

Navigating the Social Environment in Adolescence: The Role of Social Brain Development

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ABSTRACT

Successful navigation of the social environment is dependent on a number of social cognitive processes, including mentalizing and resistance to peer influence. These processes continue to develop during adolescence, a time of significant social change, and are underpinned by regions of the social brain that continue to mature structurally and functionally into adulthood. In this review, we describe how mentalizing, peer influence, and emotion regulation capacities develop to aid the navigation of the social environment during adolescence. Heightened susceptibility to peer influence and hypersensitivity to social rejection in adolescence increase the likelihood of both risky and prosocial behavior in the presence of peers. Developmental differences in mentalizing and emotion regulation, and the corticostriatal circuits that underpin these processes, might put adolescents at risk for developing mental health problems. We suggest how interventions aimed at improving prosocial behavior and emotion regulation abilities hold promise in reducing the risk of poor mental health as adolescents navigate the changes in their social environment.

<https://doi.org/10.1016/j.biopsych.2020.09.012>

Adolescence is defined as the period of life between 10 and 24 years and is characterized by biological, psychological, and social change (1). In addition, adolescence is a time of heightened susceptibility to mental health problems, with approximately 75% of adult mental health disorders first appearing before the age of 24 (2). Changes in the social environment around the time of puberty often include the transition from primary to secondary educational settings, an increase in the number of peers, and an increase in time spent with peers relative to family (3). These changes present new challenges, including the need to integrate into large and unstable social networks and the possibility of peer rejection (4). Peer judgments influence adolescents' social and self-worth (5), and young people who adapt well to these changes by gaining a stable social position have better physical and psychological health outcomes (6,7).

Social cognitive processes, such as taking others' perspectives, regulating emotions, and managing peer influence, facilitate successful social transition into adulthood. Navigating the social environment is reliant on successfully employing these processes, and training certain abilities, such as emotion regulation, might foster resilience to mental health problems in adolescence. Here, we review research on the development of social cognitive processes, and structural and functional changes in the social brain, during adolescence.

SOCIAL BRAIN DEVELOPMENT IN ADOLESCENCE

During development, the brain undergoes substantial structural change in terms of gray and white matter volume, surface

area, and cortical thickness (8–10). Magnetic resonance imaging studies have shown that cortical gray matter volume increases during childhood, reaches a peak in late childhood, and declines during the second decade of life, eventually stabilizing in the mid-20s (9,11–13). At the same time, there is a linear increase in white matter volume across childhood and adolescence (9,11,12). It is important to note that these findings are based on averages, and the precise timing and trajectories of structural development of different regions show substantial variation between individuals in terms of intercept (e.g., overall volume) and slope of change (14,15). One source of individual variation in adolescence is puberty, and it has been proposed that brain development is influenced by the sex hormones that control the onset of and progression through puberty (16–19). For example, pubertal maturation is associated with developmental changes in subcortical brain volume beyond chronological age (20,21). The neural and psychosocial changes that are associated with progression through puberty can also produce mental health vulnerabilities (22).

Some of the latest maturing brain regions are found within the social brain, which is the network of regions involved in recognizing, understanding, and interpreting social cues from others. Brain areas involved in these complex components of social cognition include the dorsomedial prefrontal cortex (dmPFC), anterior cingulate cortex, inferior frontal gyrus, posterior superior temporal sulcus, anterior temporal cortex, amygdala, and anterior insula (23). Several regions within the social brain network are involved in mentalizing, which is the ability to interpret mental states, the feelings, and the actions of others (23) (see Figure 1).

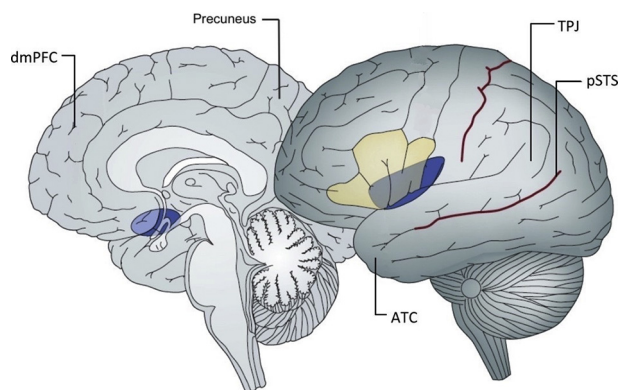


Figure 1. The mentalizing network. Regions that are involved in mentalizing include the dorsomedial prefrontal cortex (dmPFC) and temporoparietal junction (TPJ) (28,142–144), which are involved in inferring mental states; the precuneus, a region often coactivated with the medial PFC during perspective taking with mental imagery tasks; the posterior superior temporal sulcus (pSTS) (145,146), which is involved in face perception; and the anterior temporal cortex (ATC) (147), which is involved in representing and retrieving social knowledge [see meta-analysis in (148)]. [Adapted with permission from Blakemore (23).]

Longitudinal neuroimaging studies have shown that regions within the social brain undergo substantial and protracted structural development. For example, gray matter volume and cortical thickness in the posterior superior temporal sulcus, temporoparietal junction (TPJ), and dmPFC decrease from childhood into the early 20s, while in the anterior temporal cortex cortical thickness increases until early adulthood and gray matter volume increases until adolescence (24) (see Figure 2). Subcortical regions involved in the generation of emotions and emotion regulation, which is the ability to effectively manage and respond to an emotional experience (25), also show developmental change during adolescence. For example, the amygdala, which has vast connections with regulatory regions such as the PFC and anterior cingulate cortex, increases in volume by about 7% between late childhood and mid-adolescence, with no significant change after around 14 years of age on average (15) (note that there were significant individual differences in this pattern).

In addition to changes in brain structure, adolescence is a time of significant functional maturation of regions involved in social cognitive processes. These functional changes are reflected in studies exploring task-based activation patterns and functional connectivity between different brain regions. One longitudinal resting-state functional connectivity study showed that in contrast to the strong connectivity between brain regions implicated in sensory and motor function by 14 years of age (which became stronger from 14 to 26 years), disruptive development occurred in regions involved in higher-order processes. These included frontoparietal and limbic networks activated by tasks related to memory, mentalizing, and social cognition, with weak connections becoming stronger and strong connections becoming weaker (26). This suggests that disruptive maturation of functional connectivity might support the development of more sophisticated mentalizing, social

cognition, executive functioning, and emotion regulation skills as adolescents mature into independent adults.

SOCIAL COGNITIVE DEVELOPMENT IN ADOLESCENCE

Mentalizing/Perspective Taking

Mentalizing enables us to understand the minds and predict the behavior of other people (27). Developmental functional neuroimaging studies have compared the neural processing of mentalizing across age, usually by asking participants to think about other people's mental states. The TPJ, superior temporal sulcus, and precuneus show increased activity when young adolescents (28–30) listen to sections of a story describing a character's thoughts (requiring mental state attribution) compared with sections of the same story describing the physical environment (not requiring mental state attribution), and this activity is correlated with behavioral performance (30). Young adolescents have also demonstrated increasing specialization of the TPJ for mental state content with age (28,30). Other studies have also found age differences in the activation of the dmPFC and TPJ during mentalizing tasks [see review in (31)]. Several studies have found that activity in the dmPFC during mentalizing tasks decreases between adolescence and adulthood [see review in (23)]. Other studies have found that adults recruit the TPJ more strongly than adolescents when responding to scenarios relating to their own intentions versus physical events (32). Previous work in adults has found that the TPJ is recruited more by tasks requiring reasoning about others' intentions and beliefs (cognitive theory of mind) (33), while the medial PFC is recruited more by inferences about emotions and preferences (affective theory of mind) (34–36). The studies suggest that the pattern of recruitment of these brain regions during mentalizing changes across adolescence.

It has been suggested that adolescents, relative to adults, might be using different cognitive strategies when thinking about others' intentions (23). One theory proposes that during social tasks, adolescents use cognitive strategies that rely more on explicit reflection about the self and others, subserved by the dmPFC, whereas adults rely more on the automatic processing of social scripts, subserved by the temporal lobes (23). This might enable adults to process social information side by side with other demanding tasks more efficiently than adolescents. This hypothesis was tested and the prediction was supported by superimposing a working memory task on a mentalizing task (37). Studies are needed to further investigate this and replicate the limited number of developmental studies on mentalizing, particularly given the relatively small sample sizes and the dearth of longitudinal developmental studies (38).

The ability to take other people's perspectives is especially important when integrating into new social contexts and choosing peers with whom to align oneself. In one study, while both adolescents and adults recruited the dmPFC when taking someone else's perspective into account, adolescents—but not adults—also recruited the dmPFC when no social cues were present (i.e., when no perspective taking was required) (39). This suggests that adolescents recruit regions of the brain involved in mental state attribution in nonsocial contexts where

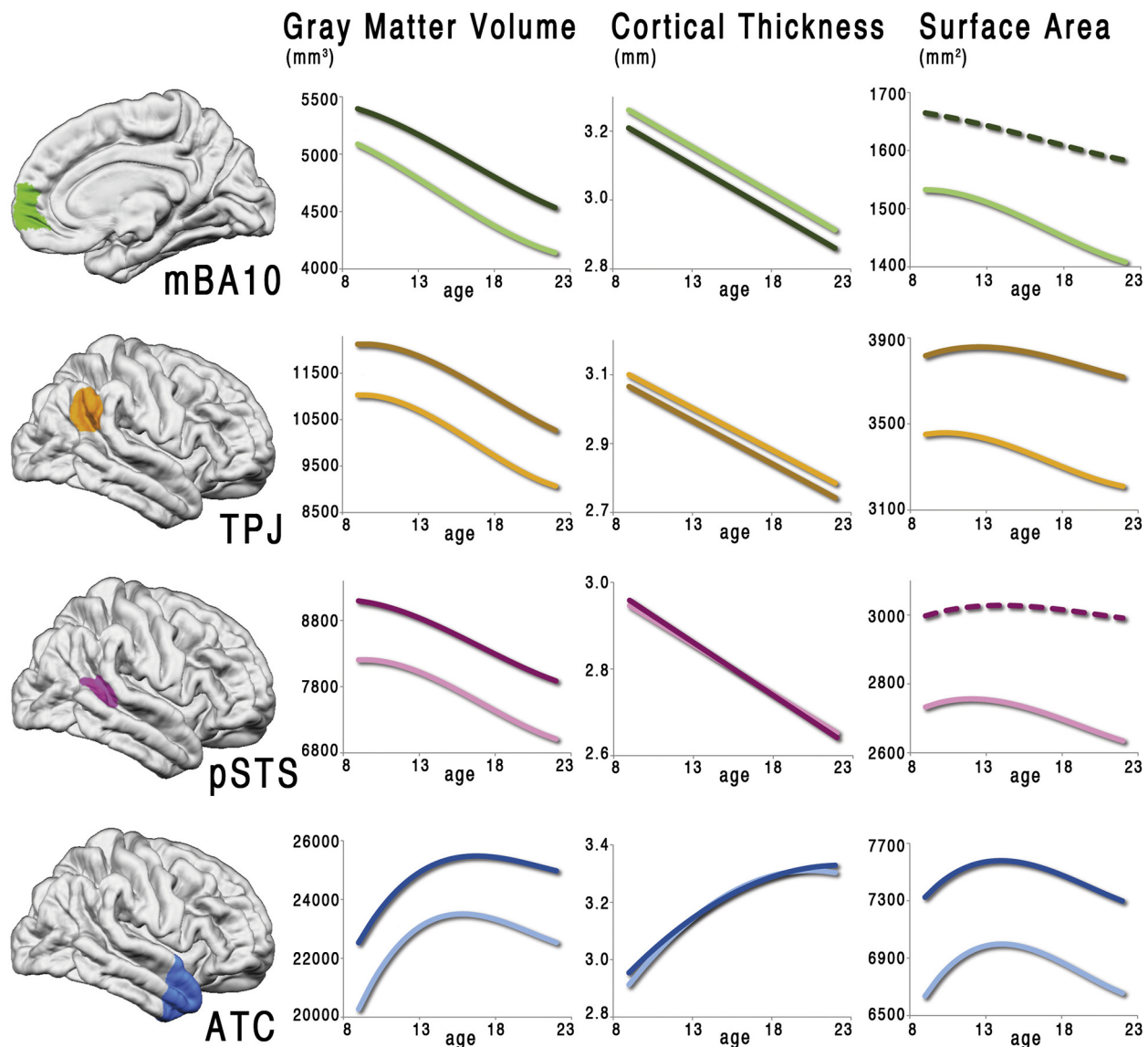


Figure 2. Best-fitting models of structural brain development across adolescence, shown for each region of interest (combined hemispheres). Each model is fitted to the middle 80% of the sample: ages 9 to 22 years for medial Brodmann area 10 (mBA10; corresponding to dorsomedial prefrontal cortex), temporoparietal junction (TPJ), and posterior superior temporal sulcus (pSTS); ages 11 to 24 years for anterior temporal cortex (ATC). Lighter lines show the fitted models applied to female subjects only, and darker lines show the fitted models applied to male subjects only. Solid lines indicate that the fitted model was significant ($p < .05$), and dashed lines indicate that the fitted model was not significant ($p \geq .05$). [Reproduced with permission from Mills *et al.* (24) and Oxford University Press.]

mentalizing is not required (37,39,40). Behavioral studies have demonstrated that the ability to take someone else's perspective is still maturing during adolescence (41–43), with children and adolescents making more errors than adults on perspective-taking tasks (41,42) [see review in (44)]. It has been suggested that inhibitory control, which is still maturing during adolescence, may be contributing to these differences (42).

To date, few studies have examined functional connectivity during mentalizing or perspective-taking tasks. In one such study, adolescents (aged 11–18 years), relative to adults, showed greater functional connectivity between regions of the

social brain (ventromedial PFC and posterior superior temporal sulcus/TPJ) when thinking about social emotions, such as guilt, relative to basic emotions, such as disgust, possibly indicating changes in the functional integration of the mentalizing network across development (45). However, other studies have found no age effects in functional connectivity within mentalizing brain regions during a false belief task (in 9- to 13-year-olds) (29) and a social evaluation task (in 8- to 16-year-olds) (46). The different age ranges studied and variations in the tasks employed may account for these differences in findings.

Mentalizing, the Peer Environment, and Mental Health

Adolescents who perform less well on tasks that involve inferring mental states from vignettes and film clips depicting social situations are more likely to report higher levels of loneliness and peer rejection, independent of age and socioeconomic status, compared with adolescents who show better mentalizing performance (47). Neuroimaging studies have reported increased activity in the medial PFC, precuneus, and TPJ (areas within the mentalizing network) in response to peer rejection (48,49). Social network studies, in which individuals' peer relationships are mapped, have related an adolescent's social network position to brain activation during tasks involving social information. In one such study involving 16- and 17-year-old boys, participants with higher brokerage—the ability to connect with otherwise disconnected others—exhibited greater activity within mentalizing brain regions when presented with divergent feedback from peers when recommending computer games (50). These findings suggest that the mentalizing network is more strongly recruited in risky social situations characterized by risk of rejection or dissimilarity to one's peers. Furthermore, interindividual variation in activity in brain regions involved in the processing of social exclusion and mentalizing following social exclusion predicted increased risk taking in the presence of a peer 1 week later (51). The authors suggested that adolescents who showed this heightened neural response in the face of social rejection may be more likely to change their behavior in the presence of peers in order to avoid further exclusion and to promote affiliation with peers.

In one study, increased functional connectivity between social brain regions involved in mentalizing during experimentally induced social exclusion, relative to social inclusion, was observed in adolescents (52). Stronger connectivity within the mentalizing network during exclusion was found among participants with less dense real-world social networks, characterized by fewer connections among one's friends (52). The authors suggested that this increased functional coupling between mentalizing regions following social exclusion might support the ability to consider the intentions of others, including people who are excluding the participants. Therefore, mentalizing may be involved in the successful adaptation to stressful social interactions. In turn, there is meta-analytic evidence of a reciprocal relationship between poor mentalizing abilities and mood disorders, such that impairments in mentalizing may be both a cause and an effect of internalizing disorders (53–55) [see review in (56)]. In one study of adolescents with depression, reduced mentalizing was associated with the severity of depression (57). The stress–reward–mentalizing model accounts for these findings by suggesting that child and adolescent depression emerges from the interaction among impairments in stress-regulatory, reward, and mentalizing systems (58).

Emotion Regulation

It has been proposed that the ability to regulate one's emotions in response to unfavorable social cues can buffer against negative mental health outcomes [see review in (25)]. One study showed that adolescents who are accepted by their peers

exhibit more adaptive emotion regulation and are at lower risk for internalizing symptoms (59). It has been hypothesized that the protracted development of the PFC (which is typically recruited during emotion regulation) renders adolescents less able to regulate their emotions successfully (25), putting them at greater risk for anxiety- and stress-related disorders [see review in (60)]. Behavioral and neuroimaging studies of typically developing young people suggest that emotion regulation capacities develop substantially across adolescence (61,62), with an increased use of adaptive emotion regulation strategies with age (63–65). Age-related improvements in emotion regulation have been associated with reduced amygdala activation (66,67) and inverse coupling (i.e., negative functional connectivity) between the ventromedial PFC and amygdala (66). By mid-adolescence, most individuals exhibit inverse amygdala–PFC connectivity (compared with positive connectivity in childhood), with stronger inverse connectivity associated with fewer symptoms of nonclinical anxiety (68,69). Disruptions in the same corticolimbic circuitry during emotion regulation have been implicated in anxiety and depression in adolescents (67,70–72) [see review in (73)]. For example, in female adolescents, positive amygdala–ventrolateral PFC connectivity during an emotion regulation task predicted future symptoms of anxiety over the subsequent 9 months (70). Positive amygdala–ventrolateral PFC connectivity was also related to greater self-reported rumination and mediated the association between self-reported rumination and depressive symptoms following a social exclusion task (74).

The ability to mentalize is considered a key factor in the development of adequate emotion regulation abilities (75). Studies have also shown that adolescents' vulnerability to peer influence may be mediated by neural mechanisms that underlie emotion regulation, attentional control, and mentalizing (61,66,76). These findings suggest that individual variation in emotion regulation abilities might contribute to risky decision making in the presence of peers. Furthermore, poor emotion regulation predicts greater participation in risky behaviors (77,78), and the mere exposure to peers online can alter self-regulation (79). Negative social situations, such as being socially excluded, require increased emotion regulation, and this has been found to recruit regulation networks in adolescents (80). Social exclusion might also require an increased effort to understand the intentions of others (e.g., “Why did they reject me?”); however, further research is needed to explore this.

Between 12 and 15 years of age, less adaptive and more maladaptive emotion regulation strategies, such as rumination, avoidance, and suppression, are observed in comparison with other age groups (63). Therefore, training adaptive emotion regulation skills may be useful in this age group [see meta-analysis in (81)] and may represent a fruitful avenue for helping adolescents to deal with stressful social situations and reduce the risk of developing depression and anxiety (25,71,82). Several studies have shown positive short-term effects of instructed emotion regulation strategies such as distraction, acceptance, and cognitive reappraisal, which is reinterpreting a negative event in a more positive way, in early and mid-adolescence (83–85) and in clinically anxious youths aged 8 to 17 years (86).

Further research is needed to investigate mechanisms of psychological interventions targeting emotion regulation

abilities and whether training emotion regulation skills mediate the impact of psychological interventions on internalizing symptoms. Emotion regulation intervention studies with larger samples and in adolescents with psychiatric conditions are needed to investigate the long-term benefits of emotion regulation training and how the neurocognitive development of social cognitive skills, such as mentalizing, contributes to the use of particular emotion regulation strategies.

PEER INFLUENCE IN ADOLESCENCE

Adolescents are particularly susceptible to peer influence, especially in risky contexts. Research has also begun to explore the positive influence peers can have on prosocial decisions, and even on prosocial risk taking, as described below.

Peer Influence on Risk Behavior

Belonging to a peer group that engages in antisocial or illegal behavior is a risk factor for engagement in a number of negative health risk behaviors (87). Evidence from longitudinal social network studies has demonstrated that this clustering of risk behavior is associated with both peer selection and peer socialization, in which an individual's behavior changes over time as a result of shifts in the behavior of friends (88). Furthermore, engagement in certain risk-taking behaviors may be dependent on status such that both high- and low-status individuals tend to take more risks, but with different intentions (e.g., to maintain or gain status) (89). Longitudinal studies have shown that risk taking is predicted by whether or not an adolescent endorses societal stereotypes of adolescent risk taking, via activity in cognitive control-related brain regions such as the ventrolateral PFC (90). This suggests that stereotypes about adolescents may play a role in how the brain responds to risk taking during adolescence (91).

Multiple theoretical models have been proposed to explain the mechanisms underlying peer influence effects on risk taking and have distinguished among social motivation, reward sensitivity, and distraction (92). While not mutually exclusive, each model emphasizes different neurodevelopmental processes that lead to altered decision-making processes during adolescence. For example, social motivation models are underpinned by developmental changes observed in the social brain (23,24) and emphasize the importance of the social value given to peer group norms in guiding decision-making processes (93). Conversely, reward sensitivity and distraction models highlight the continued maturation of cognitive control and its neural systems during adolescence. The reward sensitivity, mismatch, or dual systems model (94–96) is based on the notion that regions of the brain that support cognitive control (e.g., the PFC) mature at slower rates than brain regions implicated in reward processing (e.g., the nucleus accumbens and ventral striatum) and emotional reactivity (e.g., the amygdala). This model is also used to explain the weaker emotion regulation abilities of adolescents compared with adults (25) [note that these models have been critiqued; e.g., (97)]. Value-based explanations of adolescent decision making (98), which account for the subjective value placed on each component of a decision, are consistent with social motivation models whereby a high value is placed on peer group norms and this

guides behavior during adolescence (93). This is supported by a study showing that young adolescents (aged 12–14 years) are more influenced by the risk perception of teenagers than of adults (99) and that this susceptibility to peer influence is even stronger when they believe that other teenagers rate a situation as more risky than they initially thought it was (100).

During adolescence, the social context might influence the reward value associated with engagement in risk behaviors (101). Studies using simulated driving tasks show that adolescents are more likely than adults to take risks when in the presence of their friends compared with when driving alone (101–104). This is particularly pronounced when their passengers reported a strong preference for risk taking (105) and when participants reported lower resistance to peer influence following social exclusion (106). Adolescents also exhibited greater activity in brain regions implicated in reward processing, including the ventral striatum and nucleus accumbens, when taking driving risks in the presence of peers (101,102). Adolescents' neural sensitivity to a response inhibition task was found to predict their risk-taking behavior under peer influence; in a simulated driving game, higher activation in the ventral striatum and PFC was associated with engaging in fewer risks, when paired with cautious peers (104). This suggests that stronger inhibitory activity in a cognitive control task predicts the extent to which adolescents are influenced by the social norms of safety-promoting peers. These studies demonstrate that during adolescence the presence of peers might increase the reward value of a risky decision, supporting both social motivation and reward sensitivity models [see reviews in (107,108)].

Adolescents and young adults also take more risks on the Balloon Analogue Risk Taking task, in which participants inflate a virtual balloon for a monetary reward when encouraged by a peer compared with either being alone or in a peer's presence but without encouragement (109) or when other participants are perceived to be making high-risk choices versus low-risk choices (110). This is consistent with findings showing that adolescents follow suit when observing peers make safe, risk-averse, and prosocial decisions (92,105,111–113). Neural responses during the Balloon Analogue Risk Taking task were associated with adolescents' behavioral conformity to safe versus risky peer influence during a driving task 1 week later, and connectivity among the ventral striatum, insula, and anterior cingulate cortex predicted safer driving under risky peer influence (114).

Young people who are affiliated with antisocial peers are more prone to developing externalizing disorders such as antisocial behavior and substance use during adolescence (115–118). One study found that the genetic influence on adolescent externalizing disorders was greater when the degree of antisocial peer affiliation was higher and that it was smaller when the degree of antisocial peer affiliation was lower (119). This finding that antisocial peers appear to activate genetic risk for externalizing problems was found only in adolescents aged 17 years and not at 20, 24, or 29 years of age [see also meta-analyses in (120,121)]. This suggests that adolescence is a sensitive period for the development of externalizing problems, particularly in adverse social environments.

Avoiding the Social Risk of Rejection

Adolescents demonstrate hypersensitivity to the negative effects of social rejection (122–124), and it has been proposed that adolescents are more likely to take health and legal risks in the presence of their peers in order to avoid the social risk of rejection (31,125). Social rejection is associated with disruptions in emotion regulation (126) and is a risk factor for adolescent-onset mood disorders such as depression and anxiety (127–129). Therefore, adolescents who engage in health risk behaviors, such as smoking, when this is the peer group norm may be doing so in order to avoid the social risk of rejection even when such risks carry negative health or legal consequences (125). In one study, adolescents reported greater concern about engaging in social risks, such as defending an unpopular opinion, relative to adults. In addition, greater concern for social risk was more strongly related to rejection sensitivity and depressed mood in adolescents (11- to 17-year-olds) compared with adults (130). Making decisions that increase their social value by reducing their risk of social rejection might be adaptive for adolescents, whose social status and high-quality friendships are known to be related to better psychological and physical health outcomes (6,7). Thus, deciding to engage in risk behaviors such as smoking and binge drinking when in a peer group setting, while not being an objectively good decision, might not necessarily be an irrational choice for adolescents when these risk behaviors are valued by the peer group. Reducing their social risk by engaging in behaviors, risky or otherwise, that increase their social status and reduce their risk of rejection may be especially important for adolescents.

Peer Influence on Prosocial Behavior

While adolescents are particularly susceptible to peer influence in risky contexts, experimental research has begun to explore the positive influence peers can have on prosocial decisions [see review in (131)]. Adolescents are more likely to volunteer in the community if they observe peers doing so (132), and adolescents are more likely than adults to be influenced by others toward (hypothetical) prosocial behaviors (112). As with risk-taking behavior, high-status peers (132) and very close friends (133) tend to be more influential. In incentivized charitable donation tasks and public goods games, adolescents who observed peers being generous were more likely to be generous themselves (113) and exhibited higher activity in social brain regions, such as the dmPFC, TPJ, precuneus, and superior temporal sulcus, during prosocial decision making (113,131,134). In a study of older adolescents (mean age of 20 years), participants recruited brain regions involved in self-control and mentalizing when making decisions to donate money to family members. Greater functional coupling between self-control and mentalizing regions with the ventral striatum was observed in participants who reported stronger familial obligation (135). This suggests that prosocial behavior may be reliant on the development of brain regions involved in mentalizing and self-control in addition to reward-related regions.

Recent studies have investigated prosocial risk taking, which is making risky decisions with the intention of helping others—for example, standing up to someone who is bullying a

friend [see reviews in (136,137)]. Findings show that unlike potentially harmful risk-taking behaviors such as reckless driving and illicit drug taking, prosocial risk taking is not associated with impulsivity or risk taking in experimental tasks and is instead associated with lower reward sensitivity, higher punishment sensitivity, and greater school engagement (138). These findings demonstrate that positive risk taking, as opposed to negative risk taking, may be beneficial for adolescents.

The evidence that peers have the capacity to influence decisions toward positive outcomes can inform interventions aimed at improving health and well-being during adolescence (113,131,139). Indeed, studies that target social norms through peer-led interventions during adolescence have shown positive outcomes across a number of domains, including a 25% reduction in bullying over 1 year in middle schools (140) and a sustained reduction in the uptake of regular smoking in students aged 12 and 13 years for 2 years after the intervention's delivery (141). Therefore, peers might influence adolescent adherence to a variety of interventions. This area of research is becoming increasingly important in understanding the context in which interventions are most successful.

CONCLUSIONS

Adolescence is a time of social transition during which a number of social cognitive processes, such as mentalizing, resistance to peer influence, and emotion regulation, continue to mature alongside the brain systems that support them. Adolescents are especially vulnerable to mental health problems and risk factors in the social environment, such as peer rejection, contribute to this vulnerability. Interventions aimed at improving prosocial behavior and emotion regulation abilities, particularly in ambiguous or risky social situations, may hold promise in reducing some of this vulnerability toward poor mental health.

ACKNOWLEDGMENTS AND DISCLOSURES

S-JB is funded by Wellcome, the Jacobs Foundation, and the University of Cambridge. SPA is funded by a Wellcome grant to S-JB (Grant No. WT107496/Z/15/Z). JLA is funded by a Medical Research Council studentship.

The authors report no biomedical financial interests or potential conflicts of interest.

ARTICLE INFORMATION

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Received Feb 20, 2020; revised Sep 4, 2020; accepted Sep 14, 2020.

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