Research Statement

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My research investigates the processing mechanisms underlying cognitive development, using converging evidence from behavior, computational modeling, and cognitive neuroscience. I focus on understanding the ubiquity of task-dependent behaviors (simultaneous successes and failures on tasks meant to measure the same cognitive construct) from infancy through childhood, and their implications for the mechanisms underlying cognitive development. My main line of research explores these issues in the context of infants' memory for hidden objects. More recent lines of research explore these issues in the context of children's perseveration and spatial cognition.

Memory for hidden objects

One of the hallmarks of infants' memory for hidden objects is that it depends heavily on how infants are tested. For example, infants can appear wildly precocious in the first few months of life in the violation-of-expectation paradigm, but seem to possess an out-of-sight, out-of-mind mentality for several months longer when tested in searching for hidden objects. Such progressions raise fundamental questions about cognitive development, as revealed by the variety of explanations for such task-dependent behaviors, described below.

Inappropriateness of paradigms demonstrating limitations

Several researchers have argued that paradigms demonstrating infants' limitations are inappropriate measures of memory for hidden objects. My research instead suggests that infants' limitations cannot be discounted in this way, and so remain as important constraints on theorizing about memory development.

For example, several researchers have discounted simple search tasks as measures of infant memory for hidden objects, by arguing that infants fail such tasks due to deficits in means-ends analysis abilities (Baillargeon, Graber, DeVos, & Black, 1990; Diamond, 1991; Willatts, 1990). However, infants' failures to search for hidden toys are not based solely on such deficits (Munakata, McClelland, Johnson, & Siegler, 1997; Shinskey & Munakata, 2000). After infants were trained on various skills (e.g., pulling a towel, pushing a button, rotating a screen), they then used these skills for toy-guided retrieval more often under visible than occluded conditions. The means-ends skills required in the visible and occluded conditions were identical, indicating that infants' failures in the occluded condition were not due simply to means-ends deficits. Other researchers have discounted search tasks by arguing that infants search regardless of whether an object is hidden, indicating that the paradigm does not measure memory for hidden objects (Smith, Thelen, Titzer, & McLin, 1999). However, although infants sometimes search even when a toy has not been hidden, they clearly distinguish such behaviors from those in which they search for a hidden toy (Munakata, 1997).

Thus, infants' limitations with hidden objects cannot be fully explained away as means-ends deficits or as toy-irrelevant, suggesting the operation of other factors in infants' task-dependent behavior. My research explores two such potential factors: the gradedness of representations of hidden objects, and distinct types of representations of hidden objects.

Graded representations

According to the graded representations approach, infants gradually acquire the ability to represent hidden objects. Different tasks require different strengths of underlying representations, and infants' graded representations become stronger with development, allowing infants to demonstrate sensitivity across an increasing number of tasks (Fischer & Bidell, 1991; Haith & Benson, 1997; Munakata, 1998; Munakata et al., 1997). Similar ideas have been put forth to explain the task-dependent behavior of patients with damaged neural systems. I am extending the argument to characterize developing neural systems, and I have tested it through computational models and empirical studies.

In the computational work (Munakata et al., 1997; Munakata, 1998), neural network models were presented with simple visual sequences in which objects moved in front of and occluded other objects. Networks gradually learned to maintain representations of occluded objects to correctly predict their reappearance. The networks exhibited task-dependent behavior, using weak versions of such representations to form predictions about events with occluded objects (which might underlie behavior in violation-of-expectation studies), but requiring stronger representations of hidden objects to reach for them. Further strengthening of representations was required for even more difficult tasks, such as the A-not-B task with multiple hiding locations, in which infants must overcome perseverative tendencies to reach back to previous locations.

My empirical studies have suggested that the familiarity of objects and the degree of interference of occluders play a role in the strength of representations. Specifically, infants' representations of familiar objects may be stronger than those for novel objects, and thus more easily maintained when the toys are occluded. As a result, infants tend to retrieve familiar toys more than novel toys when they are hidden, despite showing the opposite pattern of the typical novelty preference (reaching more for novel toys than familiar ones) when they are visible. This prediction came from my simulation work, which demonstrated that networks could generalize to expect novel objects to continue to exist, but the networks' representations of familiar objects were consistently stronger. In addition, the way in which objects are occluded appears to affect the strength of representations. This work builds on previous research suggesting that infants reach for objects hidden by darkness before they reach for objects behind visible occluders (Hood & Willatts, 1986; Clifton, Rochat, Litovsky, & Perris, 1991). I have hypothesized that this dark-advantage is due to graded representations. A weak representation of an object can withstand global darkening (as a tachistoscopically-presented stimulus can withstand the global clearing of the screen) more readily than the same weak representation can withstand the direct conflicting interference of a visible occluder (as a tachistoscopically-presented stimulus is less readily perceived when followed by the direct conflicting interference of a mask). This framework leads to a counterintuitive prediction: If an object is hidden behind an occluder, infants should reach reach more for the hidden object if the room is then darkened than if the lights are left on, because representations of the occluded object face less interference in the dark. Preliminary results with 6-month-old infants confirm this prediction (Munakata, Spelke, Jonsson, von Hofsten, & O'Reilly, in preparation).

Potentially, gradedness alone could thus account for infants' task-dependent behaviors with hidden objects. However, I believe that a full account of infant behavior will also need to consider the different types of processing mechanisms available to infants, as described next.

Active vs. latent memory

Neurons can retain information in many ways, for example, through patterns of maintained firing, changes in firing thresholds, and changes in connections between neurons. I have proposed that various types of memory can be usefully distinguished as *active* or *latent* (Munakata, in press). Active memories (e.g., sustained neuronal firing) affect ongoing neuronal activity, while latent memories (e.g., changes in thresholds or connections) affect neuronal activity only in subsequent processing. In the neural network framework, active memories take the form of sustained activations of network processing units, and latent memories take the form of changes to connection weights between units.

Task-dependent behaviors may result because tasks differentially tap active and latent representations. Specifically, latent representations may suffice for violation-of-expectation studies, whereas later developing active representations may be required for search tasks (Munakata, in press). I am currently testing this possibility, in both infant-adapted versions of active-latent tasks used with monkeys (Munakata, Guzzetta, Spelke, & Miller, 2000), and in a violation-of-expectation paradigm (Munakata, Jones, Weltman, & Baillargeon, in progress). Further, my simulation work has demonstrated how a competition between active and latent representations may lead infants to search perseveratively in old, incorrect hiding locations, leading to task-dependent behaviors across search tasks with one versus multiple hiding locations (Munakata, 1998). My ongoing behavioral work is testing predictions from the simulation work.

Perseveration

Discrepancies in behavior are sometimes observed even in seemingly identical situations, across different measures. For example, when infants reach perseveratively back to an old hiding location in the A-not-B task, they sometimes nonetheless look correctly at the toy's new location (Piaget, 1954; Diamond, 1985; Hofstadter & Reznick, 1996). Similarly, patients with prefrontal damage and children can perseverate with old rules for sorting cards (e.g., according to the color of the objects on the cards) rather than using a new rule (e.g., based upon the shape of the objects on the cards), while they can nonetheless verbally report the new rule for sorting the cards (Milner, 1963; Zelazo, Frye, & Rapus, 1996). I have proposed that weak representations of hidden objects might support correct looking with perseverative reaching in the A-not-B task, and I have instantiated this idea in a neural network model (Munakata, 1998). Similarly, a weak representation of a new card sorting rule might support certain behaviors but not others. Specifically, a weak representation of a new rule may suffice in non-conflict situations (e.g., when children are simply asked, "Where do trucks go in the shape game?"), but a stronger representation may be needed in the face of conflict (e.g., when children need to sort a red truck, and an earlier rule stipulated that red things went in one tray and the current rule stipulates that trucks go in a different tray). In support of this graded framework, we found that when verbal questions and sorting measures are more closely equated on the conflict dimension (with conflict questions such as "Where do red trucks go in the shape game?"), the dissociation between children's sorting behavior and their verbal answers disappears – they do poorly on both measures (Munakata & Yerys, 2000).

Spatial cognition

Similar issues regarding task-dependent behaviors arise in the domain of spatial cognition. For example, toddlers (and rats) appear to reorient after becoming disoriented using geometric information about the shape of the room, but not featural information such as the color of the walls, even though they can use featural information for other purposes (Hermer & Spelke, 1996). One interpretation of such task-dependent behavior posits that the brain is modular, with a reorienting module encapsulated from featural information (Hermer & Spelke, 1996). We (Stedron, Munakata, & O'Reilly, 2000) tested an alternative possibility based on a view of the hippocampus (a brain structure thought to be involved in spatial cognition) as forming conjunctive representations of multiple cues in the environment (O'Reilly & Rudy, 2000). This perspective suggests that toddlers (and rats) might use featural information to reorient, if that information were presented in a way that was conducive to the formation of conjunctive representations. We found that toddlers were able to use featural information to reorient under certain circumstances, providing some support for this hypothesis.

Future directions and summary

Goals for my future work include: 1) Further specification and computational implementation of active and latent representations and their consequences in violation-of-expectation and simple search paradigms. Although the distinction between active and latent representations may be conveyed verbally relatively readily, it is not always so obvious how their consequences would be implemented. For example, in a violation-of-expectation paradigm, how would reduced neural activity get translated into a familiarity signal that drives behavior? 2) Further specification of influences on and consequences of graded representations. My work has focused on violation-of-expectation and search, two common measures in the assessment of infant cognition, but I believe that there may be hierarchies of behaviors (including verbal report, gesture, and priming) that rely on different strengths of underlying representations. 3) The exploration of potential mechanisms underlying the development of more discrete working memory representations, which may also contribute to observed task-dependent behaviors.

In summary, my research program incorporates an interdisciplinary approach to understanding successes and failures across a range of tasks designed to tap the same cognitive constructs. My work to date has explored four distinct approaches to such task-dependent behaviors (the inappropriateness of certain measures, graded representations, active vs. latent representations, and conjunctive representations). Through further empirical studies with infants and children, computational modeling, and the integration of findings from cognitive neuroscience, I hope to further the understanding of the processing mechanisms underlying cognitive development.