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## The Vertically Organized Brain in Theory and Practice

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Deborah Ely Budding, Torrance CA, USA

Dana Chidekel, Tarzana CA, USA

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Leonard F. Koziol · Deborah Ely Budding  
Dana Chidekel

# ADHD as a Model of Brain-Behavior Relationships

Leonard F. Koziol  
Neuropsychological Consultant  
Arlington Heights, IL  
USA

Dana Chidekel  
Private Practice  
Tarzana, CA  
USA

Deborah Ely Budding  
Harbor-UCLA Medical Center  
Torrance, CA  
USA

and

Private Practice  
Manhattan Beach, CA  
USA

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*To Kaitlyn, Caleb, and Allison, and to Letitia  
and Martin Wambach whose unconditional  
support will never be forgotten*

—LFK

*To Dr. Lorraine Gorlick, for her wisdom,  
graciousness, humor, and for the generosity  
with which she shares them*

—DB and DC

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# Abstract

This paper replaces a localizationist view of cognitive, affective, motivational, executive, and sensorimotor functioning with a view that highlights connections among the neocortex, the basal ganglia and the cerebellum, and their interaction within the context of large-scale brain networks and systems that define the brain's "vertical" organization. We use the behaviors or "symptoms" associated with ADHD to illustrate brain-behavior relationships within this interactive context. We emphasize a need to refine the current methods by which ADHD is defined and symptoms are measured. This paper highlights the inadequacy of current DSM behavioral criteria given their faulty foundational assumption that ADHD is a unitary disorder, inability to account for the heterogeneity of symptom presentations, and their associated frequent overlap with other diagnostic conditions. We additionally underscore the limitations of current neuropsychological nomenclature in diagnosis and treatment given its focus on individual symptoms and inability to encompass the groups of heterogeneous symptoms that characterize ADHD in its various presentations. We propose synthesizing the diffuse behavioral criteria for ADHD into foundational, measurable components and integrating these with an understanding of large-scale brain network models and patterns of intrinsic and functional connectivity. We propose replacing current models of ADHD with Research Domain Criteria ("RDoC"), which places the consideration of disorders on a continuum by examining individual symptoms within a similar framework. We discuss the manner in which connections are made among the frontoparietal network, the dorsal and ventral attentional networks, the visual network, the limbic network, the sensorimotor network, and the default network. We discuss the relationship of their function to symptoms of ADHD, and consider how their development might explain how symptoms of ADHD emerge and evolve over time. RDoC is proposed as a means to define and differentiate brain-behavior relationships within an interactive context. It allows individual symptoms within a similar framework to be examined by focusing on the fundamental mechanisms of neurobehavioral pathology that drive them so the function of specific brain networks that contribute to different symptomatic profiles of ADHD can be understood, as readily as can those that contribute to nonpathological behavior. Defining the foundational constructs allows behaviors that are not specified within behavioral criteria for a disorder, but which nevertheless create problems, to be

considered and addressed. False-negative conclusions can be avoided. Using this model will drive the development of more effective symptomatic treatments for all mental disorders, and will inform the development of treatments that can be optimally matched. New neuropsychological tests will be developed that allow critical, foundational components of behavior to be measured. The current—and often deceptive—practice of scaling test findings will be supplanted with an emphasis on pattern analysis and a consideration of pathognomonic signs. In these ways, the RDoC model promises to increase the reliability and clinical utility of neuropsychology by providing the field a more specific approach to diagnosis and treatment.

**Keywords** DSM • Research domain criteria • Brain networks • ADHD • Neuropsychological models and tests