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Exciting fear in adolescence: Does pubertal development alter threat processing?

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ABSTRACT

Adolescent development encompasses an ostensible paradox in threat processing. Risk taking increases dramatically after the onset of puberty, contributing to a 200% increase in mortality. Yet, pubertal maturation is associated with *increased* reactivity in threat-avoidance systems. In the first part of this paper we propose a heuristic model of adolescent affective development that may help to reconcile aspects of this paradox, which focuses on hypothesized pubertal increases in the capacity to experience (some) fear-evoking experiences as an exciting thrill. In the second part of this paper, we test key features of this model by examining brain activation to threat cues in a longitudinal study that disentangled pubertal and age effects. Pubertal increases in testosterone predicted increased activation to threat cues, not only in regions associated with threat avoidance (i.e., amygdala), but also regions associated with reward pursuit (i.e., nucleus accumbens). These findings are consistent with our hypothesis that puberty is associated with a maturational shift toward more complex processing of threat cues—which may contribute to adolescent tendencies to explore and enjoy some types of risky experiences.

> Strange to say, if you do not stamp yourself with the words exhilarated or terrified, those two things [can] feel exactly the same in a body.
>
> Barbara Kingsolver

1. Introduction

Fear is a fundamentally aversive sensation—an affective state that not only increases vigilance to possible danger, but also initiates action tendencies to seek safety and a natural desire to 'turn off' the distressing alarm signal. Yet, a surge of fear can sometimes contribute to a *desirable* sensation, if experienced as exhilarating or thrilling. Understanding this capacity to experience some frightening situations—like a roller coaster, horror movie, or risky sex—as a source of enjoyable thrills, may provide important insights into a paradox in the development of threat processing during adolescence. That is, risk taking and dangerous behaviors increase dramatically during adolescence despite the fact that reactivity in threat-avoidance systems *increases* during pubertal maturation (e.g., Guyer et al., 2008; Moore et al., 2012; Quevedo et al., 2009).

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Compared to children or adults, adolescents are more likely to binge drink, smoke cigarettes, have casual sex, engage in violent and other criminal behavior, and be involved in fatal or serious automobile crashes (largely attributable to risky driving/driving under the influence of alcohol, Steinberg, 2008). There is a growing consensus that the long-term consequences of these preventable risk behaviors represent a leading threat—to the immediate *and* long-term health—of youth in our nation (Ozer and Irwin, 2009).

Intense interest in the causes of these high-impact problems in youth has led to a number of neurobehavioral theories (e.g., Ernst et al., 2006; Steinberg, 2007) that have focused on the interaction of three systems (or a subset): (1) a motivational system involved in pursuing reward (sometimes termed approach/appetitive motivation), (2) a motivational system involved in escaping threat (sometimes termed avoidance/defensive motivation), and (3) a self-regulatory system involved in inhibiting inappropriate behavior (sometimes termed cognitive control). These theories generally posit a developmental increase in reward reactivity, a decrease in threat reactivity, and relatively ineffective or inconsistent self-regulation.

The proposed increase in reward reactivity during adolescence is thought to promote engagement in risky behavior, because adolescents tend to be more susceptible to the potential positive outcomes of these behaviors. Supporting this hypothesis, both behavioral and neuroscience research has demonstrated that reward processing increases during this maturational period (Galvan, 2010). For example, monetary reward in adolescence leads to enhanced anti-saccade performance (Hardin et al., 2009) and increased reactivity in brain regions commonly associated with reward (e.g., nucleus accumbens, Galvan et al., 2006).

Research focusing on the role of deficient self-regulation as a source of adolescent risk taking has yielded a more nuanced understanding of adolescent development of cognitive control (Crone and Dahl, 2012; Pfiefer and Allen, 2012). An extensive set of studies indicates that adolescent risk behavior is *not* attributable to: (a) cognitive deficits in decision making or (b) an adolescent 'sense of invulnerability'. Decades of research have failed to demonstrate any substantive *cognitive* deficits in risk assessment in adolescents relative to adults (Reyna and Farley, 2006). For example, the ability to estimate the likelihood and severity of adverse outcomes is comparable to adults by the mid-teens—at precisely the age when real-life dangerous behaviors *increase* enormously. Similarly, the myth that adolescents believe they are personally invulnerable to these dangers has been strongly refuted by data showing that adolescents tend to *over-estimate* the chances that they will suffer dire consequences from risky behaviors (Reyna and Farley, 2006).

Finally, some theories aimed at understanding risk-taking increases in adolescence focused on possible changes in fear and threat processing, such as a decrease in reactivity of the threat-avoidance that might cause adolescents to ignore or undervalue the potential negative outcomes of their decisions had been considered (e.g., Ernst et al., 2006). Contrary to theory, however, both behavioral and neuroscience data show that adolescent development is not associated with fearlessness, but rather *increased* activity in threat-avoidance systems. For example, pubertal development has been associated with increased fear-potentiated startle (Quevedo et al., 2009) and adolescents demonstrate increased reactivity in brain regions commonly associated with threat (e.g., amygdala, Guyer et al., 2008; Moore et al., 2012). At first glance, evidence of increased activity in the threat-avoidance system leads to an apparent contradiction. If adolescents are more reactive to potential negative outcomes why do they engage in more risk taking?

1.1. A heuristic model

To help resolve this paradox, we propose a novel heuristic model of adolescent affective development that focuses, in part, on maturational shifts in the tendency to experience a potential threat in more complex ways—including an enhanced capacity to experience these affective signals of threat and arousal (activated in a frightening situation) as part of a more ambiguous and potentially exhilarating sensation. As mentioned above, the affective signal of fear is *usually* aversive; however, a frightening situation can sometimes create an affective signal that is experienced as a *desirable* feeling of thrill. Moreover, courageous behavior in the face of danger can occur amidst intense fear, and an increased capacity to experience some of these situations as thrilling could facilitate *learning* to act boldly despite threat signals indicating potential harm. Thus, a developmental shift in the capacity to experience (and to *learn* to experience) some high-intensity fears as enjoyable 'thrills' could enhance the ability to overcome fears and demonstrate brave behavior. This proposed maturational shift (toward more complex and ambiguous appraisal of threat as 'thrills') may contribute not only to healthy versions of learning to be brave (or even heroic) in some extremely frightening situations, but also could contribute to the developmental increases in dangerous and unhealthy versions of thrill seeking and 'enjoyable' risk taking observed in adolescence.

This capacity to enjoy high-intensity fears may be part of a broader developmental increase in sensation seeking. As we (Dahl, 2004; Forbes and Dahl, 2010) and others (Steinberg, 2008) have reviewed, the onset of adolescence is associated with an increased tendency to seek novel, high-arousal sensations, and this appears to be directly linked to pubertal maturation (though, see Vetter-O'Hagen and Spear, 2012, for evidence in rodents that novelty seeking is related to age not puberty). There is extensive evidence showing that pubertal increases in sensation seeking predict real-world risky behavior, such as smoking and sexual risk taking (Martin et al., 2002). More generally, we (Crone and Dahl, 2012) have hypothesized that pubertal increases in sensation seeking, along with a larger set of socio-affective changes, promote healthy exploration and learning in adolescence as well as increases in potentially dangerous behavior. Accordingly, we propose that pubertal increases in sensation seeking underpin an enhanced capacity to 'like' (and thus, approach) some types of high-arousal, novel, and uncertain situations—even when these