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Commentary

Some challenges for the triadic model for the study of adolescent motivated behavior

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ABSTRACT

Within this special issue, Ernst has provided a comprehensive overview of the triadic neural systems model and its explanatory power for the conceptualization of adolescent development. Within this commentary, we encourage further consideration of several issues as this valuable model is expanded and articulated. These issues include the extent of functional distinctions among the three proposed neural nodes that comprise the triadic framework, the proposed dichotomy between motivation and emotion as linked to approach versus avoidance, the extent to which approach and avoidance can be dissociated on behavioral and neural levels during adolescent development, and how individual difference factors mechanistically interact with broader age-based developmental trends.

Introduction

Ernst has provided a comprehensive overview of the triadic neural systems model and its explanatory power for the conceptualization of adolescent brain and behavioral development. The triadic model is commendable given its mapping onto longstanding theories regarding the expression of individual differences through broad personality traits. Three-factor models have been proposed to account for the breadth of human individual differences in emotion and motivation (Tellegen & Waller, 1992), including the expression of such differences early in development (Rothbart, 2007). Like the triadic model, these models distinguish emotional tendencies that are positively- versus negatively-valenced and propose the existence of a third dimension of regulatory control. The value of recognizing the historical reach and breadth of the triadic framework is that decades of behavioral assessment contribute to the question of how emotional tendencies are defined, measured, and biologically represented. Ernst's goal to provide a general account to explain inter-individual variability from a brain-based perspective links this historical foundation of psychological theory with cutting-edge neuroscience-based methodologies. Here, several issues are mentioned for further consideration as the model is refined and applied to adolescent development. These issues concern (a) the extent of functional distinctions among the three proposed neural nodes that comprise the triadic framework, (b) a descriptive concern regarding the proposed dichotomy between motivation and emotion with respect to approach versus avoidance, (c) the extent to which the proposed approach and avoidance networks can be functionally distinguished in the context of adolescent decision-making, and (d) the need to consider individual difference factors and how these factors mechanistically interact with broader age-based developmental trends.

Functional distinctions among the three proposed primary neural nodes

Current studies of the adolescent brain focus intently on structural brain changes (for instance, declines in cortical gray matter volumes and increases in white matter volumes) as well as functional brain activations during performance on decision-making tasks. This functional anatomical perspective has led to a proposed distinction between adolescent changes in regulatory capacities and changes in motivational substrates of behavior. Ernst's triadic model builds upon this literature, in proposing a critically important distinction between motivational tendencies that are positive and approach-driven versus those that are negative and avoidance-based. Ernst links the regulatory system to prefrontal cortex (PFC) function. As recognized within the literature, this brain region is relatively vast and functionally heterogeneous (Blumenfeld, Nomura, Gratton, & D'Esposito, 2013; Bush, Luu, & Posner, 2000). The approach system is linked to the striatum (particularly the ventral striatal region), which is also relatively expansive, given

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its anatomical connections (Alexander, DeLong, & Strick, 1986; Depue & Collins, 1999; Haber, 2003). The avoidance system is proposed to be centered in the amygdala, which encompasses several nuclear groups that differentially connect to other basal forebrain structures (Alheid, 2003). Two issues are potentially problematic with respect to functional distinctions among nodes within the triadic framework.

First, the extent to which each primary neural node is unique to each behavioral repertoire varies. For instance, there is substantial disagreement regarding whether the amygdala has a limited role in facilitating fear/anxiety responses or whether it more broadly encompasses responses to contextual uncertainty (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005; Sarinopoulos et al., 2010; Zaretsky, Mendelsohn, Mintz, & Hendler, 2010) or stimulus salience regardless of valence (Adolphs, 2010). Recent formulations suggest that it is highly responsive to salient positive as well as negative cues to achieve an adaptive coordination of cortical networks (Pessoa & Adolphs, 2010), and that the amygdala functions primarily as an attentional system, not an evaluative one. Pessoa and Adolphs (2010) argue that it is the pulvinar and its associated network with the prefrontal cortex that provides the evaluative function. Similar concerns are evident with respect to the nucleus accumbens (ventral striatal region) in terms of whether it is a core substrate of reward-seeking behavior as our group has suggested (Depue & Collins, 1999; Luciana & Collins, 2012), or whether, despite an apparent bias in linking positive motivation to action, it plays a broader role in the assignment of stimulus salience and learning about aversive cues (Koob, Wall, & Bloom, 1989). The PFC can also be subdivided into limbic versus cortical subregions with topographical distinctions between areas devoted to reward/approach/positive motivation and those devoted to loss/avoidance/negative motivation (O'Doherty et al., 2003; Rushworth, Noonan, Boorman, Walton, & Behrens, 2011). Accordingly, distinct prefrontal networks may be topographically segregated to facilitate approach versus avoidance-based motivational goals, and maturation may not differentially map onto the modules in a straightforward way.

Viewed in this manner, the regulatory system could be construed as a "servant" versus "master" in that it adaptively structures pursuit of goals within each motivational arm rather than acting in a valence-free manner. While the approach and avoidance modules are not capable on their own to self-regulate (by definition), the regulatory system may end up serving the goals of the other modules and thereby engineer high-level risky behaviors. The drag-racing teenager may consciously pick a deserted street; the adventure-seeker plots carefully to obtain new drugs. Thus, a more sophisticated PFC may lead to more cautious choices, but it may also lead to well-planned risky choices as well. The triadic model implies that the regulatory module only reins in the others, but perhaps it also serves them, depending on the context. The question as to which system serves whose goals may need an answer focusing on context and opportunity in addition to maturation of brain regions.

Future iterations of the triadic model might benefit from a more nuanced network-based framework, akin to Alexander's (1986) corticostriatal loops whereby approach and avoidance motivations are each generated within topographically segregated subcortical regions (potentially within the same neural structures), interconnect with topographically distinct regions of the striatum and thalamus, and are then regulated by medial (approach) versus lateral (avoidance) regions of the prefrontal cortex, the cingulate cortex, and insula. This alternative way of viewing the emotion/regulation interface suggests two major motivational systems, each with a regulatory component. These two systems can lead to considerable individual differences (see below).

From a developmental perspective, the problem then becomes how to integrate data related to structural brain development and functional changes that occur throughout the adolescent period within a framework that is primarily centered around avoidance versus approach motivation. Developmental data suggest, for instance, that regulatory capacities mature in a linear fashion while motivational drives (at least with respect to approach/incentive motivation) peak in adolescence with lower levels observed in childhood and in adulthood. How can these distinct developmental trajectories for regulation and motivation be accommodated if the regulatory arm is inherent to the motivational system? One possibility is that a given motivational system develops such that the regulatory arm of each system is the last intra-network function to mature. Another approach is taken by Steinberg and his colleagues (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Steinberg, 2008, pp. 90–100), who assert that adolescence is a period where the balance of approach and avoidance is tipped due to specific hormonal changes and social contexts. These are factors that would need to be integrated into the triadic model.

An interesting question concerns whether regulation of approach behavior matures at the same rate as regulation over avoidance behavior. Another important consideration is that as a field of inquiry, those of us who study adolescent brain development may have become side-tracked by the wealth of available structural and functional imaging data, limiting consideration of other possible mechanisms that might explain the observed developmental trends. For instance, given the evidence for pronounced overlap in the structures that contribute to approach and avoidance responding, it may be that distinctions between approach and avoidance circuitry are neurochemical rather than structural or anatomical (Fudge & Haber, 2001). Our group has argued that the approach system is dopaminergically-modulated (Depue & Collins, 1999; Wahlstrom, Collins, White, & Luciana, 2010) and that adolescent risk-taking can be attributed to unique molecular features of the dopamine system during that period of the lifespan; others assert that avoidance-based responding is more strongly grounded in GABA-ergic and noradrenergic mechanisms (cf., Ninan, 1999), although this theorizing has not been comprehensively applied to the study of adolescent behavior outside of the clinical realm. A neurochemical framework allows the *same structures* to be strongly implicated in both motivational streams but through dissociable molecular mechanisms. Moreover, an emphasis on neurochemistry within a general framework characterized by multiple levels of analysis allows for the possibility of inverted-U-shaped quadratic patterns of behavioral and neurodevelopmental change (Luciana, Wahlstrom, Collins, & Porter, 2012), a trajectory that cannot otherwise be readily explained through structural refinements or increases in functional connectivity (Cho et al., 2013; Di Martino et al., 2008) that are hypothesized to occur between critical nodes that comprise the triadic framework with advancing development.

Terminology: Are motivation and emotion distinct?

Within the triadic framework, motivation is the term descriptively linked to approach; while "emotion" is the term linked to avoidance. Motivation is described as "the energy that fuels behavior" with the assumption that such energy will be positively valenced. In contrast, Ernst asserts that "Emotion defines internal subjective states that influence the direction of subjects' actions". A more parsimonious organizational scheme might assign distinct subjective emotional states to each system, describe the action tendencies of each system as reflective of approach versus avoidance motivations, and then describe the neural substrates of the subjective (emotional) versus objective (motor) indices of each system. In other words, both approach and avoidance are mediated