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Peer influence effects on risk-taking and prosocial decision-making in adolescence: insights from neuroimaging studies

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Peer influence plays a key role in health-compromising risky behaviors during adolescence. However, there is emerging evidence indicating that peer influence can also lead to positive psychosocial outcomes, such as learning, exploration and prosocial behavior. This review highlights the maladaptive and adaptive nature of peer influence and identifies recent functional neuroimaging research investigating the underlying neural mechanisms thereof. In the context of risk-taking, peer effects have been associated with amplified motivational circuitry, including ventral striatum. The social brain (medial prefrontal cortex, temporo-parietal junction and superior temporal sulcus) has been related to peer influence in neutral/prosocial contexts. We propose that peer influence may enhance activation in task-related brain areas; and that the interplay between the motivational circuitry and social brain regions should be investigated to advance our knowledge about the neural underpinnings of peer influence.

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Introduction

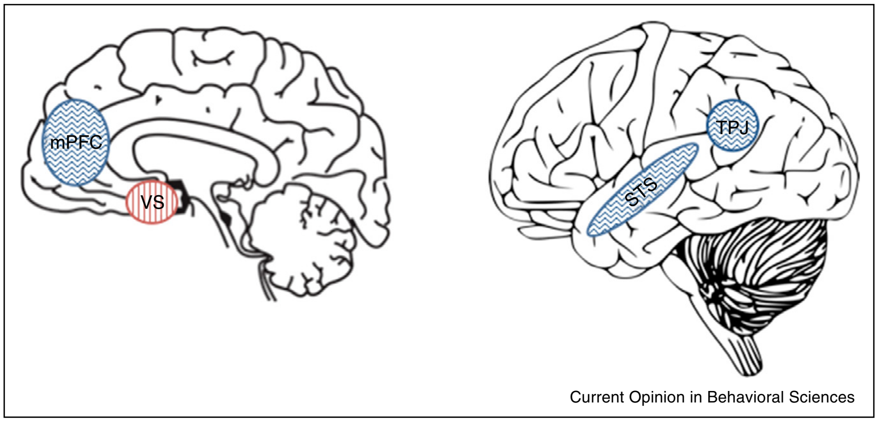
Adolescence is a developmental phase characterized by significant changes in social cognition, during which social evaluation by peers as well as the need to feel accepted become highly salient [1,2]. A vast literature indicates that health-compromising risky behaviors increase when adolescents are with their peers [3,4]. However, recent work finds that the influence of peers may be positive as well, for example in reinforcing prosocial development [e.g., 5]. Such findings suggest that adolescence may be a developmental period with particular sensitivity to the social context [2,6], which may either be either beneficial or detrimental for social development.

Neuroimaging studies have started to elucidate the neural underpinnings of peer influence and risk-taking in the adolescent brain. One theoretical framework that guided this research is the maturational imbalance model of adolescent risk-taking [7,8]. This model posits that prefrontal control systems in the developing brain show protracted maturation, whereas the motivational circuitry associated with reward and socio-emotional processing, such as ventral striatum (VS) and amygdala, is hyperactive in adolescence. Peer presence during risky decision-making is found to enhance reward-related VS activity in adolescents, but not in (young) adults [9••] (see Figure 1). Below we summarize studies that have examined how peers influence reward sensitivity in different types of risky and prosocial behavior.

A second line of research shows that peer influence is associated with heightened activation in areas within the social brain network [10•,11••,12••,13]. This network, involved in thinking about the self and others, encompasses cortical structures such as medial prefrontal cortex (mPFC), temporo-parietal junction (TPJ), and superior temporal sulcus (STS) [reviewed in 2,14]. These social brain areas are distinct from the areas described in the imbalance model, and these two lines of research are typically described separately (see Figure 1). It is not well understood how the motivational circuitry and social brain areas interact in shaping the peer influence process.

In this review, we first outline behavioral studies that address peer influence in the domain of risk-taking behavior and extend this line of research into the prosocial domain. Then, we discuss evidence of amplified activity in the motivational circuitry on the one hand, and social brain regions as underlying processes for peer influence on the other. We propose that it is important to investigate the interplay between the motivational circuitry and social brain network in the neural underpinnings of peer influence.

Figure 1



Brain regions previously implicated in risk-taking (indicated in red stripe pattern) and social information processing (indicated in blue zigzag pattern). *Abbreviations*: mPFC, medial prefrontal cortex; STS, superior temporal sulcus; TPJ, temporo-parietal junction; VS, ventral striatum.

Risk-taking behavior and beyond: the adaptive side of peers

Peer influence is a phenomenon often associated with negative connotations. There is substantial evidence showing that peers are a crucial factor in the increase of health-risk behaviors during adolescence, such as smoking, substance use and risky driving [3,4]. The majority of experimental research corroborates these real-world trends, showing that peers increase risk-taking in laboratory tasks during adolescence [9••,15,16•,17•,18–20], although other studies report mixed findings [see [21,22]].

More recently, researchers have started to present adolescence as a window for change and opportunity rather than solely a period of vulnerability [23••]. In line with this perspective, peer influence can be characterized as a socialization process that may either increase maladaptive risk-taking behaviors or facilitate learning and adaptive prosocial development. For instance, peer presence during late adolescence is linked to more exploratory behavior and higher learning rates from positive as well as negative task feedback [24••]. Although these findings imply that peer presence is adaptive for learning, such outcomes may be dependent on characteristics, including task difficulty and identity of the observer [see 25].

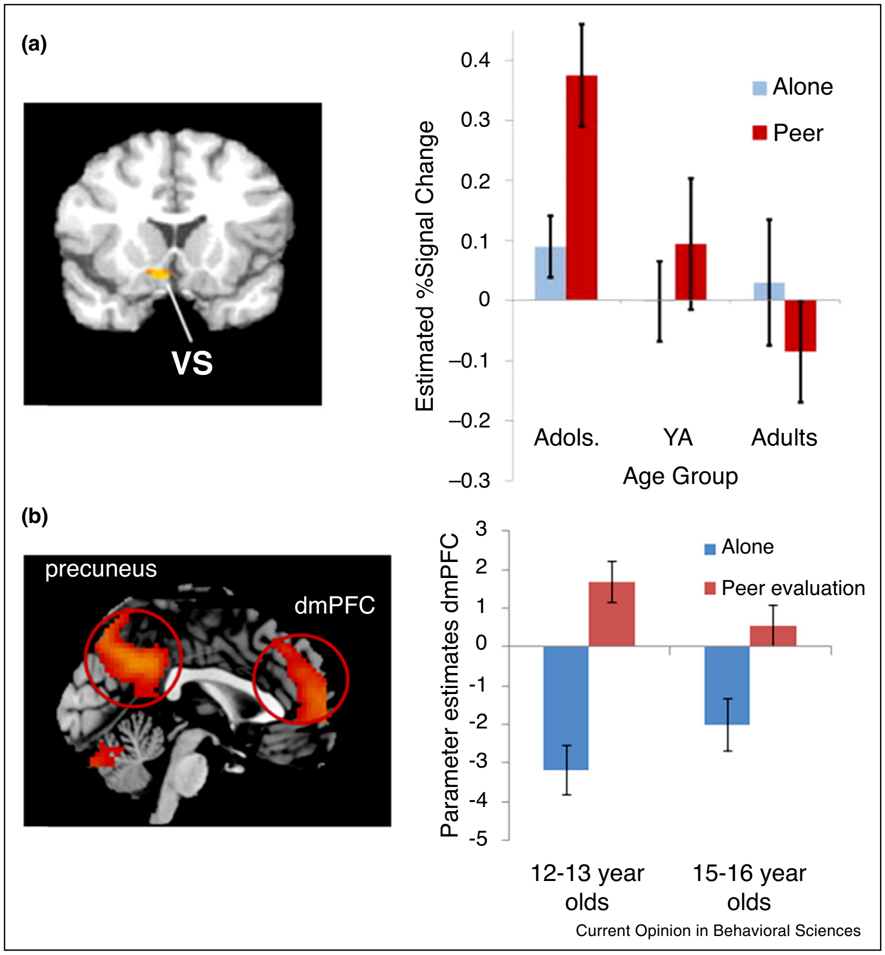
In line with these perspectives, developmental experimental research has ventured in the domain of prosocial behavior and shows promising evidence that peers can promote prosocial behaviors during adolescence [5,26]. One study investigated peer effects on public goods donations during adolescence. It showed that prosocial behavior over the task changed in line with social norms from peers (i.e. an increase after prosocial peer feedback and a decrease after antisocial peer feedback) [5, see [27,28] for background on social norms]. Moreover, another study concluded that peers positively affect the intention to volunteer in adolescence when they endorse volunteering, but even more so when these peers have a high status than a low status [26]. There is also evidence from non-experimental studies suggesting links between peer influence and prosocial outcomes [e.g. 29–31, for a review on social network analysis see [32]]. The next section identifies the brain regions responsible for the above findings, particularly enhanced motivational circuitry and social brain regions.

Peer influence: amplified motivational circuitry

The interconnections between ventral striatum (VS), involved in learning and prediction of rewarding outcomes, and amygdala, implicated in associative learning and determining emotional significance, lead to motivated and goal-oriented actions [reviewed in 6]. In line with the imbalance model, VS activity in response to reward peaks during adolescence [33–36] and is linked to self-reported risk-taking behavior [37,38]. Research suggests that laboratory-based risk taking is also associated with enhanced VS activity, a phenomenon that is exaggerated in the presence of peers [9••].

Chein and colleagues asked adolescents, young adults and adults to play a computerized risky driving task either alone or with a peer present ([9••]; see Figure 2a). With peers present, risk-taking behavior increased in adolescents - but not (young) adults — and this was associated with enhanced activation in the VS and orbitofrontal cortex. This age-specific peak in reward-related activity is also present during a gambling task with no risk involved [39], and thus occurs even outside the context of risky decision-making. These neuroimaging findings are consistent with peer effects in behavioral studies reporting that peer presence and influence are related

Figure 2



(a) Ventral striatum activity in response to reward is enhanced when peers observe risky decision-making for adolescents, but not young adults or adults [9••; reprinted with permission from authors]. **(b)** dmPFC, precuneus, TPJ and STS show heightened activation during prosocial decision-making with peer evaluation in adolescence [11••; reprinted with permission from authors].

to an increased preference for smaller immediate rewards over larger long-term rewards [18,20,40]. Taken together, these findings suggest that the presence of peers increases the motivational salience of rewards, likely motivating adolescents to seek out opportunities for reward [9••].

Peer influence: implications of the social brain

Consistent evidence has demonstrated that the social brain network is comprised of dorsal and ventral medial PFC, TPJ, precuneus and STS [2,10•,14,41]. Although the broader medial PFC is implicated in social cognition, the peak in functional activity during adolescence is generally observed in dorsal medial PFC [42]. These social brain areas also exhibit protracted structural development throughout adolescence [43], but it is currently not known how exactly these regions develop across adolescence. The social brain has been the focus of recent investigations regarding social influence more broadly (i.e. from different sources) and outside the context of risk-taking behavior.

Basic peer evaluation elicits uniquely heightened mPFC activation and physiological arousal in adolescents relative to children or adults, even without performing a laboratory task [10•]. Furthermore, one study investigated the neural correlates of influence from peers and parents on artwork ratings in adolescence [12••]. Influence from both peers and parents elicited activity in a more extensive network of brain regions, including mPFC and TPJ (mentalizing), vmPFC (reward-related processing) and vlPFC (self-control). Thus, peer and parental influence in the context of this relatively neutral task seem to share the same underlying networks in adolescence [12••]. Collectively, these studies point to the recruitment of mPFC and other (social) brain areas in peer and parent influence, which is consistent with previous studies in adults that also revealed an important role for mPFC in social influence [13,44].

These neural findings align with developmental comparisons in the domain of social influence on risk-taking by Knoll and colleagues, which suggest that peers are more influential than adults only in early adolescence (12–14 year-olds) [16•]. Although both parents and peers are an important context for socialization during the adolescent years, each can provide a very different perspective with distinct courses of action [12••]. Therefore, it is important for future research to further clarify developmental patterns and investigate the impact of different sources of influence in various contexts [also see [45] for a recent review on adolescent neurobiological susceptibility].

To study if these social cognition processes also influence prosocial behavior, a recent neuroimaging study assessed peer effects on public goods donations during adolescence [11••]. Donation choices with a spectator group present, as opposed to donations when playing alone, revealed heightened activity in dmPFC, precuneus, TPJ and STS. However, no increase was found for reward-related processing (see Figure 2b). These findings highlight the role of such mentalizing regions in peer influence and are consistent with research relating to the effect of prosocial behavior toward the family [46•] and public goods donations in adults [47].

Prosocial decision-making during adolescence has previously been linked to activity in both the social brain network (e.g. taking the perspective of others) and reward-related regions (possibly reflecting the rewarding nature of prosocial behavior) [48–50]. The social brain and reward-related regions have connections to the control circuits, such as dlPFC to control selfish or self-oriented decisions. Taken together, these studies suggest that peers may influence prosocial decision-making by triggering regions of the social brain network that have been shown to be implicated in prosocial behavior.

Conclusions and future directions

This review highlights emerging research illustrating that peer influence in adolescence can be characterized as a socialization process that leads to either health-compromising risky behaviors (i.e. risky driving) or positive psychosocial outcomes (i.e., learning, exploration and prosocial behaviors). The latter is a promising basis for school-based interventions to promote prosocial behaviors [see e.g., Good Behavior Game 51]. This notion of peer influence having both negative and positive effects on social development is consistent with prior studies, which indicate that adolescents are specifically attuned to the social context. An important future direction will be to test if these effects are uniquely social (i.e. more sensitivity to social than non-social signals) or illustrate a general enhanced sensitivity to learning signals [2].

On a neural level, peer influence during risk-taking behavior elicits heightened activation in subcortical reward-processing areas, mainly ventral striatum (VS). Peers also evoke activation in the social brain network, including cortical social brain areas (medial PFC and TPJ) during prosocial decision-making. We propose that peer influence may *heighten* activity in task-relevant brain areas, contingent on the type of behavior. Heightened activity may be reflected as enhanced reward-related processing in VS during risk-taking behavior, and in social brain areas such as mPFC and TPJ in the context of prosocial behavior [11••]. There are suggestions in the literature that heightened activity can be interpreted as greater activation of the psychological constructs associated with these regions [e.g. 37]. Future studies should focus on the relation between brain activation and behavioral outcomes, to unravel in more detail how neural activity relates to the underlying psychological constructs.

Currently, it is unclear how the motivational circuit and social brain network interact to shape peer influence processes. It is crucial to study these networks and their interactions collectively rather than separately. This may be possible with a task that draws upon both processes to begin with (e.g., gambling for a friend [52]), to which a peer influence condition can be added. Moreover, most studies have not compared peer influence to other sources of influence, such as parents. In the neutral domain, peer and parental influence seem to rely on the same neural basis [12••]. More research is needed to replicate these findings and to compare sources of influence in different contexts in order to draw conclusions about the specificity of the current findings.

There are several other outstanding questions for future research. For instance, to what extent do peers affect cognitive control during adolescence? Initial evidence shows that adolescent — but not adult — performance on a cognitive relational reasoning task is affected by an audience [25•]. Taking a slightly different approach, one recent study related brain activation in control systems (inferior frontal gyrus and basal ganglia) during a go-no-go task to simulated driving behavior with a peer one week later [53]. Activation in control systems was predictive for safer driving when a cautious peer confederate was present; but not with a risk-encouraging peer confederate. This context-dependent activation may implicate that neural resources are used differently depending on characteristics of the peer [13].

By further researching the effects of peer influence, we may be able to assist adolescents in navigating a complex social phase of their lives [2,6]. Importantly we can begin to gain traction on identifying overlapping and non-overlapping neural systems that contribute to characteristic adolescent behavior.

Conflicts of interest

Nothing declared.

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