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Review

The dual systems model: Review, reappraisal, and reaffirmation

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ABSTRACT

According to the dual systems perspective, risk taking peaks during adolescence because activation of an early-maturing socioemotional-incentive processing system amplifies adolescents' affinity for exciting, pleasurable, and novel activities at a time when a still immature cognitive control system is not yet strong enough to consistently restrain potentially hazardous impulses. We review evidence from both the psychological and neuroimaging literatures that has emerged since 2008, when this perspective was originally articulated. Although there are occasional exceptions to the general trends, studies show that, as predicted, psychological and neural manifestations of reward sensitivity increase between childhood and adolescence, peak sometime during the late teen years, and decline thereafter, whereas psychological and neural reflections of better cognitive control increase gradually and linearly throughout adolescence and into the early 20s. While some forms of real-world risky behavior peak at a later age than predicted, this likely reflects differential opportunities for risk-taking in late adolescence and young adulthood, rather than neurobiological differences that make this age group more reckless. Although it is admittedly an oversimplification, as a heuristic device, the dual systems model provides a far more accurate account of adolescent risk taking than prior models that have attributed adolescent recklessness to cognitive deficiencies.

Contents

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Social scientists and casual observers of human development have long noted that the transitional period between childhood and adulthood is a time of heightened risk-taking. Indeed, despite the relative absence of illness and disease during this period, rates of morbidity and mortality increase substantially in adolescence, largely due to risk taking. The question of why adolescents seem predisposed toward recklessness is age-old; however, work in the field of developmental psychology, and more recently, developmental neuroscience, has provided new insights into the phenomenon.

For many years psychologists had attempted to explain adolescent recklessness as a consequence of cognitive deficiencies in young people's thinking, including irrationality, poor information processing, and ignorance about risk. As we have noted in previous publications (e.g., Steinberg, 2008), these accounts have been largely undermined by available evidence. Generally speaking, by age 15 or so, adolescents perform as well as adults on tasks measuring logical reasoning, information processing, and risk perception.

1. The emergence of dual systems models

About a decade ago, the budding field of developmental cognitive neuroscience began to provide insight into how patterns of brain development might explain aspects of adolescent decision-making (see, e.g. Dahl, 2004). In 2008, our lab at Temple University (Steinberg, 2008; Steinberg et al., 2008) and Casey's lab at Cornell (Casey et al., 2008) simultaneously proposed similar variations of a "dual systems" account of adolescent decision-making. This perspective attributes adolescents' vulnerability to risky, often reckless, behavior in part to the divergent developmental courses of two brain systems: one (localized in the striatum, as well as the medial and orbital prefrontal cortices) that increases motivation to pursue rewards and one (encompassing the lateral prefrontal, lateral parietal, and anterior cingulate cortices) that restrains imprudent impulses (see e.g., Casey et al., 2008; Duckworth and Steinberg, 2015; Evans and Stanovich, 2013; Luna and Wright, 2016; Metcalfe and Mischel, 1999; Steinberg, 2008). Specifically, it proposes that risk-taking behaviors peak during adolescence because activation of an early-maturing incentive-processing system (the "socioemotional system") amplifies adolescents' affinity for exciting, novel, and risky activities, while a countervailing, but slower to mature, "cognitive control" system is not yet far enough along in its development to consistently restrain potentially hazardous impulses.

Several variations on this dual systems model have been proposed. The version that guides our work (Steinberg, 2008) is very similar to that proposed by Casey et al. (2008). Both conceive of a slowly developing cognitive control system, which continues to mature through late adolescence. However, whereas we propose that the socioemotional system follows an inverted-U shaped developmental course, such that responsiveness to reward increases in early adolescence and declines in early adulthood, Casey et al. have portrayed the socioemotional system as increasing in arousability until mid-adolescence, at which point it reaches a plateau, remaining at this level into adulthood. Furthermore, our version of the dual systems model posits that the decline in socioemotional arousability occurs independently of the development of the control system, whereas Casey et al.'s model proposes that the strengthening of the cognitive control system causes the socioemotional system to become less arousable. More recently, Luna and Wright (2016) have proposed another variation on the dual systems model (the "driven dual systems" model), which, like our model, hypothesizes an inverted-U shaped trajectory of socioemotional arousability, but, unlike our model, hypothesizes a trajectory of cognitive control that plateaus in mid-adolescence rather than continuing to increase into the 20s, as suggested by us and by Casey et al. In a similar vein, Luciana and Collins (2012) endorse a model that emphasizes the role of a hyperactive socioemotional system ("subcortical limbic-striatal systems" in their terminology) undermining the regulatory ability of the cognitive control system (the "prefrontal executive system") resulting in greater risk-taking during adolescence. Like Luna and Wright, Luciana and Collins argue that the development of cognitive control is complete by mid-adolescence, as evidenced by adolescents' adult-like performance on non-affective measures of cognitive capacity. Fig. 1 illustrates the similarities and differences between these versions of the dual systems model.

Another perspective, Ernst's (2014) triadic model, expands on the dual systems concept by hypothesizing that a third brain system—one responsible for emotional intensity and avoidance, anchored in the amygdala—is also important for understanding the developmental differences in "motivated behavior." With respect to the type of reward-seeking risky behavior that the dual systems models seek to explain, Ernst (2014) speculates that this emotion/avoidance system may serve to boost impulsive decisions in adolescence by amplifying the perceived cost of delay. She also proposes that this system may become hypoactive—dampening avoidance impulses—in the face of a potential reward that activates the socioemotional system. While this model is intuitively appealing, there is not much evidence to date indicating that the emotion/avoidance system and its developmental trajectory help to explain heightened levels of risk taking in adolescence. Also, the role of the amygdala in decision-making is not yet clear (see e.g., Somerville et al., 2014). Therefore, our review does not address this third hypothesized system.

2. The current article

In this article, we review evidence from both the behavioral and neuroimaging literatures that has emerged since the dual systems model was originally articulated in 2008. In particular, we consider the degree to which extant research findings support, extend, modify, and challenge the theory. We focus our discussion on three main propositions of the model: (1) that reward sensitivity peaks in adolescence; (2) that cognitive control increases linearly during this period; and (3) that heightened risk-taking during adolescence is the product of heightened reward-seeking and relatively weaker cognitive control.

We begin by addressing a recent criticism of the basic premise that middle adolescence is an especially intensified period of risky behavior. We then examine evidence regarding the trajectory of sensation seeking across development, the reward processing circuitry that might underlie developmental changes in sensation-seeking behavior, and the extent to which heightened sensation seeking and reward sensitivity are related to pubertal development. Next, we survey evidence on the developmental trajectory of the ability to control impulsive behavior through self-regulatory processes, and on the maturation of the brain's cognitive control network, which is proposed to undergird this ability. Finally, we consider evidence concerning the interaction of the two proposed systems during risky decision making, identify several unresolved issues, and offer some recommendations for how they might be addressed in future research.

In examining how recent evidence informs the dual systems model, we are cognizant of critiques of this viewpoint, including contentions that the model inadequately accounts for studies that do not find adolescents to be particularly sensitive to reward (Pfeifer and Allen, 2012; but see Strang et al., 2013 for a response to this critique), that cognitive control does not unequivocally improve during adolescence (Crone and Dahl, 2012), and that