Title
Brain and Behavior Correlates of Risk Taking in Pediatric Anxiety Disorders

Journal
Biological Psychiatry, 89(7)

ISSN
0006-3223

Authors
Peris, Tara S
Galván, Adriana

Publication Date
2021-04-01

DOI
10.1016/j.biopsych.2020.11.003

Peer reviewed

Published in final edited form as:
Biol Psychiatry. 2021 April 01; 89(7): 707–715. doi:10.1016/j.biopsych.2020.11.003.

Brain and Behavior Correlates of Risk Taking in Pediatric Anxiety Disorders

Tara S. Peris,
Division of Child and Adolescent Psychiatry, University of California, Los Angeles, Los Angeles, California

Jane and Terry Semel Institute for Neuroscience, University of California, Los Angeles, Los Angeles, California

Adriana Galván
Department of Psychology, University of California, Los Angeles, Los Angeles, California

Abstract

Avoidant behavior is a defining feature of pediatric anxiety disorders. Although prior research has examined it from the perspective of early information processing events, there has been relatively less consideration of the processes by which anxious youth make avoidant decisions and how these choices are reinforced over time. Studies of risk taking are valuable in this regard because they consider how individuals identify the pros and cons of their choices, how they weigh potential gains and losses and estimate their respective probabilities, and how they tolerate the uncertainty intrinsic to any decision. In this review, we place risk taking within existing models of information processing in pediatric anxiety disorders and highlight the particular value of this construct for informing models of developmental psychopathology and individual differences in outcome over time. We review existing behavioral and neurobiological studies of risk taking in anxious youth and conclude by identifying directions for future research.

Anxiety disorders are the most common mental health condition affecting children and adolescents, with prevalence rates ranging from 10% to 20% (1). They are characterized by impairment across multiple domains of functioning and carry risk for a host of poor long-term outcomes (2). The burden of disease associated with these conditions is recognized around the globe (3,4) and within the United States in particular, where they are among the biggest drivers of health care costs for individuals under age 18 (5). Much of the cost—both personal and economic—associated with anxiety disorders can be traced to the behavioral avoidance that defines them. Across the 10 disorders under the anxiety umbrella in DSM-5, avoidance of stimuli or situations perceived as dangerous or threatening is a cardinal feature. This avoidance is self-reinforcing, shaping further retreat over time (6); it is a primary intervention target.

Among numerous factors that drive avoidant behavior, study of risk-taking behavior may be particularly informative. At its core, avoidant behavior is fueled by a desire to avoid

---

Address correspondence to Tara S. Peris, Ph.D., at tperis@mednet.ucla.edu.

danger, a feature that makes anxious youth vigilant for threat and prone to exaggerate their interpretations of it. However, risk taking moves beyond attentional and interpretation biases to encompass how potential gains and losses are evaluated, how uncertainty is navigated, and how behavioral decisions to approach or avoid are made. It holds particular value for providing an integrated view of how approach and avoidance systems—typically studied in isolation in anxiety—interact to produce symptoms and related impairments, and, crucially, how they develop over time. In the context of pediatric anxiety, it has the potential to inform not only our understanding of behavioral avoidance—one extreme of the risk-taking continuum—but also the subset of anxious youth who gravitate toward high-risk behaviors (e.g., substance use). Here, we define risk taking as involving decisions with multiple possible outcomes that can be estimated in terms of probability (where a broader range of possible outcomes corresponds to higher risk). “Risk” itself is determined based on whether there is uncertainty in the outcome; the outcome need not involve a possible adverse effect to be classified as a “risk.”

In this review, we focus on risk taking as an understudied construct in the pediatric anxiety literature. We begin by reviewing information processing (IP) models of anxiety and linking them to the literature on risk taking in youth, noting the relatively limited work on risk taking among anxious youth. We highlight the particular value of this construct for understanding the developmental psychopathology of pediatric anxiety disorders and individual differences in outcome, and we identify directions for future research.

INFORMATION PROCESSING MODELS OF ANXIETY

Risk-taking behavior occurs within the context of larger IP events that are well documented in the anxiety literature (7–9). Work in this area highlights perturbations in attention, emotion processing, and working memory that define the phenotype of anxiety and may result in behavioral avoidance (10–13). Moreover, this work articulates how genes and environment influence these cognitive processes at the neural level and how they interact to produce the features characteristic of anxiety (12). Anxious individuals have a propensity to selectively attend to threatening stimuli (14–20) and to make threatening appraisals or biased interpretations of neutral stimuli (21–25). In addition, they may exhibit altered fear conditioning—and faulty threat–safety cue discrimination in particular—that crystalize fears over time (26–29). There is also evidence—albeit more mixed—for related memory biases (30,31). Collectively, these processes set the stage for risk-avoidant behavior. Yet, until recently, study of how these features give way to risky decision making and behavior—or avoidance thereof—in anxious youth has been relatively sparse (32,33).

RISKY DECISION MAKING

Individual decisions all involve some degree of risk—some larger than others—and are often examined through the lens of behavioral economics. Research in this area focuses on parsing the component processes of decision making to understand how individuals arrive at the choices they make, and it considers features such as the valence, magnitude, and timing of outcomes along with whether aspects of risk are observed or experienced directly. Within these models, risky decisions are those with multiple possible outcomes that can be estimated in terms of probability (where a broader range of possible outcomes corresponds to higher risk).

These decisions may also involve varying degrees of uncertainty, defined here as the psychological state in which a decision maker lacks knowledge about which outcome will follow from which choice (34). Following the neuroeconomic convention to distinguish uncertainty and ambiguity, uncertainty is present when there are multiple possible outcomes with well-defined or estimable probabilities (35). Ambiguity is present when there are multiple possible outcomes whose probabilities are unknown or ill defined (36). Unlike uncertainty, in which individuals can compute the expected utility of different options, ambiguity renders the expected utility of different options incalculable because the probabilities are unknown (35). Thus, probabilities are known under uncertainty but unknown under ambiguity. Research based on psychological experiments (37) and personality tests (38) shows that people typically prefer options with known probabilities to those with ambiguous probabilities [e.g., (37,38)].

From an IP perspective, the choices we make about whether to approach or avoid are shaped by the features of a given situation to which we attend, our interpretation of them, and associated learning and memory processes (39,40), which may exist outside of conscious awareness. Because risk taking requires active deliberation and because it draws on prior learning, memories of outcomes of prior decisions, and appraisals of the current situation, it can be viewed as a step in the IP chain that links basic automatic processes (e.g., attention) to those that can be conceptualized as more deliberative (behavioral decisions).

Risk taking occurs along a continuum that captures a range of healthy, adaptive responses as well as potentially maladaptive behaviors that occur at the extremes. Often, study of these extremes has focused on high levels of risk taking and impulsivity that are concerning, given the consequences they can engender (e.g., unwanted pregnancy, accidental injury, death) (41). However, the continuum can also be conceptualized as including avoidance of risk at the other extreme, a response pattern likely to bring its own adverse outcomes by diminishing valuable opportunities for learning, exploration, and mastery of new situations. Whether distinct neural substrates underlie the different aspects of the risk-taking continuum remains an open question. The marked individual differences in risk taking are thought to be a product of both person-specific (age, genetics, temperament) and environmental (social context) influences (33,42–44), and they are of particular interest in anxiety, in which some youths go on to exhibit high levels of risk-taking behavior.

Age is recognized widely as one of the largest determinants of risk-taking behavior. Both behavioral and neuroimaging studies (45–47) find age-dependent shifts in risk taking such that it peaks during adolescence and corresponds to increases in novelty and sensation seeking during this stage of development. Healthy risk-taking behavior is adaptive, preparing young people for greater autonomy and helping them to explore their environment and calibrate their behavior over time (47). Accordingly, increases in novelty seeking, exploration, and risky behavior are observed cross-species and cross-culturally and are thought to serve an evolutionary purpose that supports independence and reproduction (48,49). At the same time, they account for many of the risks that accrue to youth during this stage of development, including increases in sexually transmitted diseases (50), unwanted pregnancy, distracted and drunk driving, and death ascribed to risky behaviors (51,52).

BEHAVIORAL STUDIES OF RISK TAKING

Although adolescent decision making has been the subject of considerable research (53), recent reviews have highlighted the challenges that arise in the study of risky decision making in particular (54). Indeed, while developmental differences in risk taking are documented in both real-world settings and epidemiological studies, as assessed using self-report and survey data (55,56), recent meta analyses and systematic reviews paint a more complex picture of developmental trends, which may result from laboratory-based risk-taking scenarios in which it is difficult to simulate real-life risk taking.

Most experimental studies rely on computer tasks that present participants with two (or more) options with varying degrees of risk and reward. The Balloon Analogue Risk Task (BART) is one such task, and it presents participants with a balloon on a computer screen that they can inflate by pushing a button. With each button press, the balloon is inflated, and the participant earns coins. However, at any moment there is a chance the balloon will pop, so the participant must weigh the benefits of earning coins against the costs incurred if it breaks. One strand of experimental research suggests a peak in reward processing (57) and risk taking (58) among adolescents relative to either children or adults using a reward sensitivity task and the BART, respectively. Separate work has suggested that adolescents may be relatively similar to adults in their attitudes toward an aversion of risk (59–61) but more distinct in their attitudes toward ambiguity (60,61), whereby there are no age-related changes in risk attitude but there are age-related changes in ambiguity attitude, with younger adolescents more tolerant of ambiguity than adults (60). Specifically, these studies suggest that adolescents are just as averse to uncertainty but are more willing to accept ambiguous conditions—situations in which the likelihood of winning/losing is unknown—than adults (61).

A meta-analysis by Defoe *et al.* (45) examined more than two dozen laboratory-based studies involving an array of widely used paradigms of risk-taking behavior and found evidence that adolescents take more risks than adults, a finding that was stronger among early versus older adolescents. However, in contrast to prior studies, these findings also suggested that adolescents made generally similar levels of risky choice when compared with children. Although this finding is complicated both by the small number of studies including child reference groups and by variability in the tasks that were employed, it underscores the need for further study.

In addition to accounting for variability in findings across extant developmental studies of risk taking, the measurement of risk-taking behavior is also noteworthy because it highlights the design trade-offs that come with various approaches as well as growing efforts to refine measurement. Questionnaire, self-report of life events, and event momentary assessment tap the propensity for risk taking in real life, but they are subject to the limitations of self-report and allow only broad understanding of the risky behaviors rather than the specific factors that motivate them. By contrast, in experimental settings, the basic structure of most risk-taking tasks involves the manipulation of different aspects of value-based decisions. Tasks vary from those that provide naturalistic risky decision-making probes (e.g., the Stoplight Driving Task wherein participants drive along a simulated track and yellow “stoplight” driving choices are tracked) to those that more carefully isolate specific components of decision making (e.g., expected reward value, level of uncertainty, or delay/immediacy of outcome). The former offer the advantage of ecological validity and may capture developmental differences—particularly between adolescents and adults—observed in real-world settings. Yet they often cannot isolate specific facets of decision making that would offer a mechanistic understanding of those developmental differences. As such, experimental paradigms borrowed from behavioral economics take a more agnostic approach that may not mirror real-world youth decision making as closely but are better situated to specify features of interest.

Behavioral economic frameworks have facilitated efforts to parse aspects of risky decision making that have been conflated in prior research (e.g., risk/ambiguity; risk aversion/loss aversion). For example, many commonly used risk-taking tasks involve gambles with known magnitude, valence, and probabilities (“Choose between an X% chance of winning $10 and or a sure win of $2”). However, more recent work using economic-based tasks that include conditions in which probabilities are known and conditions in which probabilities are unknown has explicitly delineated risk and ambiguity (60,61), revealing that adolescents may be more tolerant of ambiguity than adults—an important distinction given that these two aspects of decision making (risk and ambiguity) show only weak associations (62). Similarly, as decision making and risk taking are decomposed into their constituent parts, there has been further attention to distinctions between risk aversion and loss aversion. The former encompasses difficulty tolerating the uncertainty of the decision whereas the latter captures the weighing of negative outcomes more heavily than potential gains. As detailed later, these distinctions may be particularly important for the study of youth anxiety disorders.

NEUROIMAGING STUDIES OF RISK TAKING

Behavioral shifts in risk taking track closely to neurodevelopmental changes. For typically developing adolescents, risky behaviors are a product of heightened approach motivation and limited inhibition, factors that distinguish them from their adult counterparts in meta-analytical studies (63). However, these constructs are quite distinct and tap into different aspects of risk taking that may parallel those of reward-related response and cognitive control, respectively (64). Specifically, approach motivation has a curvilinear, inverted U-shaped relationship with age, similar to the pattern of reward-related response in the ventral striatum (VS), as shown in a longitudinal study in which 254 participants between the ages of 8 and 27 years were scanned twice when performing a gambling task (58). A separate longitudinal study provided a mechanistic account of this effect, whereby the VS exhibited greater coupling with the ventral tegmental area in early adolescence when the participants were in a motivational state (65); interestingly, this effect decreased by adulthood. Indeed, high levels of sensation seeking are linked to increased reward-related VS response (58). The data on inhibition suggest a linear developmental trajectory reflecting improvements from childhood to adolescence into adulthood (66–68), mirroring developmental refinements in prefrontal cortex (PFC) regions (69).

While dual systems frameworks have focused on the interplay of cognitive control and reward systems, newer models include threat-related systems and their interaction with person-specific and environmental variables in contributing to motivated behavior (70). The triadic model of motivated behavior moves beyond the dual systems model by including not only motivation/approach and regulation nodes but also the avoidance system, centered on amygdala-related circuits; this model provides a basis for studying behavioral responses including risk seeking, emotional intensity, and social reorientation (70). In this model, avoidance is a passive construct that can be distinguished from inhibition, which is an active one. For example, one might "inhibit" the temptation to consume a cookie that is offered while one is on a diet whereas one would "avoid" the temptation by not buying cookies at a store. Neurobiologically, inhibition requires the active engagement of neural systems implicated in behavioral suppression (e.g., prefrontal regulatory systems), but recruiting these systems to achieve avoidance is likely unnecessary.

Importantly, the triadic model is based on the assumption that motivated behavior is the product of these three systems, which together exhibit functional but overlapping equilibrium that is contingent on both sustained and transient factors that vary across individuals. Broader still are conceptualizations that take into consideration the dynamic and interactive effects of multiple systems that, collectively, influence behavior and decision making (71,72). For example, functional networks have the capacity to support complex thought and action that any single element of the system would be unable to support alone. This is consonant with the principles of dynamic systems theory (73), which state that development can only be understood as the multiple, mutual, and continuous interaction of all levels of the developing system.

RISK TAKING AND ANXIETY

Aversion to risk is well documented among adults (74–76) as assessed using the BART and the Iowa Gambling Task and, to a lesser extent, among children and adolescents with anxiety (33,59,77). Anxious individuals have a preference for certain outcomes over those perceived as risky, an inclination that can be motivated by both risk aversion and loss aversion. Studies of adults suggest that anxious individuals overestimate potential losses in gambling-based tasks in which participants choose between a "sure" and "risky" outcome (78) but that risk-avoidant behavior may be motivated more heavily by risk aversion than by sensitivity to potential loss (10). There is also some evidence that risk aversion is specific to anxiety versus other disorders (75).

Only a handful of studies have extended this work to anxious children and adolescents, and these studies have varied with respect to the segment of development and aspects of risk taking studied. In a sample of adolescents and young adults, the expected links emerged between social anxiety symptoms and self-reported risk aversion, but not risk perception (79). In the only study of loss aversion in youths to date, there were no differences between the anxious and comparison youths in performance on a mixed gambles task (80), which presented the participants with gambles in which they had a 50% chance of gaining or losing money. The participants decided whether or not they would accept the gamble. The amount of the potential gain and loss varied across these trials, allowing the calculation of an expected value and a determination of whether the participants were loss averse. Importantly, there have not yet been efforts to dissect risk versus loss aversion within the same task for anxious youth or to determine whether findings in the literature on adults replicate these results.

A separate study examined age and social context as determinants of risk taking among anxious children and adolescents and healthy controls (33), finding that anxious children became more risk avoidant when they were led to believe that peers were evaluating their performance. Surprisingly, this finding did not emerge in either the anxious or healthy control adolescents, underscoring the need for further inquiry. A final study used a community sample of youths to explore the intersection of anxiety level, social stress, and risk-taking behavior (81). Among youths with higher levels of anxiety there was evidence of enhanced sensitivity to the magnitude of reward such that highly anxious youths took more risks as the expected values shifted from negative to positive. Moreover, youths with higher levels of anxiety did not appear to differentiate their responses in risk-taking situations across different levels of stress, suggesting perhaps that anxious youths approach all risk taking with a certain degree of hypervigilance.

NEURAL BASIS OF ANXIETY

Efforts to understand the neural underpinnings of anxiety have highlighted the fear circuitry that encompasses the amygdala, hippocampus, PFC (82–84). Consistent with animal models and adult human research (85), aberrant responses to threat are observed in these regions among behaviorally inhibited (86) or anxiety-disordered (82–84,87–89) youth. Previous studies (82,90) have suggested that the ventrolateral PFC regulates arousal through its effects on attentional control. Human lesion (91) and functional magnetic resonance imaging (fMRI) (92) work also implicate the ventromedial PFC in regulating amygdala activity in individuals with and without trait anxiety. Other research has focused on approach systems, finding evidence for heightened striatal sensitivity among adolescents with a history of behavioral inhibition (93–95) and/or current anxiety disorder (96).

Notably, the role of the striatum has—until recently—received limited attention in these models (97). Although often thought of in relation to its role in reward systems, it also links to several anxiety processes (e.g., attention bias, fear conditioning, motivation, intolerance of uncertainty) (97,98). The striatum is functionally linked to components of fear circuitry, particularly in the context of stress reactivity (99), and has strong interactive effects with the amygdala (100). Glutamatergic projections from the basolateral amygdala to the VS (101,102) facilitate the VS's role as an interfacing region able to translate evaluative signals into action (100). The basolateral amygdala encodes the sensory and affective properties of stimuli and outcomes (i.e., value), which are then relayed to the VS to translate into value-based actions (e.g., pursue, avoid) (101–103); thus, amygdala–VS connections may be critical for learning and updating stimulus value. Preliminary evidence suggests that atypical engagement of the striatum is characteristic of youths with anxiety (104).

NEURAL CORRELATES OF RISKY DECISION MAKING IN ANXIETY

Although research on the neural circuitry undergirding anxiety disorders has proliferated, study of the correlates of risky decision making in anxiety remains limited. This is unfortunate given that such work has the potential to inform our understanding of the developmental psychopathology of anxiety disorders by leveraging what is already known about risk taking among typically developing youth to understand divergent neurodevelopmental trajectories. Indeed, many anxiety disorders have their onset in adolescence during the very window when typically developing youth are exhibiting age-expected peaks in risk-taking behavior, underscoring the potential that risk-taking paradigms have to capture deviations in approach/avoidance behavior and how they develop over time.

Surprisingly, only one study to date has directly examined the neural correlates of risk taking in anxious youth. Using a sample of adolescents with anxiety disorder and healthy control adolescent, it found evidence for both behavioral and neurobiological differences during risky decision making on the Cups Task that varied as a function of both symptom severity and gain/loss condition (32). The Cups Task consists of decision trials that vary on explicit probabilities and reward value, and thus vary in expected value, under two contextual frames—a reward-motivated context (gain frame) and a nonrewarding context (lose frame). Participants decide between a certain monetary gain (or loss) of a small amount and an uncertain gain (or loss) of a larger monetary amount or no gain (or loss). On this task, the anxious youths made fewer risky choices during potential loss compared with the control youths, and these decisions were paralleled by divergent patterns of activation. Neural activation during risky choice was associated with individual differences in anxiety symptom severity, such that greater anxiety was associated with decreased recruitment of the VS in the gain condition and increasing recruitment of the amygdala, dorsolateral PFC, and medial frontal cortex in the loss condition (32). These data suggest that even when anxious youths make a risky choice, their neural circuitry is responsive to the potential negative outcomes of the risk rather than the potential earnings of the reward.

Related work has examined the neural correlates of risk avoidance in a community sample of young adults (mean age = 27.6 years), finding that risk aversion is associated with activation in both the striatum and precuneus activation during both risky and certain task conditions (105). More recently, research using event-related potentials methods has examined the intersection of risk and reward using the BART task among adults with a range of psychopathology, finding that dampened neural engagement in response to reward versus loss may characterize both extremes of aberrant risk-taking behavior (impulsivity and avoidance) (106). Further work with pediatric samples is needed in light of other research suggesting heightened striatal response to reward when the outcome was contingently associated with choice among youths with high levels of anxiety (104) as well as those with a history of behavioral inhibition (107).

CHALLENGES AND FUTURE DIRECTIONS

Taken together, this work highlights both the promise and challenges that accompany studies of risk taking. While the construct holds promise for linking early information processing to more deliberative decisions that may result in impairment, several methodological issues limit our understanding. First, across both behavioral and neurobiological investigations, definitions of risky behavior and its core components often differ, complicating efforts to link and compare findings. Measurement issues remain, and there is a clear need to probe the extent to which task-based avoidance maps to clinically relevant, real-world avoidance. Small sample sizes are common and understandable in this emerging line of research, yet they are ill-suited to capturing the heterogeneity and individual differences inherent in risk taking.

These challenges are particularly important for understanding anxious youths who will exhibit heightened risk taking (e.g., substance use, unprotected sex, impulsive decisions), which is often theorized to serve as a strategy for regulating affective distress (108–114). Whether the tendency toward heightened risk taking is specific to some anxiety disorders versus others and whether it is modulated by age and/or contextual factors also remains unclear. Moreover, our view of how development intersects with risk taking for anxious youths is limited by study designs that often do not include a child reference group or compare only adolescents and adults. Relatedly, the traditional reliance on case-control designs may hamper efforts to understand individual differences in risk taking by failing to consider the full continuum of the anxiety phenotype and its relationship with risk. Finally, the growing move toward more refined measurement of risk taking has yet to fully translate to studies of pediatric anxiety. Beyond the challenge of fMRI tasks that do not precisely mimic the risk taking (or avoidance) observed in real life, studies have yet to parse closely related constructs, including aversion to risk, loss, and ambiguity, that would deepen our understanding of the choices anxious youths make.

These methodological shortcomings are to be expected as the pediatric anxiety literature comingles with the adolescent risk-taking literature. As work in this area moves forward, we highlight four areas for advancement and innovation. First, there is a need for longitudinal designs that can shed light on relevant developmental processes and in doing so capture key transitions both into and out of adolescence. Second, future work will benefit from a dimensional perspective geared toward capturing individual differences in both anxiety and risk taking. Longitudinal studies of community youth reveal striking heterogeneity in anxiety outcomes during the transition to adolescence (115–117). Yet individual differences are seldom a focus of developmental fMRI studies. The broad brushstroke group comparisons often conducted among different age groups and/or between pathological and healthy groups reveal sweeping developmental trajectories, but such comparisons may rob these studies of the power to attain a nuanced understanding of individual differences in neural sensitivity and phenotypic variability. Third, we echo the calls of others in the field to carefully consider the component and interactive contributions of striatal activation to youth anxiety. Given the bidirectional projections between the striatum and other affective regions (e.g., amygdala) and its role in learning, zooming in on the striatum's role in anxiety will expand our understanding of the network of regions associated with anxious phenotypes. Finally, we stress the importance of integrating other strands of developmental research (e.g., sleep, puberty, inflammation) that might provide a more complete view of both risk taking and anxiety. Each of these topics merits its own review, and we refer readers to the growing literature linking puberty and risk taking, a rich topic beyond the scope of the current review [see (58,118,119)].

However, to illustrate the value of this broader developmental view, we highlight sleep as a domain of interest that undergoes sweeping changes in adolescence (120), has clear links to risk-taking behavior, and also impacts emotional well-being. Sleep is a fundamental need; when sleep is insufficient, it impacts virtually every domain of functioning, including learning, memory, decision making, brain function, and mental health (120). A growing body of work has highlighted not only the sleep disturbances that adolescents face (121) but the link of these disturbances to cognitive control and reward sensitivity neural circuitry, crucial determinants of risk-taking behavior (122). Separate work has linked it to adolescent depression (123) and, to a lesser extent, anxiety (124). An fMRI comparison of anxious and nonanxious adolescents found that anxiety modulated the effects of sleep duration on neural activity in the anterior cingulate and hippocampus in response to negative faces (125). Prospective longitudinal data suggest that sleep disturbance commonly precedes anxiety during this developmental window (124,126), and growing daily diary evidence suggests developmental sensitivity of this effect in early adolescence (127). Yet there remains a need to determine whether poor sleep exacerbates anxiety symptoms or vice versa and how each of these processes influences behavioral decisions. Such knowledge will be important for designing effective interventions that improve both sleep and anxiety. Indeed, recent work suggests that a sleep intervention can improve sleep in anxious youth and that sleep improves over the course of anxiety treatment (128).

In conclusion, the study of risk taking has the potential to elucidate a central impairment in pediatric anxiety disorders and to provide meaningful guidance about how we might intervene. Although risk aversion is an accepted feature of the anxiety phenotype, our understanding of risk taking in this population is still emerging. Future work, rooted in behavioral economics paradigms that deconstruct the decision-making process into its component pieces, will inform our understanding of how youth arrive at the decisions they make, how these choices are shaped by individual and contextual factors, and how they are moderated by other key developmental processes.

ACKNOWLEDGMENTS AND DISCLOSURES

This study was supported by funding from the National Institute of Mental Health (Grant No. R01MH110476 [to TSP and AG]) and additional research funding from Patient Centered Outcomes Research Institute and the TLC Foundation for Body Focused Repetitive Behaviors (to TSP).

TSP receives royalties from Oxford University Press. AG receives funding from the National Science Foundation, Russell Sage Foundation, California Tobacco-Related Disease Research Program, Hope Lab, and the Jeffrey/Wenzel Term Chair in Behavioral Neuroscience. The authors report no biomedical financial interests or potential conflicts of interest.

REFERENCES

1. Costello EJ, Mustillo S, Erkanli A, Keeler G, Angold A (2003): Prevalence and development of psychiatric disorders in childhood and adolescence. Arch Gen Psychiatry 60.. 837–834. [PubMed: 12912767]
2. Essau CA, Lewinsohn PM, Olaya B, Seeley JR (2014): Anxiety disorders in adolescents and psychosocial outcomes at age 30. J Affect Disord 163:125–132. [PubMed: 24456837]

3. Bodden DHM, Dirksen CD, Bögels SM (2008): Societal burden of clinically anxious youth referred for treatment: A cost-of-illness study. J Abnorm Child Psychol 36:487–497. [PubMed: 18214667]
4. Beddington J, Cooper CL, Field J, Goswami U, Huppert FA, Jenkins R, et al. (2008): The mental wealth of nations. Nature 455:1057–1060. [PubMed: 18948946]
5. Bui AL, Dieleman JL, Hamavid H, Birger M, Chapin A, Duber HC, et al. (2017): Spending on children's personal health care in the United States, 1996–2013. JAMA Pediatr 171:181–189. [PubMed: 28027344]
6. LeDoux JE, Moscarello J, Sears R, Campese V (2017): The birth, death and resurrection of avoidance: A reconceptualization of a troubled paradigm. Mol Psychiatry 22:24–36. [PubMed: 27752080]
7. Lau JYF, Waters AM (2017): Annual research review: An expanded account of information-processing mechanisms in risk for child and adolescent anxiety and depression. J Child Psychol Psychiatry 58:387–407. [PubMed: 27966780]
8. Pine DS, Fox NA (2015): Childhood antecedents and risk for adult mental disorders. Annu Rev Psychol 66:459–485. [PubMed: 25559116]
9. Shechner T, Britton JC, Pérez-Edgar K, Bar-Haim Y, Ernst M, Fox NA, et al. (2012): Attention biases, anxiety, and development: Toward or away from threats or rewards? Depress Anxiety 29:282–294. [PubMed: 22170764]
10. Charpentier CJ, Aylward J, Roiser JP, Robinson OJ (2017): Enhanced risk aversion, but not loss aversion, in unmedicated pathological anxiety. Biol Psychiatry 81:1014–1022. [PubMed: 28126210]
11. Hartley CA, Phelps EA (2012): Anxiety and decision-making. Biol Psychiatry 72:113–118. [PubMed: 22325982]
12. Pine DS (2007): Research review: A neuroscience framework for pediatric anxiety disorders. J Child Psychol Psychiatry 48:631–648. [PubMed: 17593144]
13. Robinson OJ, Vytal K, Cornwell BR, Grillon C (2013): The impact of anxiety upon cognition: Perspectives from human threat of shock studies. Front Hum Neurosci 7:203. [PubMed: 23730279]
14. Dodd HF, Hudson JL, Williams T, Morris T, Lazarus RS, Byrow Y (2015): Anxiety and attentional bias in preschool-aged children: An eyetracking study. J Abnorm Child Psychol 43:1055–1065. [PubMed: 25434325]
15. Dudeney J, Sharpe L, Hunt C (2015): Attentional bias towards threatening stimuli in children with anxiety: A meta-analysis. Clin Psychol Rev 40:66–75. [PubMed: 26071667]
16. Shechner T, Jarcho JM, Britton JC, Leibenluft E, Pine DS, Nelson EE (2013): Attention bias of anxious youth during extended exposure of emotional face pairs: An eye-tracking study. Depress Anxiety 30:14–21. [PubMed: 22815254]
17. Salum GA, Desousa DA, do Rosário MC, Pine DS, Manfro GG (2013): Pediatric anxiety disorders: From neuroscience to evidence-based clinical practice. Braz J Psychiatry 35(suppl 1):S03–S21. [PubMed: 24142122]
18. Waters AM, Bradley BP, Mogg K (2014): Biased attention to threat in paediatric anxiety disorders (generalized anxiety disorder, social phobia, specific phobia, separation anxiety disorder) as a function of "distress" versus "fear" diagnostic categorization. Psychol Med 44:607–616. [PubMed: 23591000]
19. Bar-Haim Y, Kerem A, Lamy D, Zakay D (2010): When time slows down: The influence of threat on time perception in anxiety. Cogn Emot 24:255–263.
20. Eldar S, Apter A, Lotan D, Edgar KP, Naim R, Fox NA, et al. (2012): Attention bias modification treatment for pediatric anxiety disorders: A randomized controlled trial. Am J Psychiatry 169:213–220. [PubMed: 22423353]
21. Creswell C, Schniering CA, Rapee RM (2005): Threat interpretation in anxious children and their mothers: Comparison with nonclinical children and the effects of treatment. Behav Res Ther 43:1375–1381. [PubMed: 16086987]
22. Muris P, Rassin E, Mayer B, Smeets G, Huijding J, Remmerswaal D, Field A (2009): Effects of verbal information on fear-related reasoning biases in children. Behav Res Ther 47:206–214. [PubMed: 19135650]

23. Rozenman M, Amir N, Weersing VR (2014): Performance-based interpretation bias in clinically anxious youths: Relationships with attention, anxiety, and negative cognition. Behav Ther 45:594–605. [PubMed: 25022771]
24. Peris TS, Galván A (2013): Contextual modulation of medial prefrontal cortex to neutral faces in anxious adolescents. Biol Mood Anxiety Disord 3:18. [PubMed: 24229444]
25. Rozenman M, Vreeland A, Piacentini J (2017): Thinking anxious, feeling anxious, or both? Cognitive bias moderates the relationship between anxiety disorder status and sympathetic arousal in youth. J Anxiety Disord 45:34–42. [PubMed: 27923164]
26. Britton JC, Grillon C, Lissek S, Norcross MA, Szuhany KL, Chen G, et al. (2013): Response to learned threat: An fMRI study in adolescent and adult anxiety. Am J Psychiatry 170:1195–1204. [PubMed: 23929092]
27. Lau JYF, Lissek S, Nelson EE, Lee Y, Roberson-Nay R, Poeth K, et al. (2008): Fear conditioning in adolescents with anxiety disorders: Results from a novel experimental paradigm. J Am Acad Child Adolesc Psychiatry 47:94–102. [PubMed: 18174830]
28. Cohen Kadosh K, Haddad ADM, Heathcote LC, Murphy RA, Pine DS, Lau JYF (2015): High trait anxiety during adolescence interferes with discriminatory context learning. Neurobiol Learn Mem 123:50–57. [PubMed: 25982943]
29. Waters AM, Henry J, Neumann DL (2009): Aversive Pavlovian conditioning in childhood anxiety disorders: Impaired response inhibition and resistance to extinction. J Abnorm Psychol 118:311–321. [PubMed: 19413406]
30. Dalgleish T, Taghavi R, Neshat-Doost H, Moradi A, Canterbury R, Yule W (2003): Patterns of processing bias for emotional information across clinical disorders: A comparison of attention, memory, and prospective cognition in children and adolescents with depression, generalized anxiety, and posttraumatic stress disorder. J Clin Child Adolesc Psychol 32:10–21. [PubMed: 12573928]
31. Daleiden EL (1998): Childhood anxiety and memory functioning: A comparison of systemic and processing accounts. J Exp Child Psychol 68:216–235. [PubMed: 9514771]
32. Galván A, Peris TS (2014): Neural correlates of risky decision making in anxious youth and healthy controls. Depress Anxiety 31:591–598. [PubMed: 24867804]
33. Rosen D, Patel N, Pavletic N, Grillon C, Pine DS, Ernst M (2016): Age and social context modulate the effect of anxiety on risk-taking in pediatric samples. J Abnorm Child Psychol 44:1161–1171. [PubMed: 26659306]
34. Platt ML, Huettel SA (2008): Risky business: The neuroeconomics of decision making under uncertainty. Nat Neurosci 11:398–403. [PubMed: 18368046]
35. Huettel SA, Stowe CJ, Gordon EM, Warner BT, Platt ML (2006): Neural signatures of economic preferences for risk and ambiguity. Neuron 49:765–775. [PubMed: 16504951]
36. Camerer C, Weber M (1992): Recent developments in modeling preferences: Uncertainty and ambiguity. J Risk Uncertain 5:325–370.
37. Heath C, Tversky A (1991): Preference and belief: Ambiguity and competence in choice under uncertainty. J Risk Uncertain 4:5–28.
38. Lauriola M, Levin IP (2001): Relating individual differences in attitude toward ambiguity to risky choices. J Behav Decis Mak 14:107–122.
39. Lempert KM, Tricomi E (2016): The value of being wrong: Intermittent feedback delivery alters the striatal response to negative feedback. J Cogn Neurosci 28:261–274. [PubMed: 26439265]
40. Marvin CB, Shohamy D (2016): Curiosity and reward: Valence predicts choice and information prediction errors enhance learning. J Exp Psychol Gen 145:266–272. [PubMed: 26783880]
41. Dir AL, Hummer TA, Aalsma MC, Hulvershorn LA (2019): Pubertal influences on neural activation during risky decision-making in youth with ADHD and disruptive behavior disorders. Dev Cogn Neurosci 36:100634. [PubMed: 30889545]
42. Sonuga-Barke EJS, Cortese S, Fairchild G, Stringaris A (2016): Annual research review: Transdiagnostic neuroscience of child and adolescent mental disorders—differentiating decision making in attention-deficit/hyperactivity disorder, conduct disorder, depression, and anxiety. J Child Psychol Psychiatry57 321–349. [PubMed: 26705858]

43. Guassi Moreira JF, Telzer EH (2018): Family conflict shapes how adolescents take risks when their family is affected. Dev Sci 21: e12611. [PubMed: 28975678]
44. Somerville LH, Haddara N, Sasse SF, Skwara AC, Moran JM, Figner B (2019): Dissecting "peer presence" and "decisions" to deepen understanding of peer influence on adolescent risky choice. Child Dev 90:2086–2103. [PubMed: 29701282]
45. Defoe IN, Dubas JS, Figner B, Van Aken MAG (2015): A meta-analysis on age differences in risky decision making: Adolescents versus children and adults. Psychol Bull 141:48–84. [PubMed: 25365761]
46. Cauffman E, Shulman EP, Steinberg L, Claus E, Banich MT, Graham S, Woolard J (2010): Age differences in affective decision making as indexed by performance on the Iowa Gambling Task. Dev Psychol 46:193–207. [PubMed: 20053017]
47. Crone EA, Van Duijvenvoorde ACK, Peper JS (2016): Annual research review: Neural contributions to risk-taking in adolescence—developmental changes and individual differences. J Child Psychol Psychiatry 57:353–368. [PubMed: 26889896]
48. Duell N, Steinberg L, Icenogle G, Chein J, Chaudhary N, Di Giunta L, et al. (2018): Age patterns in risk taking across the world [published correction appears in J Youth Adolesc 2019;48: 835–836]. J Youth Adolesc 47:1052–1072. [PubMed: 29047004]
49. Spear LP (2004): Adolescent brain development and animal models. Ann N Y Acad Sci 1021:23–26. [PubMed: 15251870]
50. Satterwhite CL, Torrone E, Meites E, Dunne EF, Mahajan R, Ocfemia MC, et al. (2013): Sexually transmitted infections among US women and men: Prevalence and incidence estimates, 2008. Sex Transm Dis 40:187–193. [PubMed: 23403598]
51. Eaton DK, Kann L, Kinchen S, Shanklin S, Ross J, Hawkins J, et al. (2008): Youth risk behavior surveillance—United States, 2007. MMWR Surveill Summ 57:1–131.
52. Kann L, McManus T, Harris WA, Shanklin SL, Flint KH, Queen B, et al. (2018): Youth risk behavior surveillance—United States, 2017. MMWR Surveill Summ 67:1–114.
53. Hartley CA, Somerville LH (2015): The neuroscience of adolescent decision-making. Curr Opinion Behav Sci 5:108–115.
54. Rosenbaum GM, Hartley CA (2019): Developmental perspectives on risky and impulsive choice. Philos Trans R Soc Lond B Biol Sci 374:20180133. [PubMed: 30966918]
55. Centers for Disease Control and Prevention (2020): 2019 Youth Risk Behavior Survey Questionnaire Available at: https://www.cdc.gov/yrbs. Accessed August 1, 2020.
56. Harris KMK, Halpern CT, Whitsel E, Hussey J, Tabor J, Entzel P, Udry JR (2009): The National Longitudinal Study of Adolescent to Adult Health: research design. Add Health: The National Longitudinal Study of Adolescent to Adult Health. 10.1136/bmj.a3191. Accessed August 1, 2020.
57. Galvan A, Hare TA, Parra CE, Penn J, Voss H, Glover G, Casey BJ (2006): Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. J Neurosci 26:6885–6892. [PubMed: 16793895]
58. Braams BR, van Duijvenvoorde ACK, Peper JS, Crone EA (2015): Longitudinal changes in adolescent risk-taking: A comprehensive study of neural responses to rewards, pubertal development, and risk-taking behavior. J Neurosci 35:7226–7238. [PubMed: 25948271]
59. Barkley-Levenson EE, Van Leijenhorst L, Galván A (2013): Behavioral and neural correlates of loss aversion and risk avoidance in adolescents and adults. Dev Cogn Neurosci 3:72–83. [PubMed: 23245222]
60. Blankenstein NE, Crone EA, van den Bos W, van Duijvenvoorde ACK (2016): Dealing with uncertainty: Testing risk- and ambiguity-attitude across adolescence. Dev Neuropsychol 41:77–92. [PubMed: 27028162]
61. Tymula A, Rosenberg Belmaker LA, Roy AK, Ruderman L, Manson K, Glimcher PW, Levy I (2012): Adolescents' risk-taking behavior is driven by tolerance to ambiguity. Proc Natl Acad Sci U S A 109:17135–17140. [PubMed: 23027965]
62. Tymula A, Belmaker LAR, Ruderman L, Glimcher PW, Levy I (2013): Like cognitive function, decision making across the life span shows profound age-related changes. Proc Natl Acad Sci U S A 110:17143–17148. [PubMed: 24082105]

63. Silverman MH, Jedd K, Luciana M (2015): Neural networks involved in adolescent reward processing: An activation likelihood estimation meta-analysis of functional neuroimaging studies. Neuroimage 122:427–439. [PubMed: 26254587]
64. Steinberg L (2008): A social neuroscience perspective on adolescent risk-taking. Dev Rev 28:78–106. [PubMed: 18509515]
65. Murty VP, Shah H, Montez D, Foran W, Calabro F, Luna B (2018): Age-related trajectories of functional coupling between the VTA and nucleus accumbens depend on motivational state. J Neurosci 38:7420–7427. [PubMed: 30030394]
66. Zhou D, Thompson WK, Siegle G (2009): MATLAB toolbox for functional connectivity. Neuroimage 47:1590–1607. [PubMed: 19520177]
67. Galvan A, Hare T, Voss H, Glover G, Casey BJ (2007): Risk-taking and the adolescent brain: Who is at risk? Dev Sci 10:F8–F14. [PubMed: 17286837]
68. Ernst M, Paulus MP (2005): Neurobiology of decision making: A selective review from a neurocognitive and clinical perspective. Biol Psychiatry 58:597–604. [PubMed: 16095567]
69. Giedd JN, Blumenthal J, Jeffries NO, Castellanos FX, Liu H, Zijdenbos A, et al. (1999): Brain development during childhood and adolescence: A longitudinal MRI study. Nat Neurosci 2:861–863. [PubMed: 10491603]
70. Ernst M (2014): The triadic model perspective for the study of adolescent motivated behavior. Brain Cogn 89:104–111. [PubMed: 24556507]
71. Crone EA, Dahl RE (2012): Understanding adolescence as a period of social-affective engagement and goal flexibility. Nat Rev Neurosci 13:636–650. [PubMed: 22903221]
72. Casey BJ, Galván A, Somerville LH (2016): Beyond simple models of adolescence to an integrated circuit-based account: A commentary. Dev Cogn Neurosci 17:128–130. [PubMed: 26739434]
73. Smith LB, Thelen E (2003): Development as a dynamic system. Trends Cogn Sci 7:343–348. [PubMed: 12907229]
74. Giorgetta C, Grecucci A, Zuanon S, Perini L, Balestrieri M, Bonini N, et al. (2012): Reduced risk-taking behavior as a trait feature of anxiety. Emotion 12:1373–1383. [PubMed: 22775123]
75. Maner JK, Richey JA, Cromer K, Mallott M, Lejuez CW, Joiner TE, Schmidt NB (2007): Dispositional anxiety and risk-avoidant decision-making. Pers Individ Dif 42:665–675.
76. Mueller EM, Nguyen J, Ray WJ, Borkovec TD (2010): Future-oriented decision-making in generalized anxiety disorder is evident across different versions of the Iowa Gambling Task. J Behav Ther Exp Psychiatry 41:165–171. [PubMed: 20060098]
77. Chorpita BF, Barlow DH (1998): The development of anxiety: The role of control in the early environment. Psychol Bull 124:3–21. [PubMed: 9670819]
78. Clark L, Li R, Wright CM, Rome F, Fairchild G, Dunn BD, Aitken MRF (2012): Risk-avoidant decision making increased by threat of electric shock. Psychophysiology 49:1436–1443. [PubMed: 22913418]
79. Pailing AN, Reniers RLEP (2018): Depressive and socially anxious symptoms, psychosocial maturity, and risk perception: Associations with risk-taking behaviour. PLoS One 13:e0202423. [PubMed: 30110384]
80. Ernst M, Plate RC, Carlisi CO, Gorodetsky E, Goldman D, Pine DS (2014): Loss aversion and 5HTT gene variants in adolescent anxiety. Dev Cogn Neurosci 8:77–85. [PubMed: 24280015]
81. Richards JM, Patel N, Daniele-Zegarelli T, MacPherson L, Lejuez CW, Ernst M (2015): Social anxiety, acute social stress, and reward parameters interact to predict risky decision-making among adolescents. J Anxiety Disord 29:25–34. [PubMed: 25465884]
82. Monk CS, Nelson EE, McClure EB, Mogg K, Bradley BP, Leibenluft E, et al. (2006): Ventrolateral prefrontal cortex activation and attentional bias in response to angry faces in adolescents with generalized anxiety disorder. Am J Psychiatry 163:1091–1097. [PubMed: 16741211]
83. Monk CS, Telzer EH, Mogg K, Bradley BP, Mai X, Louro HMC, et al. (2008): Amygdala and ventrolateral prefrontal cortex activation to masked angry faces in children and adolescents with generalized anxiety disorder. Arch Gen Psychiatry 65:568–576. [PubMed: 18458208]
84. Britton JC, Bar-Haim Y, Carver FW, Holroyd T, Norcross MA, Detloff A, et al. (2012): Isolating neural components of threat bias in pediatric anxiety. J Child Psychol Psychiatry 53:678–686. [PubMed: 22136196]

85. Phan KL, Fitzgerald DA, Nathan PJ, Tancer ME (2006): Association between amygdala hyperactivity to harsh faces and severity of social anxiety in generalized social phobia. Biol Psychiatry 59:424–429. [PubMed: 16256956]

86. Pérez-Edgar K, Roberson-Nay R, Hardin MG, Poeth K, Guyer AE, Nelson EE, et al. (2007): Attention alters neural responses to evocative faces in behaviorally inhibited adolescents. Neuroimage 35:1538–1546. [PubMed: 17376704]

87. McClure EB, Monk CS, Nelson EE, Parrish JM, Adler A, Blair RJR, et al. (2007): Abnormal attention modulation of fear circuit function in pediatric generalized anxiety disorder. Arch Gen Psychiatry 64:97–106. [PubMed: 17199059]

88. Guyer AE, Lau JYF, McClure-Tone EB, Parrish J, Shiffrin ND, Reynolds RC, et al. (2008): Amygdala and ventrolateral prefrontal cortex function during anticipated peer evaluation in pediatric social anxiety. Arch Gen Psychiatry 65:1303–1312. [PubMed: 18981342]

89. Beesdo K, Lau JYF, Guyer AE, McClure-Tone EB, Monk CS, Nelson EE, et al. (2009): Common and distinct amygdala-function perturbations in depressed vs anxious adolescents. Arch Gen Psychiatry 66:275–285. [PubMed: 19255377]

90. Telzer EH, Mogg K, Bradley BP, Mai X, Ernst M, Pine DS, Monk CS (2008): Relationship between trait anxiety, prefrontal cortex, and attention bias to angry faces in children and adolescents. Biol Psychol 79:216–222. [PubMed: 18599179]

91. Motzkin JC, Philippi CL, Wolf RC, Baskaya MK, Koenigs M (2014): Ventromedial prefrontal cortex is critical for the regulation of amygdala activity in humans. Biol Psychiatry 77:276–284. [PubMed: 24673881]

92. Xu P, Gu R, Broster LS, Wu R, Van Dam NT, Jiang Y, et al. (2013): Neural basis of emotional decision making in trait anxiety. J Neurosci 33:18641–18653. [PubMed: 24259585]

93. Guyer AE, Nelson EE, Perez-Edgar K, Hardin MG, Roberson-Nay R, Monk CS, et al. (2006): Striatal functional alteration in adolescents characterized by early childhood behavioral inhibition. J Neurosci 26:6399–6405. [PubMed: 16775126]

94. Bar-Haim Y, Fox NA, Benson B, Guyer AE, Williams A, Nelson EE, et al. (2009): Neural correlates of reward processing in adolescents with a history of inhibited temperament. Psychol Sci 20:1009–1018. [PubMed: 19594857]

95. Helfinstein SM, Benson B, Perez-Edgar K, Bar-Haim Y, Detloff A, Pine DS, et al. (2011): Striatal responses to negative monetary outcomes differ between temperamentally inhibited and non-inhibited adolescents. Neuropsychologia 49:479–485. [PubMed: 21167189]

96. Guyer AE, Choate VR, Detloff A, Benson B, Nelson EE, Perez-Edgar K, et al. (2012): Striatal functional alteration during incentive anticipation in pediatric anxiety disorders. Am J Psychiatry 169:205–212. [PubMed: 22423352]

97. Lago T, Davis A, Grillon C, Ernst M (2017): Striatum on the anxiety map: Small detours into adolescence. Brain Res 1654:177–184. [PubMed: 27276526]

98. Justin Kim M, Shin J, Taylor JM, Mattek AM, Chavez SJ, Whalen PJ (2017): Intolerance of uncertainty predicts increased striatal volume. Emotion 17:895–899. [PubMed: 28517947]

99. Tottenham N, Galván A (2016): Stress and the adolescent brain: Amygdala-prefrontal cortex circuitry and ventral striatum as developmental targets. Neurosci Biobehav Rev 70:217–227. [PubMed: 27473936]

100. Fareri DS, Tottenham N (2016): Effects of early life stress on amygdala and striatal development. Dev Cogn Neurosci 19:233–247. [PubMed: 27174149]

101. Everitt BJ, Morris KA, O'Brien A, Robbins TW (1991): The basolateral amygdala-ventral striatal system and conditioned place preference: Further evidence of limbic-striatal interactions underlying reward-related processes. Neuroscience 42:1–18. [PubMed: 1830641]

102. Groenewegen HJ, Wright CI, Beijer AVJ, Voorn P (1999): Convergence and segregation of ventral striatal inputs and outputs. Ann N Y Acad Sci 877:49–63. [PubMed: 10415642]

103. Hart G, Leung BK, Balleine BW (2014): Dorsal and ventral streams: The distinct role of striatal subregions in the acquisition and performance of goal-directed actions. Neurobiol Learn Mem 108:104–118. [PubMed: 24231424]

104. Benson BE, Guyer AE, Nelson EE, Pine DS, Ernst M (2014): Role of contingency in striatal response to incentive in adolescents with anxiety. Cogn Affect Behav Neurosci 15:155–168.

105. Roy AK, Gotimer K, Kelly AMC, Castellanos FX, Milham MP, Ernst M (2011): Uncovering putative neural markers of risk avoidance. Neuropsychologia 49:937–944. [PubMed: 21354189]

106. Huggins AA, Weinberg A, Gorka SM, Shankman SA (2019): Blunted neural response to gains versus losses associated with both risk-prone and risk-averse behavior in a clinically diverse sample. Psychophysiology 56:e13342. [PubMed: 30719737]

107. Lahat A, Benson BE, Pine DS, Fox NA, Ernst M (2018): Neural responses to reward in childhood: Relations to early behavioral inhibition and social anxiety. Soc Cogn Affect Neurosci 13:281–289. [PubMed: 27531387]

108. Hanby MSR, Fales J, Nangle DW, Serwik AK, Hedrich UJ (2012): Social anxiety as a predictor of dating aggression. J Interpers Violence 27:1867–1888. [PubMed: 22203628]

109. Kashdan TB, Elhai JD, Breen WE (2008): Social anxiety and disinhibition: An analysis of curiosity and social rank appraisals, approach-avoidance conflicts, and disruptive risk-taking behavior. J Anxiety Disord 22:925–939. [PubMed: 17981434]

110. Kashdan TB, Hofmann SG (2008): The high-novelty-seeking, impulsive subtype of generalized social anxiety disorder. Depress Anxiety 25:535–541. [PubMed: 17935217]

111. Kashdan TB, McKnight PE (2010): The darker side of social anxiety: When aggressive impulsivity prevails over shy inhibition. Curr Dir Psychol Sci 19:47–50.

112. Kashdan TB, McKnight PE, Richey JA, Hofmann SG (2009): When social anxiety disorder co-exists with risk-prone, approach behavior: Investigating a neglected, meaningful subset of people in the National Comorbidity Survey-Replication. Behav Res Ther 47:559–568. [PubMed: 19345933]

113. Rounds JS, Beck JG, Grant DMM (2007): Is the delay discounting paradigm useful in understanding social anxiety? Behav Res Ther 45:729–735. [PubMed: 16890909]

114. Schneier FR, Foose TE, Hasin DS, Heimberg RG, Liu SM, Grant BF, Blanco C (2010): Social anxiety disorder and alcohol use disorder comorbidity in the National Epidemiologic Survey on Alcohol and Related Conditions. Psychol Med 40:977–988. [PubMed: 20441690]

115. Allan NP, Capron DW, Lejuez CW, Reynolds EK, MacPherson L, Schmidt NB (2014): Developmental trajectories of anxiety symptoms in early adolescence: The influence of anxiety sensitivity. J Abnorm Child Psychol 42:589–600. [PubMed: 24062146]

116. Crocetti E, Klimstra T, Keijsers L, Hale WW, Meeus W (2009): Anxiety trajectories and identity development in adolescence: A five-wave longitudinal study. J Youth Adolesc 38:839–849. [PubMed: 19636785]

117. Morin AJS, Maïano C, Nagengast B, Marsh HW, Morizot J, Janosz M (2011): General growth mixture analysis of adolescents' developmental trajectories of anxiety: The impact of untested invariance assumptions on substantive interpretations. Struct Equ Modeling 18:613–648.

118. Wierenga LM, Bos MGN, Schreuders E, Vd Kamp F, Peper JS, Tamnes CK, Crone EA (2018): Unraveling age, puberty and testosterone effects on subcortical brain development across adolescence. Psychoneuroendocrinology 91:105–114. [PubMed: 29547741]

119. Deater-Deckard K, Li M, Lee J, King-Casas B, Kim-Spoon J (2019): Poverty and puberty: A neurocognitive study of inhibitory control in the transition to adolescence. Psychol Sci 30:1573–1583. [PubMed: 31557444]

120. Galván A (2019): The unrested adolescent brain. Child Dev Perspect 13:141–146.

121. Fuligni AJ, Bai S, Krull JL, Gonzales NA (2019): Individual differences in optimum sleep for daily mood during adolescence. J Clin Child Adolesc Psychol 48:469–479. [PubMed: 28820607]

122. Uy JP, Galván A (2017): Sleep duration moderates the association between insula activation and risky decisions under stress in adolescents and adults. Neuropsychologia 95:119–129. [PubMed: 27986636]

123. Chiang JJ, Kim JJ, Almeida DM, Bower JE, Dahl RE, Irwin MR, et al. (2017): Sleep efficiency modulates associations between family stress and adolescent depressive symptoms and negative affect. J Adolesc Health 61:501–507. [PubMed: 28729144]

124. McMakin DL, Alfano CA (2015): Sleep and anxiety in late childhood and early adolescence. Curr Opin Psychiatry 28:483–489. [PubMed: 26382163]

125. Carlisi CO, Hilbert K, Guyer AE, Ernst M (2017): Sleep-amount differentially affects fear-processing neural circuitry in pediatric anxiety: A preliminary fMRI investigation. Cogn Affect Behav Neurosci 17:1098–1113. [PubMed: 28913727]

126. Kelly RJ, El-Sheikh M (2014): Reciprocal relations between children's sleep and their adjustment over time. Dev Psychol 50:1137–1147. [PubMed: 24188035]

127. Kouros CD, El-Sheikh M (2015): Daily mood and sleep: Reciprocal relations and links with adjustment problems. J Sleep Res 24:24–31. [PubMed: 25212526]

128. McMakin DL, Ricketts EJ, Forbes EE, Silk JS, Ladouceur CD, Siegle GJ, et al. (2019): Anxiety treatment and targeted sleep enhancement to address sleep disturbance in pre/early adolescents with anxiety. J Clin Child Adolesc Psychol 48(suppl 1):S284–S297. [PubMed: 29873503]