRI studies rely on a cognitive theory to interpret neuroimaging data. In this case, the cognitive theory is treated as the known quantity, and the cognitive function of a particular region of the brain is treated as the unknown quantity. An example can be found in studies concerned with the relationship between the dual-process theory of recognition memory (Atkinson & Juola, 1974; Mandler, 1980) and activity in the medial temporal lobe, particularly the hippocampus. In general, dual-process theory holds that recognition can be based on a context-free sense of familiarity (e.g., when a face is familiar, but nothing else about the person comes to mind) or it can involve recollection (e.g., remembering where and when the familiar individual was last encountered). What role does the hippocampus play in recollection and familiarity? The answer is not yet known, and cognitive theories have been used in conjunction with fMRI—and with particular behavioral methods—to find the answer.

In a typical study of recognition memory, the participant's task is to distinguish "old" items that appeared on a recent list from "new" items that did not. To determine which memory process is supported by the hippocampus when a test item is recognized as being old, researchers can use fMRI to separately measure activity for recollection-based old decisions and activity for familiarity-based old decisions. However, to do so, some other method must first be used to sort recognition

decisions into those that were based on recollection and those that were based on familiarity (and this is where a specific cognitive theory comes into play). One method that is widely used for this purpose is the remember-know procedure. In this procedure, for each test item that is recognized as old, participants are asked to directly indicate whether their decision was based on recollection (by saying "remember") or familiarity (by saying "know"). Studies using this procedure have consistently found that hippocampal activity is elevated for *remember* judgments but not for *know* judgments (e.g., Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Yonelinas, Otten, Shaw, & Rugg, 2005).

What does this finding suggest about the role of the hippocampus in recollection and familiarity? The answer depends on the specific cognitive model that is used to understand the meaning of remember-know judgments and (therefore) the brain activity associated with them. For example, according to the dual-process signal-detection (DPSD) model (Yonelinas, 1994), recollection is a discontinuous threshold process that either occurs for a test item (e.g., the participant remembers thoughts that were prompted by the item back when it was presented on the study list) or does not occur. If it does occur, the participant makes both a recollection-based decision (labeling the item as old) and a *remember* judgment. If it does not occur, and if the test item seems sufficiently familiar, the participant makes both a familiarity-based decision (labeling the item as old) and a *know* judgment. Thus, according to this account, *remember* and *know* judgments accurately distinguish between recollection-based and familiarity-based recognition decisions. If so, then the fact that hippocampal activity is selectively elevated for *remember* judgments provides evidence that the hippocampus selectively supports recollection. However, if the assumptions of the DPSD model are not correct, then the meaning of the measured brain activity would change. To illustrate that point, we next consider what the same neuroimaging results would mean according to a different dual-process model.

Unlike the DPSD model, the continuous dual-process (CDP) model holds that recollection (like familiarity) is a continuous signal-detection process, not a discontinuous threshold process (Wixted, 2007; Wixted & Mickes, 2010). For example, just as the familiarity of a face can vary over a wide range, so too can the clarity (and accuracy) of the recollected details that are associated with that face. In addition, because both processes are continuous variables that can range from weak to strong (and because both provide valid evidence of prior occurrence), the CDP model assumes that recognition decisions are ordinarily based on a combined memory signal consisting of both recollection and familiarity (not on one process or the other, as in the DPSD model).

If the CDP model is correct, then participants face a dilemma when asked to indicate which process—recollection or familiarity—served as the basis of their recognition decision. If, for example, recollection and familiarity both happen to be weak for a particular test item, yet, when combined, the

two processes are strong enough for the item to be declared as old, should the participant say “remember” or “know”? Because there is no obvious solution, the CDP model assumes that participants say “remember” when recollection is strong (whether familiarity is weak or strong) and that they say “know” when recollection is weak (again, whether familiarity is weak or strong). If so, then *remember* judgments would, on average, be based on a stronger memory signal than *know* judgments and should therefore be associated with higher confidence and higher accuracy. Much evidence shows that this is indeed the case (e.g., see Dunn, 2004, and Wixted & Stretch, 2004, for reviews). Thus, the fact that hippocampal activity is selectively elevated for *remember* judgments could simply mean that the memory signal, whether based on recollection or on familiarity, needs to be strong in order to be detected in the hippocampus using fMRI (Squire, Wixted, & Clark, 2007). In agreement with this idea, Smith, Wixted, and Squire (2011) found that when steps are taken to equate confidence and accuracy for *remember* and *know* judgments at a high level (i.e., when recollection and familiarity are similarly strong), hippocampal activity is similarly elevated for both (see also Song, Jeneson, & Squire, 2011).

Which view of the recollection process is correct: the discontinuous threshold view (in the DPSD model) or the continuous signal-detection view (in the CDP model)? Both behavioral studies (e.g., Wais, Mickes, & Wixted, 2008) and neuroimaging studies (e.g., Johnson, McDuff, Rugg, & Norman, 2009) have been designed to test the predictions of these two models. More often than not, the predictions of the continuous view have been supported. However, our main point is not that one model has been supported over the other. Instead, it is that the interpretation of the same activity measured in the hippocampus will change depending on which model is judged to be correct (based on independent tests of their predictions). This issue is not specific to fMRI but also applies to lesion studies, many of which also depend on the DPSD model to justify their conclusions (e.g., Fortin, Wright, & Eichenbaum, 2004; Sauvage, Fortin, Owens, Yonelinas, & Eichenbaum, 2008). In fMRI studies and lesion studies that investigate the functional neuroanatomy of cognition, the validity of the interpretation lives and dies with the validity of the cognitive theory on which it depends.

fMRI Data ↔ Cognitive Theory

To this point, we have tried to illustrate how, sometimes, fMRI data can be used to test the predictions of a cognitive theory (fMRI data → cognitive theory), whereas, at other times, a cognitive theory can be used to interpret fMRI data (cognitive theory → fMRI data). These considerations invite an additional question: Can an fMRI experiment use measured brain activity to test a cognitive theory and then turn around and use that same cognitive theory to interpret the same brain activity? In principle, this might be possible when one has reasonably high confidence in both the validity of the cognitive theory

and the meaning of the measured brain activity (based on independent prior evidence). In that case, a correspondence between the two might further increase confidence in both. However, if either the cognitive theory or the brain activity is treated as an unknown quantity to be elucidated by the experimental investigation, then trying to accomplish both objectives at the same time runs the risk of circular reasoning. Moreover, because it seems deceptively easy to convince oneself after the fact that one’s preferred cognitive theory and one’s preferred interpretation of brain activity both have high a priori validity, the risk of inadvertent circular reasoning under these conditions seems uncomfortably high to us. Thus, although we argue that the arrow between fMRI and theories of cognition points in both directions, we do not mean to suggest that it typically does so at the same time.

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.

References

- Atkinson, R. C., & Juola, J. F. (1974). Search and decision processes in recognition memory. In D. H. Krantz, R. C. Atkinson, & P. Suppes (Eds.), *Contemporary developments in mathematical psychology* (pp. 243–290). San Francisco, CA: Freeman.
- Brunel, L., Labeye, E., Lesourd, M., & Versace, R. (2009). The sensory nature of episodic memory: Sensory priming effects due to memory trace activation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*, 1081–1088.
- Dunn, J. C. (2004). Remember-know: A matter of confidence. *Psychological Review*, *111*, 524–542.
- Eldridge, L. L., Knowlton, B. J., Furmanski, C. S., Bookheimer, S. Y., & Engel, S. A. (2000). Remembering episodes: A selective role for the hippocampus during retrieval. *Nature Neuroscience*, *3*, 1149–1152.
- Fortin, N. J., Wright, S. P., & Eichenbaum, H. (2004). Recollection-like memory retrieval in rats is dependent on the hippocampus. *Nature*, *431*, 188–191.
- Gottfried, J. A., Smith, A. P. R., Rugg, M. D., & Dolan, R. J. (2004). Remembrance of odors past: Human olfactory cortex in cross-modal recognition memory. *Neuron*, *42*, 687–695.
- Johnson, J. D., McDuff, S. G., Rugg, M. D., & Norman, K. A. (2009). Recollection, familiarity, and cortical reinstatement: A multivoxel pattern analysis. *Neuron*, *63*, 697–708.
- Mandler, G. (1980). Recognizing: The judgment of previous occurrence. *Psychological Review*, *87*, 252–271.
- Sauvage, M. M., Fortin, N. J., Owens, C. B., Yonelinas, A. P., & Eichenbaum, H. (2008). Recognition memory: Opposite effects of hippocampal damage on recollection and familiarity. *Nature Neuroscience*, *11*, 16–18.
- Smith, C. N., Wixted, J. T., & Squire, L. R. (2011). The hippocampus supports both recollection and familiarity when memories are strong. *Journal of Neuroscience*, *31*, 15693–15702.
- Song, Z., Jeneson, A., & Squire, L. R. (2011). Medial temporal lobe function and recognition memory: A novel approach to separating

- the contribution of recollection and familiarity. *Journal of Neuroscience*, 2, 16026–16032.
- Squire, L. R., & Wixted, J. T. (2011). The cognitive neuroscience of human memory since H.M. *Annual Review of Neuroscience*, 34, 259–288.
- Squire, L. R., Wixted, J. T., & Clark, R. E. (2007). Recognition memory and the medial temporal lobe: A new perspective. *Nature Reviews Neuroscience*, 8, 872–883.
- Wais, P., Mickes, L., & Wixted, J. T. (2008). Remember/know judgments probe degrees of recognition. *Journal of Cognitive Neuroscience*, 20, 400–405.
- Wheeler, M. E., Petersen, S. E., & Buckner, R. L. (2000). Memory's echo: Vivid remembering activates sensory-specific cortex. *Proceedings of the National Academy of Sciences, USA*, 97, 11125–11129.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, 9, 625–636.
- Wixted, J. T. (2007). Dual-process theory and signal-detection theory of recognition memory. *Psychological Review*, 114, 152–176.
- Wixted, J. T., & Mickes, L. (2010). A continuous dual-process model of remember/know judgments. *Psychological Review*, 117, 1025–1054.
- Wixted, J. T., & Stretch, V. (2004). In defense of the signal detection interpretation of remember/know judgments. *Psychonomic Bulletin & Review*, 11, 616–641.
- Yonelinas, A. P. (1994). Receiver-operating characteristics in recognition memory: Evidence for a dual-process model. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 1341–1354.
- Yonelinas, A. P., Otten, L. J., Shaw, K. N., & Rugg, M. D. (2005). Separating the brain regions involved in recollection and familiarity in recognition memory. *Journal of Neuroscience*, 25, 3002–3008.