RUNNING HEAD: Value-Based Decision-Making in Adolescence

**Self and Identity Development in Adolescence: Neural Evidence and Implications
for a Value-Based Choice Perspective on Motivated Behavior**

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Abstract

Following a key developmental task of childhood, namely building a foundation of self-knowledge in the form of domain-specific self-concepts, adolescents begin to explore their emerging identities in ways that foster both autonomy and connectedness. Neuroimaging studies of self-related processes demonstrate enhanced engagement of ventromedial prefrontal cortex (vmPFC) in adolescence, which may both facilitate and reflect identity development by integrating across multiple sources of value. Drawing from neuroeconomic and social cognitive accounts, we propose that motivated behavior during adolescence can be modeled by a general value-based decision-making process centered around value accumulation in vmPFC. This approach advances models of adolescent neurodevelopment that focus on reward sensitivity and cognitive control by considering more diverse value inputs, including contributions of developing self- and identity-related processes. It also considers adolescent decision-making and behavior from their point of view, rather than primarily taking adults' perspectives on what adolescents should value or how they should behave.

It is well known that adolescents are physically, cognitively, and socioemotionally more advanced than children – but are still prone to behave in ways that are inconsistent with adult values and norms. Adolescents are frequently caricatured as excessive risk-takers, overly self-focused, and highly susceptible to social pressure. Despite general agreement that such a portrayal is an oversimplification, the field is still searching for agreement on an overarching framework to explain why these tendencies are more common in adolescents than either children or adults. One influential approach, the dual-systems model (1), conceptualizes behavior in terms of a competition or conflict between orthogonal developing neural circuits implicated in reward sensitivity and cognitive control, and has made significant headway in describing how functioning of these networks may relate to adolescent risk-taking. Another prominent approach considers contributions of social information processing networks, particularly in an effort to understand the adolescent ‘social reorientation’ that broadens social influences beyond the family to feature an emphasis on peers (2). However, these models collectively do not account for the contributions of identity- and self-related processes, such as core personal values and self-verification, to motivated adolescent behavior. This is a disconcerting gap, as the self represents a key point of intersection between social, cognitive, affective, motivational, and regulatory processes (3).

To address such a gap in the field, we propose adopting a neurobiologically-grounded model of value-based decision-making that can more flexibly accommodate more diverse inputs to behavior, such as self- and identity-related considerations, that are particularly relevant during adolescence and can alternately promote or prevent

risky behavior depending on the context. We first review adolescent self and identity development, linking the behavioral and neural levels. We then outline the general value-based decision-making approach and describe the predictions of this model in the context of adolescent development. Our goal is to produce a more flexible, comprehensive account of adolescent behavior, particularly to the extent that such a model may reveal additional leverage points for translational approaches to improve adolescent outcomes, as well as enhance our understanding of positive and prosocial development in adolescence.

Adolescent Self and Identity Development

The adolescent period is believed to be crucial for many aspects of self and identity development including commitments, personal goals, motivations, and associated psychosocial well-being (4-7). An enhanced priority for autonomy, particularly from parents, develops concurrently with increased relational identity commitments and needs for connectedness with peers (8). Relatedly, self-evaluations become increasingly differentiated and complex across roles and relationships (9). Adolescents also frequently self-report high levels of self-consciousness, and more generally exhibit greater concern with and interest in others' perceptions of the self (10).

Given the theoretical and empirical prominence of changes in aspects of self and identity during adolescence, a growing body of research has begun to examine how this may be expressed at a neural level. Most of this work has examined self-evaluation, typically by asking participants to engage in explicit reflection on the self-descriptiveness of various (often overtly positive or negative) traits and attributes. Like

adults, children and early adolescents engage cortical and subcortical midline structures, in particular vmPFC and adjacent rostral/perigenual anterior cingulate cortex (ACC), more during self-evaluations than when evaluating another social target (10-12; although this pattern can be attenuated with very close others like adolescents' best friends, 13, 14). Even in varied clinical populations of children and adolescents, there is usually activation of vmPFC during self-evaluations relative to most control conditions. Typically-developing youth also seem to engage vmPFC more during self-evaluations in comparison to those with autism spectrum disorder (3), and perhaps those experiencing depression (15, 16).

We are just beginning to learn more about how neural responses elicited by self-evaluation develop *across* adolescence, rather than between childhood or adolescence and adulthood. Two cross-sectional studies focusing on the self-reference effect in memory (wherein information evaluated in relation to the self is remembered better than other information), revealed some relatively continuous developmental trajectories for neural correlates of self-evaluation. The studies found that rostral/perigenual ACC activity increased across ages 7-13 during encoding for self versus mother (17), and increased across ages 13-19 during encoding for self versus distant other (18).

Furthermore, in a longitudinal fMRI study examining children at age 10 and again at age 13, stable responses across timepoints were observed in rostral/perigenual ACC (and VS) during self-evaluations (19). There were also increases over time during evaluations of self (relative to other) in vmPFC, which were most pronounced for self-evaluations made in the social (compared to academic) domain, and adolescents who reported more advancement through pubertal development exhibited the greatest

increases in vmPFC during social self-evaluations. This suggests the interrelated biological and social changes associated with puberty may impact self-referential processes, and potentially the value derived from them.

Although vmPFC and adjacent rostral/perigenual ACC is emphasized in these studies eliciting self-evaluative processes, several other regions of interest appear in these studies. As mentioned above, VS responses have been observed not only during direct self-evaluations (19), but also indirect (“reflected”) social self-evaluations, specifically thinking about what a best friend thinks of your social abilities (14). The involvement of VS during self-evaluation is consistent with the adult literature, which highlights the overlap between self-reference and reward (20) through the assignment of value (21). Additionally, dorsal mPFC (dmPFC) and TPJ are sometimes more active in child and adolescent self-evaluations (10, 11, 18), whereas in adults these regions are typically attuned to mentalizing, social perspective-taking, and evaluations of others. Notably, in adults, functional connectivity between TPJ and vmPFC is positively related to generosity (22), suggesting that TPJ might affect social value by modulating the vmPFC during choices involving the self and others.

In summary, the functional neuroimaging literature demonstrates that explicit self-evaluative processes as well as more indirect forms of social self-evaluation implicated in relational identity robustly engage vmPFC and rostral/perigenual ACC (as part of a broader network including VS, TPJ, and dmPFC) in children and adolescents, often more so than in adults. Early evidence from several studies suggests activity in vmPFC and rostral/perigenual ACC appears to increase from late childhood through middle adolescence, at which point it may either plateau or continue to increase. These

findings are consistent with empirical evidence and theoretical proposals that the adolescent period is critical for identity development (4-7).

Despite the behavioral and neural evidence of the elevated importance of self- and identity-related processes during adolescence, what role these processes may play in neurodevelopmental models of adolescent behavior is unclear. Dual-systems models in particular focus on a mismatch between mature reward-related circuitry and immature cognitive control circuitry (1). However, self/identity does not fit clearly in either category, including because it can alternately or concurrently contribute to reward-seeking and regulatory behavior. For example, a teen with an emerging academic identity is likely to prioritize studying over other activities, though it is unclear whether the effect of such an identity operates through rewarding or regulatory processes (or both, or this distinction may not even be theoretically meaningful for self/identity). In the next section, we present a model that gives self- and identity-related processes a prominent role in determining behavior and provides an explanation for one prominent functional role of the vmPFC during this period.

Value-Based Decision-Making as a Mechanism of Motivated Behaviors in Adolescence

Choosing to attend a party where there may be alcohol and also that cute classmate, against parental wishes and despite math tutoring in the morning, sounds like a failure of self-control – to parents, at least. But from an adolescent's point of view, this decision might be driven by the high subjective value of partying and associated opportunities relative to some alternative, like studying algebra. This should not be surprising; as noted decades ago, adolescents routinely choose to engage in behaviors

of optimal utility for their social microenvironments (23), and utility-maximizing functions with some predictable quirks can provide a good model for decisions such as this one made by humans of many ages (24, 25). In recent years, however, researchers in the decision sciences have made rapid progress characterizing the computational and neural processes involved in value-based decision-making, defined as either-or choices between two or more options with varied attributes (26). A value-based decision-making approach models choice as a dynamic and stochastic integration of diverse gains and costs, which can be clustered in various ways as illustrated in Figure 1. Note that the clustering depicted in Figure 1 is intended to be illustrative; relevant inputs are specific to a given choice and not necessarily confined to one cluster or type (e.g., parental incentives for good grades are both “tangible” and “social” rewards). As described below, this flexibility is a key feature of the model. The gains and costs (represented throughout the brain) act as inputs to the process, and are integrated in vmPFC after being weighted and transformed into a common neural value currency (27).

[Figure 1 here]

From this perspective, one cause of what adults consider to be problematic adolescent behavior may be a normative developmental process that increases the subjective value of a host of self- and identity-relevant inputs relative to childhood. The increased vmPFC activity observed during self-evaluation and relational identity processes in adolescence overlaps spatially with the representation of “value” in the brain (see Figure 2), and thus could reflect greater subjective value afforded to the self and its varied traits, roles, and aspirations. This suggests that identity and other associated self-related processes may increase as a source of value to shape decision-

making and motivated behavior across the course of adolescence; whether this subsequently plateaus, decreases, or continues to increase in adulthood is an open question.

[Figure 2 here]

Value-based choice describes decision-making as the output of a unified value accumulation process centered in the vmPFC. The valuation process integrates signals from regions that represent various relevant choice attributes (e.g., self-related value in the medial PFC, social values in temporal-parietal junction [TPJ], abstract goals such as health in lateral PFC [IPFC]). Two aspects of this value integration process are notable here. First, it is not presumed to be deliberative – in other words, inputs are computationally integrated without relying on explicit reasoning. This model therefore allows for the possibility of rational decision-making independent of formal reason, making it related to but distinct from fuzzy-trace theory, which distinguishes between decision-making processes that are explicitly reasoned and those that are intuitive or gist-based (28).

A second notable aspect of this model is related to a different feature that distinguishes it from alternatives. A value-based decision-making approach explicitly accounts for the diversity of inputs, and recognizes that they may not fall neatly into consistent clusters. For example, “hot” processes such as reward and “cold” ones such as regulation do not necessarily map on to risky and safe behaviors, respectively, and are not necessarily in opposition to one another. As such, observed activations in two or more regions during choice might reflect simultaneous contributions to value integration rather than competition or inhibition (see 29 for a similar point and more integrative

account). Dissolving the one-to-one mapping between process (e.g., hot vs. cold, or reward vs. regulation) and outcome (e.g., risky and safe) averts the thorny issue that can arise when these inputs are funneled through two systems that battle for control over behavior (e.g., 1, 30). The most important distinction in a value-based decision-making model is in fact not between types of processes, but rather between factors that contribute to the value of one behavior or another. For example, what matters in this model is which behavior is promoted by social influence, regardless of whether it is hot or cold. By refocusing on the multiple and diverse reasons behind potential behaviors, this model also suggests new experimental paradigms that manipulate the motivating reasons behind a given behavior, as well as new pathways for intervention from the wide variety of value inputs to choice, rather than just two processes (reward and control) whose functioning is mainly determined by neurodevelopment.

The Identity-Value Model (31) expands on this general value-based decision-making approach by emphasizing the special role of identity for self-regulation and motivated behavior broadly. The central hypothesis of the Identity-Value Model is that an activated identity can increase the value of goal-directed behaviors when they are seen as relevant to the identity. Consider the example from earlier: if the adolescent had a strong academic identity commitment, the identity might boost the chance that he or she skips the party by increasing the value of studying. If, instead, the adolescent wished to fit in better with a peer group that valued late-night socialization, that aspect of his or her identity would increase the value of going to the party.

The model considers identity to be multi-faceted, so different aspects of identity (e.g., academic, social/relational, familial, ethnic/cultural, interest-based, etc.) can each

influence the value of self-regulatory behaviors to the extent that such aspects are salient and perceived as relevant to the decision (see also 32). Key features of identity posited to facilitate its effectiveness in adulthood include stability, positivity, and accessibility. Given that identity development is considered a core task of adolescence (33), and there is significant evidence for exploration of and commitments to key identities during this period (4, 5, 7), we expect that identity-relevant inputs will garner increased value across adolescence, thus impacting self-regulation and other motivated behaviors. Additionally, there might be mutual reinforcement between identities and behaviors: aspects of identity that favor actions that are consistently chosen might come to be more valued, and aspects of identity that favor actions that are consistently not chosen might come to be less valued (e.g., through dissonance or reward devaluation processes (34).

Additional Developmental Considerations for Value-Based Decision-Making

One important consideration is the extent of developmental change in the decision-making processes implicated in this model. Even young children appear to have an early understanding of expected value (EV), and by late childhood use EV at least in gain frames to make decisions in a manner similar to adults, which includes sensitivity to both probability and outcome magnitude (35, 36). These abilities appear to mature by mid-adolescence, particularly for decision-making contexts that are relatively less affective in nature (37). However, adolescents may also exhibit heightened behavioral and neural sensitivity to increasing EV when compared with adults (38), as well as greater tolerance for ambiguity (39), both of which may be adaptive depending

on the context. It is notable that these studies utilize a limited range of simple value inputs, and future research should attempt to remedy this by expanding to more complex stimuli (e.g., identity-relevant ones) and ecologically valid decision-making contexts. Additionally, despite this support for the general value-based choice model in adolescence, no study of adolescents has yet manipulated the self-relevance of response options to directly test the contribution of identity-based values to adolescent decision-making processes.

There are other components of the value-based decision-making model (detailed further in 27) that may be affected by development. These include choice “anomalies,” such as temporal discounting and the endowment effect, whereby choice deviates from strict rationality in predictable ways. For example, we expect that known developmental effects in intertemporal choice patterns, such as the rapid decrease in delay discounting from early to middle adolescence, represent additional important constraints (and opportunities for intervention) shaping the value-based decision-making process in adolescence differently than in adulthood (40, 41).

Finally, in addition to the possibility that identity-based and other self-related values become increasingly important to adolescent decision-making, particular social motivations like social status and peer or romantic relationships are expected to surge in relevance as well (2, 42, 43). One set of social-cognitive weights on the decision-making process undoubtedly includes perceptions of what others value – especially peers (e.g., friends, romantic partners, members of social ingroups, members of high status social groups) but also other respected individuals (e.g., family members, teachers). An interesting consideration is the interaction between this and identity

development processes. Specifically, these social perceptions provide a source of information about the self (10, 14) and help to shape adolescents' personal values and identity, which subsequently or concurrently are perceived as increasingly significant in the decision-making process.

Concluding Thoughts

Although adolescent behavior is indeed influenced by normative developmental changes in sensitivity to rewards and social context, the self also evolves to become an important source of value and intrinsic motivation. With increasing development and exploration of identity commitments and autonomy, it can be harnessed for self-regulation and other motivated behavior. This creates a space for intervening to improve outcomes in maladaptive cases of adolescent decision-making that is not available within existing models, since such behaviors are portrayed to result in significant part from expected maturational trajectories of frontostriatal circuitry. In particular, identity-based and other self-related values may be dramatically more modifiable targets, either in terms of the content of identity within various contexts or the relative salience of different aspects of identity that might promote different behaviors (e.g., athletic vs. academic). For example, in the juvenile justice system there is growing interest in fostering positive and prosocial identities as a pathway to desistance (44).

At a broader level, a neurodevelopmentally informed value-based decision-making approach may provide not only a more comprehensive theory but also an opportunity to reframe our thinking about adolescent choices and actions. If a value-based decision-making account is correct, choices that adults perceive to be bad

decisions are instead rational from the adolescent point of view, at least inasmuch as they represent choices with the highest subjective value. There is nothing broken about the adolescent decision-making system; adolescents (individually and as a group) may simply consider different value attributes and assign different weights to them than do adults. By taking the normative adult perspective we may be artificially constraining the sources of value we consider as relevant to adolescent decision-making, thereby restricting what we can learn about how and why adolescent priorities are different from those of adults, and limiting our ability to develop ways to encourage positive outcomes. Given that developing positive personal and social identities (4-7, 9), as well as fostering a balance between autonomy and connectedness are core tasks of adolescence (8, 33), these self-related and social sources of value are well worth prioritizing in future empirical investigations and translational efforts.

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Figure Legends

Figure 1. *Value-based decision-making in adolescence.* Solid arrows from value inputs represent positive value, dashed arrows represent negative value, and line thickness indicates relative weight. Sample tangible inputs (primary or secondary gains and costs) are tagged in orange; sample social inputs are tagged in blue; and sample self/identity related inputs are tagged in purple. Note that value inputs can be cross-tagged.

Adapted from (27).

Figure 2. *Developmental self-evaluation studies and value.* The binarized forward inference map calculated by Neurosynth's automated meta-analysis tool for the term "value" is shown in red. Individual spheres (diameter 10mm) from neurotypical developmental self-evaluation studies are overlaid; blue represents main effects in child or adolescent samples for self > other, and green represents increases with age. Slices are displayed at $x = -6$, $y = 44$, $z = -10$. To be included in this figure, studies needed to report results in mPFC within developmental samples from a contrast representing self > other, and/or changes in this contrast with age. See <http://osf.io/64qh5> for a full list of studies and coordinates included.

Figures

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