THE PLACE OF THE MIND IN CONTEMPORARY NEUROSCIENCE

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INTRODUCTION

In 2007, ten world-renowned neuroscientists, including James Albus, George Bekey, John Holland, Nancy Kanwisher, Jeffrey Krichmar, Mortimer Mishkin, Dharmendra Modha, Marcus Raichle, Gordon Shepherd, and Giulio Tononi proposed "A Decade of the Mind Initiative". The contention was that, despite the successes of the *Decade of the Brain* (DoB), "a fundamental understanding of how the brain gives rise to the mind [was] still lacking" (2007, 1321). The primary aims of the *Decade of the Mind* were "to build on the progress of the recent Decade of the Brain (1990-99)" by focusing on "four broad but intertwined areas" of research, including: healing and protecting, understanding, enriching, and modeling the mind. These four aims were to be the result of "transdisciplinary and multiagency" research spanning "across disparate fields, such as cognitive science, medicine, neuroscience, psychology, mathematics, engineering, and computer science. The proposal for a Decade of the Mind (DoM) initiative prompted many questions (See Spitzer 2008). Here, we focus on three of them:

(1) WHAT IS "MIND"? Proponents of DoM define the term "mind" ostensively, rather than discursively. Examples of mind put forward by them, including "theory of mind," "self," and "higher-order consciousness," indicate a revival of a *cognitive* notion of mind. Here, we define this cognitive notion of mind and demonstrate how the investigative strategies that were part and parcel of cognitive neurobiology during the DoB jettisoned the mind.

(2) WHY REVIVE THE COGNITIVE NOTION OF MIND? The history of science has witnessed several decades of the mind, and a primary aim of the DoB was to advance scientific understanding of the mind past these decades. So, how can moving backwards take neuroscience forward? Here, we make a more cogent case for reviving a cognitive notion of mind in cognitive neurobiology and thereby lend support to the idea that another, but different, DoM is necessary. As we show via an historical analysis of a widely celebrated experimental paradigm, the absence of the cognitive notion of mind, particularly in low-level neuroscience, may serve to obscure the cellular and molecular mechanisms that give rise to cognitive functions.

(3) WHAT SHOULD THE DoM LOOK LIKE? Proponents of DoM argue that this new Decade should be broad in scope and interdisciplinary in nature. However, they offer no positive proposals with respect to what form such interdisciplinary interactions should take. Given the insights revealed from our analysis of the case study, we suggest that the appropriate venue for methodological pluralism is the context of experimentation in which collaborative efforts are aimed at designing and implementing more goal-appropriate investigative strategies. We put forward an example as a basis for describing the form that such methodological pluralism may take.

Before proceeding, we issue two caveats. (1) The criticisms made here do not apply exclusively to cognitive neurobiology, nor are the prescriptions put forward only applicable to low-level neuroscience. The limitations identified for investigative strategies in cognitive neurobiology are not unique to it, and pluralism in the context of experimentation is fundamental for understanding how the brain gives rise to the mind. (2) DoM proponents may have had high-level neuroscience in mind in their proposal. However, work on model organisms takes center stage in the drive to understand the mechanisms that give rise to the human mind, and the prescriptions put forward here are essential if cognitive neurobiology is to play a fundamental role in a DoM initiative.

(1) WHAT IS MIND?

Proponents of DoM indicate that the decade should focus on "those aspects of mind that are uniquely human" (2007, 1321). They mention in particular "Theory of Mind"—which alludes to the fact that we human beings are in the business of ascribing contentful, internal, representational states to ourselves and to others, and we appeal to these states to explain ours' and others' behavior. Beliefs, thoughts, desires, feelings, and memories all qualify as internal mental states, and believing, thinking, desiring, hoping, and remembering all qualify as internal mental faculties or processes. Within this conceptual-explanatory framework, mind is the total set of an organism's internal cognitive states and processes that are causally responsible for, but not identical to, the organism's overt behavior.

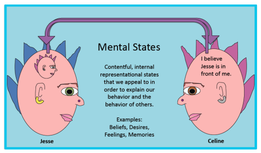

Figure 1. Mental states are understood to be representational. Such representations have been described as pictures or sentences in the head.

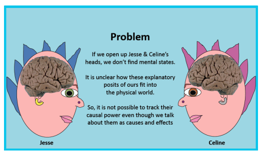

Figure 2. This conceptual position is problematic, because when we crack open a human skull we do not find pictures or sentences in the head. It thus is unclear how these explanatory posits of ours fit into the physical world, nor is it clear how we can study them scientifically. One approach to solving this problem is to abandon talk of mental states and cognitive processes, and to replace them with terms referring to something more tangible. This is, in fact, the investigative strategy in cognitive neurobiology.

Investigative Strategy in Cognitive Neurobiology

Step 1. Replace framework of mental states and mental processes with taxonomy of cognitive functions. [Eliminate]

Step 2. Develop experimental paradigms that specify conditions requisite to produce, measure, and detect cognitive functions when they occur by appeal to observable changes in behavior. [Reduce]

Step 3. Use intervention techniques to identify cellular and molecular mechanisms implicated in the production of behavioral effects. [Intervene]

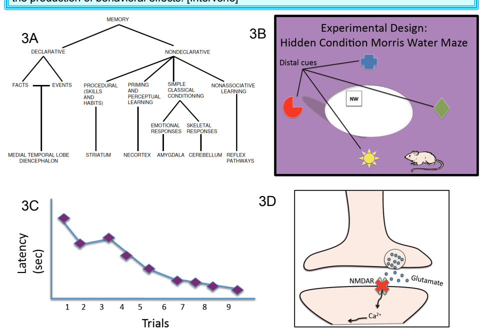

Figure 3A-D. A. Squire's taxonomy of long-term memory functions (adapted from Squire 2004). **B**. Cartoon representation of an experimental paradigm—the Morris water maze. **C.** Representation of behavioral effects (i.e., escape latency over trials in a Morris water maze) that are equated with cognitive functions (e.g., spatial memory, which is a function not explicitly mentioned in 3A). **D.** Cartoon representation of an intervention experiment – blockade of N-methyl-D-aspartate receptors (NMDAR).

(2) WHY REVIVE THE COGNITIVE NOTION OF MIND?

A primary aim of cognitive neurobiology is to identify the cellular and molecular mechanisms of learning and memory. Achieving this aim requires investigative strategies that individuate learning and memory functions, and clearly differentiate them from their causes. However, experimental learning paradigms—the key investigative tools for individuating cognitive functions—are often not adequate for this purpose. Our contention is that increasing the adequacy of experimental learning paradigms requires reviving a cognitive notion of mind.

In support of these claims, it is relevant to consider a representative example of an experimental learning paradigm that has been implemented across numerous cognitive neurobiological laboratories since the 1980's: *the Morris water maze*. Richard Morris published his first results from the water maze in 1981. Of particular interest were his findings from training rats in the hidden condition (*Figure 3B*). The aim of this condition was to determine whether rats could navigate to a hidden target exclusively on the basis of *distal* rather than proximal cues. The psychologist Edward Tolman (1948) had dubbed this form of learning "place learning," but prior to the hidden condition of the water maze, no experimental paradigm was considered reliable for discriminating it from associative forms of learning and memory. Thus, Morris developed the water maze to go after a more complex form of learning than had previously been considered in cognitive neurobiology, and he succeeded in showing that the water maze could be used reliably to produce a robust set of behavioral effects. For both of these reasons, the water maze became an overnight hit in cognitive neurobiology for conducting intervention experiments directed at determining the cellular and molecular mechanisms of "place learning". In fact, from the years 1989 to 2001 alone, over 2,000 papers based on water maze experiments were published (D'Hooge & De Deyn 2001).

However, an historical analysis of the water maze reveals that over a 30-year time span, across the experimental and review literature, the term used to designate the phenomenon under study in the hidden condition oscillated. Candidate terms included *place learning, place navigation, spatial learning, spatial memory, spatial navigation, water maze navigation, and water maze performance*. Such oscillations suggest not only that investigators were unclear what function was under study in the water maze, but also that over a 30-year time span, only slight efforts were directed at achieving clarity. This makes sense given that cognitive neurobiologists are not concerned with "what" rodents trained in the water maze learn or what cognitive functions are involved in the production of the behavioral effects. However, this lack of concern is an impediment to explanatory progress because to discover the mechanisms of a cognitive function, it is necessary to know what the function is.

Given that illuminating the neurobiology of mind ultimately requires an understanding of the cellular and molecular mechanisms that give rise to *high-level cognitive functions*, the water maze moved the field of cognitive neurobiology in the right direction. Yet, one of the reasons the water maze is such an interesting experimental paradigm is that it teaches us lessons about the challenges of the scientific study of cognitive functions over and above the vast array of empirical findings to which it has given rise. Taken in combination, the lessons identified below emphasize the important role that the cognitive notion of mind has to play in developing and implementing investigative strategies that illuminate the neurobiology of mind.

LESSONS ABOUT EXPERIMENTAL LEARNING PARADIGMS GLEANED FROM AN HISTORICAL ANALYSIS OF THE MORRIS WATER MAZE

- When an experimental paradigm is designed, establishing its reliability for individuating a discrete cognitive function requires a consideration of "what" an organism trained in the paradigm is learning. This suggests that investigators must appeal to a cognitive understanding of the mind and take seriously the potential mental states and information processes of the whole intact organism.
- When an experimental paradigm is used to reliably produce a discrete set of behavioral effects, investigators often assume that they have individuated the cognitive function of interest. The search for the systems, synaptic, cellular, and molecular mechanisms productive of those behavioral effects then begins.
- However, cognitive functions are not identical to behavioral effects that result from training an organism in an experimental paradigm. The causes of the changes in behavior likely include many more changes in internal states and processes than are captured by the term designating the cognitive function under study in the paradigm.
- The limitations of an experimental paradigm will be missed precisely because cognitive neurobiologists fail to take an organism's mental states seriously once they have located an experimental paradigm that seems to work. However, the problems that arise from failing to raise questions about "what" an organism is learning, remembering, or doing, and what representational processes are involved are an impediment to individuating discrete explanatory targets and identifying their mechanisms.

(3) WHAT SHOULD THE DoM LOOK LIKE?

Given our understanding of the nature and source of the limitations of current investigative strategies in cognitive neurobiology for illuminating the neurobiology of mind, we advocate for a revival of the cognitive notion of mind in the *experimental context* in cognitive neurobiology, thus filling in an additional detail that is absent from the DoM proposal.

To increase the reliability of experimental paradigms for individuating cognitive functions, practitioners from a variety of different areas of the mind-brain sciences, including but not limited to: cognitive psychologists, cognitive neuroscientists, experts in animal behavior, computational scientists, and molecular and cellular cognitive neurobiologists, should combine forces to develop and implement experimental paradigms in the laboratory. Furthermore, extensive dialogue across research teams and disciplines using the same experimental paradigm should be on-going. Such interdisciplinarity makes good sense for several reasons. (1) In any area of science that uses whole intact organisms, one must be privy to the fact that a variety of different processes—molecular, cellular, synaptic, network, systems, representational, informational, and behavioral—co-occur simultaneously. (2) Different investigators, given different areas of expertise, have different explanatory interests, and they face different obstacles in developing and implementing experiments that work for their distinct explanatory purposes. These explanatory interests and obstacles require a forum within which solutions may be located and the impact of such solutions on the phenomenon under study may be considered. (3) It makes sense for such interdisciplinary dialogue to take place in the context of experimentation rather than the context of explanation. To return to the case study of the Morris water maze: Given that it is unclear what actually is the cognitive function under study, it also is unclear how explanatory claims emanating from different laboratories over the past 30+ years can be fit into a coherent explanatory model. In the interest of providing coherent explanatory models, investigative strategies should be tailored so as to avoid such conundrum.

To provide an example of how revival of the cognitive notion of mind in the experimental context might work in practice and shed new light on the neurobiology of mind, or, in this case, on the cognitive functions involved when animals are trained in the water maze, we end with a brief consideration of a paper Bannerman, Morris, and colleagues, published in *Nature* in 1995. The investigators raised the question of why rats with blocked NMDARs do not exhibit decreases in escape latency during training in the hidden condition nor spatial bias on probe trials. They employed a battery of cognitive tests designed to identify (i) "what" informational processes are disrupted by NMDAR blockade, and (ii) "what" information rats do in fact learn in the context of the water maze paradigm (e.g., that there is a platform, that climbing onto the platform offers refuge, etc). Two of these experiments are described below (Figures 4A, 4B). The study provides instructive evidence of how concern for "what" organisms actually learn in a given paradigm may promote the development of more rigorous testing batteries capable of teasing apart discrete cognitive functions.

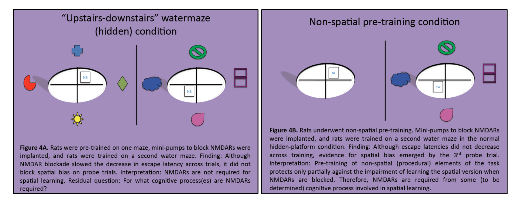

Figure 4A. Rats were pre-trained on one maze, mini-pumps to block NMDARs were implanted, and rats were trained on a second water maze. Finding: Although NMDAR blockade slowed the decrease in escape latency across trials, it did not block spatial bias on probe trials. Interpretation: NMDARs are not required for spatial learning. Residual question: For what cognitive process(es) are NMDARs required?

Figure 4B. Rats underwent non-spatial pre-training. Mini-pumps to block NMDARs were implanted, and rats were trained on a second water maze in the normal hidden-platform condition. Finding: Although escape latencies did not decrease across training, evidence for spatial bias emerged by the 3rd probe trial. Interpretation: Pre-training of non-spatial (procedural) elements of the task protects only partially against the impairment of learning the spatial version when NMDARs are blocked. Therefore, NMDARs are required from some (to be determined) cognitive process involved in spatial learning.

SUMMARY:

(1) Mind consists of those internal representational states and processes that play a causal role in our behaviors while being distinct from those behaviors. Investigative strategies in cognitive neurobiology get rid of this notion of mind.

(2) The most fundamental tools for individuating cognitive functions in cognitive neurobiology—experimental learning paradigms—fail to be successful for this purpose. Ironically, the only solution for ensuring their future success is to revive the cognitive notion of mind.

(3) In order for a new DoM to yield investigative strategies appropriate for illuminating the mechanisms by which brain gives rise to mind, practitioners from different areas of the mind-brain sciences must combine forces in developing and implementing experimental learning paradigms.