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A Place for Learning in Executive Function Development

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In their *Monograph*, *Dynamic Field Theory of Executive Function: Identifying Early Neurocognitive Markers*, McCraw and colleagues present a theory-driven test of the mechanisms driving the early development of executive function. Their dynamic field model makes an unintuitive prediction that dimensional label learning underlies executive function as measured in the Dimensional Change Card Sort (DCCS) task. The DCCS is a canonical probe of executive function abilities in early childhood that requires children to use one rule to sort cards depicting two-dimensional objects (e.g., red star) by one dimension (e.g., color) and flexibly switch to another dimension (e.g., shape). Three-year-old children typically fail to switch rules, whereas 4-year-old children readily switch rules.

The dynamic field model provides a unique view of executive function because there are no components or control processes as in traditional views (Doebel, 2020; Miyake et al., 2000). Instead, executive function emerges through interactions between label (e.g., 'color') and object (e.g., blue star) representational systems. Executive function is an emergent product of neural dynamics within and between these systems. The model has made numerous empirically confirmed behavioral and neural predictions, and so it is in a good position to guide the current research (Buss & Spencer, 2018).

A critical implication of the dynamic field model is that labels guide attention to dimensions that are used to build object representations, such as 'color' to hues and 'shape' to shapes. A dimensional label is a key piece of being able to sort objects by the dimension and switch rules in the DCCS by guiding attention to new dimension. The main driver of the rapid developmental change in DCCS performance between 3 and 4 years of age is the strength which label representations interact with neural populations that represent objects along dimensions. The implication is that learning about labels for features and dimensions should drive developmental change in executive function.

The data in the *Monograph* showed that the neural systems underlying labeling dimensions predicted DCCS performance. A key result was that stronger neural activation during the label production tasks in left inferior frontal gyrus at 30 months of age was positively associated with performance on the DCCS task at 54 months of age. More activation at 30 months of age suggested that children were showing more developmentally advanced activation in this region. Weaker neural activation during the shape tasks in left middle occipital gyrus at 30 months of age was negatively associated with DCCS performance at 54 months of age. The weaker activation during shape trials could reflect a shift toward higher level processing of shape information. One question is whether this pattern of neural activation at 30 months would also predict executive function on other tasks that involve making decisions about objects consisting of colors and shapes as well as other dimensions.

Traditional theory has not considered the role of learning as a driver of executive function, especially learning to map labels to features and dimensions. The dynamic field model opens the door to re-think executive function as well as how we might promote it. Thus, a clear implication of the research presented in this monograph is that training executive function - which has proven difficult to do - should not be done through training executive processes but instead by providing learning experiences that alter the neural systems that allow such cognitive processes to operate.

The research presented by McCraw and colleagues points to at least two important future directions. The dynamic field model is a formal implementation of a dynamic system with different interactive components that together give rise to executive function. Altering one component can change the entire dynamics of the system. One future direction is testing the role of the other components of the model, such as learning about visual feature dimensions on executive function. We know learning about feature dimensions over the time scale of a laboratory task impacts executive function. It is unknown how much experience children require to alter executive function more permanently (Perone et al., 2019), but computational modeling suggests accumulation of memories for objects over dimensions over a longer time scale is needed to impact real-time neurocognitive dynamics (Perone & Spencer, 2014). A second and perhaps most important future direction is manipulating children's everyday experience with labels for features and dimensions to further understand the learning process in daily life so it can be optimized to improve executive function.

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