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Review

Impact of socio-emotional context, brain development, and pubertal maturation on adolescent risk-taking

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ABSTRACT

This article is part of a Special Issue "Puberty and Adolescence".

While there is little doubt that risk-taking is generally more prevalent during adolescence than before or after, the underlying causes of this pattern of age differences have long been investigated and debated. One longstanding popular notion is the belief that risky and reckless behavior in adolescence is tied to the hormonal changes of puberty. However, the interactions between pubertal maturation and adolescent decision making remain largely understudied. In the current review, we discuss changes in decision making during adolescence, focusing on the asynchronous development of the affective, reward-focused processing system and the deliberative, reasoned processing system. As discussed, differential maturation in the structure and function of brain systems associated with these systems leaves adolescents particularly vulnerable to socio-emotional influences and risk-taking behaviors. We argue that this asynchrony may be partially linked to pubertal influences on development and specifically on the maturation of the affective, reward-focused processing system.

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As the roaring of the waves precedes the tempest, so the murmur of rising passions announces the tumultuous change. . . . Keep your hand upon the helm, or all is lost (Rousseau, 1762/1911, pp. 172–173).

The notion that the hormonal changes of puberty compromise individuals' rational decision making has a long and sturdy history in writings on adolescence, as Rousseau's warning to parents in his 18th century book *Emile*, one of the first treatises on this stage of development, aptly illustrates. For as long as individuals have been writing about teenagers, they have described them as victims of their own raging hormones. Even today, popular advice books for parents of teenagers, with titles like *Yes, Your Teen is Crazy* (Bradley, 2002), continue to portray adolescents' judgment as hopelessly compromised by the disruptive impact of this period's endocrinology.

One likely reason for the persistence of this idea is that rates of most forms of risky and reckless behavior do, in fact, increase between preadolescence and middle or late adolescence and decline in early adulthood. This is the case with regard to a wide range of behaviors that are partially or wholly attributable to risk taking, including violent and non-violent crime (Piquero, 2007), driving crashes and fatalities (Twisk and Stacey, 2007), unprotected sex (CDC, 2012), attempted suicide (Mościcki, 2001), accidental drownings (CDC, 2011), self-inflicted injuries (Kessler et al., 1999), and initial experimentation with tobacco, alcohol, and illicit drugs (SAMHSA, 2012). Indeed, the leading causes of morbidity and mortality during adolescence are behavioral.

Given the longstanding popular notion that risky and reckless behavior in adolescence is tied to the hormonal changes of puberty, there is a surprising absence of research on the direct links between

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pubertal maturation and adolescent risk taking (or adolescent decision making, more generally), with the possible exception of research on the behavioral consequences of early or late pubertal maturation (for a recent review, see Negriff and Susman, 2011). Instead, studies have generally examined the relationship between pubertal development and changes in decision making by way of indirect correlational studies, which often confound the direct influences of puberty with other factors such as chronological age, aspects of emotional, cognitive, and social development that are independent of puberty, and variations in contexts in which decisions are made.

In other words, although the fact that risk taking increases during the first part of adolescence is consistent with the idea that puberty plays a role in the process, some changes in risk taking and decision making may coincide with puberty, but be independent of it. For example, normative changes in the context in which individuals live during adolescence may contribute to changes in decision making, and to the increase in risk taking in particular. Because peers take on increased importance at this time, adolescents may begin to engage in certain types of risky behavior in order to demonstrate or facilitate their affiliation with others. Similarly, because there is typically a weakening of parental supervision as individuals transition from childhood into adolescence, increases in risky behavior may be the consequence of greater opportunity to engage in behaviors that at earlier periods of development had been deterred by the presence of parents.

Our purpose in this article is to examine research on the relation between puberty and risk taking in adolescence (and, especially, on aspects of decision making that are relevant to our understanding of risky behavior), and to begin sorting out the developmental processes that are likely to be puberty-dependent and puberty-independent. Because there are so few studies of the direct role of pubertal development in adolescent decision making about risk, we approach the issue indirectly and speculatively, describing how decision making changes around the time of puberty, discussing the links between changes in decision making and changes in brain structure and function during adolescence, and, where there is evidence, noting what is known about the ties between the hormonal changes of puberty and changes in brain and behavior and, perhaps more importantly, what is not.

Before proceeding with this discussion, a few caveats are in order. First, because there are relatively few studies that examine the direct links between puberty and decision making, or risky decision making in particular, it is hard to draw generalizations from this literature. Our assessment of this body of work is that there are sufficient grounds to advance several informed hypotheses, but not yet grounds to draw firm conclusions. The main aim of this article is not to summarize research on puberty and risky decision making, but to stimulate more of it by providing readers with some suggestions for further study.

Second, one reason for many apparent inconsistencies and contradictions in this literature is the wide diversity of constructs used and the methods and measures employed. Many different terms are used for constructs that are similar but not exactly identical; for example, sensation-seeking, reward-seeking, novelty-seeking, and thrill-seeking have all been used to refer to the inclination to engage in potentially arousing experiences, although not all of the experiences that are often discussed with respect to sensation seeking are novel (e.g., riding on a roller coaster that one has ridden previously) or thrilling (e.g., drinking alcohol), and some may not even be immediately rewarding (e.g., self-inflicted cutting). Moreover, researchers use a wide variety of measures and methods to assess the same constructs, some of which may not measure what they purport to measure, or may inadvertently measure multiple phenomena. For instance, although sensation-seeking and impulsivity are entirely different constructs (e.g., one can pursue a novel or exciting goal with a great degree of planning and self-control), self-report measures of these constructs often contain overlapping items (see Steinberg et al., 2008). For example, the Zuckerman Sensation-Seeking Scale (Zuckerman et al., 1978), perhaps the most widely used self-report measure of sensation seeking, includes items such as "I often do things on impulse," "I usually think about what I am going to do before doing it," and "I am an impulsive person." As a consequence, studies that link a specific construct to age or puberty might produce results that differ from those that examine a related, but not identical, construct. Apparent inconsistencies in findings may be due to inconsistencies in the constructs and operationalizations employed. In addition, the way that pubertal maturation is measured, defined, and demarcated can vary drastically from one study to another. Commonly used measures of puberty include self-reports, clinician observations, and hormonal assays, which have been scored both continuously and categorically, and there have been many discussions about the validity and reliability of various measures, as well as their intercorrelations (for review see Dorn and Biro, 2011).

Third, studies in this area of inquiry often define the outcome variables of interest at different levels of analysis. For purposes of this paper, we view "reward sensitivity" and "cognitive control" as neurobiological constructs that are measured in studies of brain structure and/or function (see Fig. 1). These neurobiological phenomena have psychological manifestations (in our terminology, "sensation seeking" and "self-regulation") that are measured by assessing psychological states or traits through the subjective reports of individuals or their evaluators. For heuristic purposes, we use "sensation seeking" as an overarching label for a number of interrelated constructs that refer to the inclination to "seek varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal, and financial risks for the sake of such experiences" (Zuckerman, 1994, p. 26). Recruitment of brain regions and systems implicated in reward-processing (e.g., ventral striatum, orbitofrontal cortex) has been linked to measures of sensation seeking in humans and animals (Abler et al., 2006; Leyton et al., 2002; Lind et al., 2005).

In a similar vein, we use the label "self-regulation" to refer to a group of interrelated but distinguishable constructs that refer to the capacity to deliberately modulate one's thoughts, feelings, or actions in the pursuit of planned goals; among these constructs are impulse control, response inhibition, emotion regulation, and attentional control. Aspects of self-control have been linked to the functioning of brain regions and systems that subserve cognitive control (e.g., lateral prefronal, lateral parietal, and anterior cingulate cortices).

Variations in sensation seeking and self-regulation, in turn, are associated with variations in behaviors, including risk-taking, which can be measured through objective reports or observations. In our model, risk-taking is a subset of many aspects of decision making that share some, but not all, characteristics in common. Furthermore, as the Figure indicates, all decision making takes place within a broader context that encourages and enables some acts but discourages and prohibits others.

Fourth, the links among these neurobiological, psychological, and behavioral constructs are imperfect, because they are moderated by other, often unmeasured, individual and contextual variables. An individual might be highly reward-sensitive but might have other qualities that lead him or her to inhibit the pursuit of arousing stimuli (e.g., high trait anxiety). Someone may be high in self-regulation, but in the face of strong peer pressure, might behave more recklessly than one would have predicted on the sole basis of a score on a measure of impulse control. An individual whose neurobiological and psychological inclinations would point to binge drinking will be more likely to drink to intoxication in a context in which alcohol is easily available than in one in which it is much harder to obtain.

Not surprisingly, then, the relation between puberty and reward-sensitivity or cognitive control may be different from that between puberty and sensation seeking or self-regulation, and the relation between puberty and sensation seeking or self-regulation, may not be the same as that between puberty and actual risk taking. In particular, the sharpest increase in risky behavior may occur later in development than the peak in pubertal change or the peak in sensation seeking, because real-world risk taking is influenced by a wide constellation of factors