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Social contextual risk taking in adolescence

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Abstract | Adolescence is a time of heightened risk-taking behaviours. Such risk taking does not occur in a vacuum because most decisions of adolescents to engage in risky behaviours are shaped by their social environment. These risk-taking behaviours also change across adolescence, in line with the development of their underlying brain structure and function. In this Review, we discuss how adolescents take risks that affect themselves (self-oriented risks) by using social contextual information (risks that affect themselves in the presence of their peers or parents) and how adolescents take risks that affect others (other-oriented risks), whereby the target of their risk taking serves as the social contextual information (risks that affect their peers or parents). Self-oriented and other-oriented risks are shaped by reconfigurations in brain systems implicated in processing affective-salience, cognitive control and social cognition. Given the developmental changes in self-oriented and other-oriented processes across adolescence, we also discuss how both the 'self' and the 'other' are integrated into the social contextual risk taking of adolescents throughout this period of development.

Adolescence is a developmental window marked by socio-emotional, cognitive and neurobiological transformations. Early adolescence (approximately ages 10 to 13), which typically coincides with the start of middle school in the USA, is characterized by the onset of a myriad of changes including the beginning of independence from parents, the emergence of advanced reasoning skills, and the start of puberty[1]. By late adolescence (approximately ages 17 to the early 20s), individuals have typically completed formal schooling, established a sense of self, consolidated advanced reasoning skills and reached sexual maturity[1–3]. Between these ages, an uptick in risk-taking behaviours is one defining feature[4,5]. Risk-taking behaviours involve decisions with uncertain outcomes that may result in either detriments or benefits in a given domain including finance, health and social relationships[6]. Whereas some risk-taking behaviours are negative and health-compromising, such as substance use and unsafe sexual practices, other risk-taking behaviours are positive and strategic, such as protesting against racism and standing up to a bully[7–12]. Risk-taking behaviours are diverse and ubiquitous in an adolescent's daily life but range in severity, spanning from leaving home without an umbrella on a cloudy day to driving recklessly without wearing a seatbelt. Moreover, adolescents' risk-taking behaviours have a range of short-term and long-term implications for their academic performance, social relationships and mental and physical health[13–15]. Thus, understanding the psychological features of risk-taking behaviours during adolescence is crucial for helping adolescents to succeed within the growing complexity of their social world.

Risk taking in adolescence does not occur in a social vacuum: most risk-taking behaviours take place in a social context, because most risks involve other people (for example, adolescents engaging in risky behaviours together with friends)[5,16,17]. In this Review, social contextual risk taking refers to risk-taking behaviours that occur in social settings. Indeed, adolescence is characterized by amplified sensitivity to social information and improvements in social-cognitive abilities such as perspective taking[18–20]. Adolescents' social contextual risk taking can be broadly categorized into two types: self-oriented risks in which the risk taking using social contextual information primarily affects the individual self, and other-oriented risks in which the risk taking primarily affects others, for which the social target of the risk taking itself is the social contextual information. We emphasize that whether a risk is self-oriented or other-oriented depends on the primary target of the risk-taking behaviour. Furthermore, important neurodevelopmental changes in the brain occur across adolescence that have implications for modulating self-oriented and other-oriented risks, including changes that make social stimuli particularly salient and are thought to contribute to the observed changes in social contextual risk taking[5,19,21–25].

Both self-oriented and other-oriented risks are common in adolescents' everyday lives. An example of a self-oriented risk is when adolescents drink alcohol at

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a party after seeing their friends drinking and having fun. This social landscape encourages adolescents to engage in alcohol use, a behaviour that may benefit them by helping them fit in, but also may harm them by compromising their attention, memory and physical health. By contrast, an example of other-oriented risk is a newly licensed adolescent driving the family car. Here, adolescents may benefit their parents by running errands on their behalf, but may also harm their parents if they get into an accident, and thereby impose emotional and financial damages. Indeed, the role of social context could be made more pertinent by having a friend in the family car, but the consequences of the risky behaviour continue to target the adolescent's parents primarily in that scenario. Self-oriented and other-oriented risks can occur within finance, health and social relationship domains. In a financial domain, for instance, adolescents may spend their own money in a less regulated manner when around their friends (self-oriented risk) or use their parents' money intended for groceries on miscellaneous purchases instead (other-oriented risk). In a health domain, adolescents may be influenced by their friends to join a parkour club and get physically hurt (self-oriented risk) or may smoke in front of their younger sibling who looks up to the adolescent as a role model and subsequently adopts their smoking behaviour too (other-oriented risk). Finally, in a social relationship domain, adolescents may disclose a secret about themselves to their friends (self-oriented risk) or a secret confided to them by someone else (other-oriented risk). Although social information from the environment shapes adolescents' risk-taking behaviours for both self-oriented and other-oriented risks, how adolescents gauge and respond to the 'self' and the 'other' in their decision-making processes varies, and these examples thereby represent risk-taking behaviours with varying levels of self–other integration.

In this Review, we seek to understand self-oriented and other-oriented risk taking from a neurodevelopmental perspective. We first review social and developmental theories to provide a theoretical framework within which to define social contextual risk taking. Next, we review key brain systems that undergird changes to social contextual risk taking during adolescence, and we provide insights from functional magnetic resonance imaging (fMRI) studies investigating self-oriented and other-oriented risk taking. We then discuss the overlap between self-oriented and other-oriented risks by probing how both self-referential and other-referential processes are integrated in risky decision-making. We conclude by discussing suggestions for future research to investigate other-oriented risk taking using diverse targets and longitudinal changes in neural patterns that subserve social contextual risk taking.

Social and developmental theories

The psychological mechanisms that take in, process and ultimately incorporate various social information from the environment are elaborate processes that together undergird social contextual risk taking[4,5]. In this section, we review three social and developmental theories to define social contextual risk taking in terms of how adolescents identify with social agents, construe social norms, learn social behaviours and integrate social information into their actions. Social contextual risk taking is a complex behaviour and so these theories shed light on the various psychological mechanisms through which this behaviour may take place.

Social identity theory. According to social identity theory, an individual's sense of self depends on the social group to which they belong[26]. An individual's group membership and its associated norms determine how one should behave in various social contexts, and therefore an adolescent's group membership may inform how they take risks on the basis of the risk norms espoused by their group[26,27]. As an adolescent's social world rapidly evolves beyond their family — the first social group to which an individual generally belongs — they become a part of multiple social groups such as primary friendship and school-related groups. Indeed, peer groups become increasingly important as adolescents begin to form intimate friendships that are grounded on shared interests, interdependence and attachment[28,29]. Simultaneously, ties to family are also reorganized during this time, such that adolescents seek greater individuation and parent–child relationships become more equal[30,31].

As maintained by social identity theory, individuals activate different identities in different social circumstances, are guided by various norms, and are able to switch flexibly between these norms depending on the social context[32,33]. When multiple norms are activated simultaneously, individuals adhere to the norms endorsed by the group they affiliate with more closely in that specific context and moment[32]. Consider an example scenario where peers endorse a risky behaviour whereas parents endorse a safe behaviour (FIG. 1). Here, an adolescent's decision to engage in risky or safe behaviour will depend on the saliency of the social context promoting either behaviour. If an adolescent more strongly affiliates with their peers' risk norms than their parents' risk norms in the given context, then social identity related to their peers is likely to be activated and the adolescent will select the risky behaviour. Thus, the more salient social identity in that context will affect how adolescents make decisions by more strongly activating that social group's risk norms (FIG. 1a).

Social information processing theory. Social information processing theory posits that an adolescent's social competence is the byproduct of a sequence of five social-cognitive processes; deviations during any of them may result in interpersonal conflicts and delinquent behaviours such as negative risk taking[34–36]. According to social information processing theory, adolescents first encode social cues from their environment and then interpret those cues using attributes such as affect and intent. Next, adolescents clarify their goals by assessing the given context and identifying what their priorities are within that context. With this goal in mind, adolescents then prepare to respond by evaluating the encoded cues using their past experiences. Finally, adolescents make their response decision by considering the likelihood of achieving their goals and whether their response

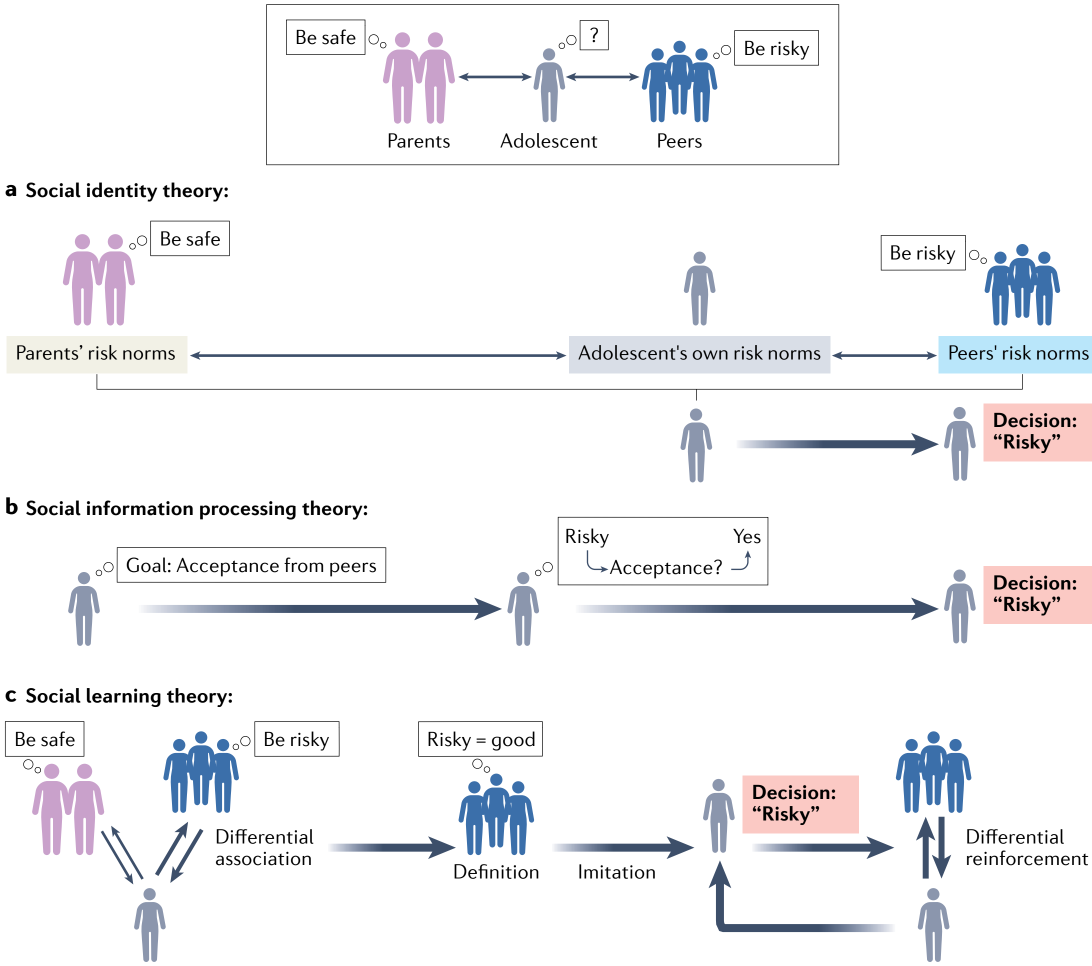

Fig. 1 | **Social contextual risk taking according to three social and developmental theories.** In this example, parents endorse safe behaviours whereas peers endorse risky behaviours. Adolescents adhere to peers' risky behaviours, but the proposed decision-making mechanisms differ. **a** | According to social identity theory, adolescents make their decisions on the basis of whose risk norms they more closely identify with in the given context. Here, adolescents more closely identify with their peers' risky behaviour than with their parents' safe behaviour. **b** | According to social information processing theory, adolescents make their decisions on the basis of their relevant goals in the given context. Here, adolescents may be seeking to gain peer acceptance and therefore follow peers' advice to take risks. **c** | According to social learning theory, adolescents make their decisions on the basis of how they associate with others. Here, adolescents associating with peers leads them to adopt their peers' positive definition of risks and imitate their peers' risky behaviours, which is subsequently positively reinforced.

decision aligns with their personal values. If acceptable, adolescents will then enact their decision[35].

Recall the above scenario in which peers endorse a risky behaviour whereas parents endorse a safe behaviour. As stated by social information processing theory, adolescents will first encode both social cues from their environment (peer and parent) and then interpret those cues using affect and intent information about each social agent (endorsement of risk by peers and of safety by parents). Next, adolescents will clarify their goals by assessing this particular risk-taking context and identifying their priority in this instance, which may be acceptance by their peers. With this goal in mind, adolescents will then evaluate the actions needed to attain peer acceptance using their past experiences. For example, adolescents will reflect on whether previously conforming to peers' endorsements led to peer acceptance and closer friendships. If so, adolescents will then consider whether conformity to peers will result in peer acceptance in this particular situation, where their parents are promoting an alternative safe behaviour. Finally, if adolescents continue to believe that they will achieve their goal of peer acceptance despite their parents' opposition and this action aligns with their personal values, then they will ultimately conform to their peers' endorsement and decide to engage in the risky behaviour (FIG. 1b).

Social learning theory. Social learning theory characterizes how social behaviours are acquired and internalized[37]. According to social learning theory, four principal mechanisms underpin social learning[37,38]. First, adolescents interact with different social groups directly and indirectly (differential association). These associations with different social groups vary in frequency, duration and intensity that together determine the social context that is most salient for social learning to take place[39]. Second, adolescent behaviours are acquired by modelling other's actions (imitation). Hence, mere exposure to other individuals' behaviour allows adolescents to observe others' actions and their positive or negative outcomes, and subsequently to model these actions. Third, these modelled behaviours are then further strengthened and increased through past, present or anticipated future gain of reward or loss of punishment, or they may be weakened or decreased through loss of reward or gain of punishment that follow the behaviours (differential reinforcements). That is to say, differential reinforcement through positive and negative reinforcements facilitates learning of social behaviours. Last, adolescents attach meaning to their behaviours, and label them as 'good' or 'bad' by using social attitudes and norms (definition). The more the adolescents' behaviours are classified as desirable or justified, the more likely these behaviours are to persist[37].

Social learning theory can also be illustrated using the above scenario where peers endorse a risky behaviour whereas parents endorse a safe behaviour. For example, older adolescents may more strongly associate with their peers, which results in greater exposure to their peers' risky behaviours than to their parents' safe behaviours (differential association). Thus, adolescents may more strongly internalize their peers' risky behaviours and model them, owing to the associated positive outcomes such as social connections with friends they may observe (imitation). Given the relative reinforcement from their parents and their peers, stronger positive reinforcement such as continued affirmations of peer acceptance may result in enhanced risky behaviours (differential reinforcement). Additionally, their peers' definition of risk may be more socially desirable to adolescents than their parents' definition of safety (definition), which may further motivate adolescents to continue their risky behaviours (FIG. 1c).

Summary of theories. The three social and developmental theories described above are complementary, but each theory uniquely contributes to our understanding of social contextual risk taking. According to social identity theory, adolescents adjust their risky behaviours because they comprehend the idea of different individuals adopting different risk norms. According to social information processing theory, adolescents want to achieve a specific goal at that moment. According to social learning theory, adolescents observe others' behaviours and their subsequent outcomes, which they want to model. These alternatives are not mutually exclusive; some or all of these sources of information may influence adolescents' risky decision-making. As in the scenario discussed above, the decision-making process to engage in risky behaviours may be supported by all three theoretical definitions presented, which can explain the same risky behaviour in several ways. We have therefore reviewed these theories not to compare and contrast them, but rather, to discuss the many ways through which social contextual risk taking can occur via self-oriented and other-oriented risks.

Neurodevelopment in adolescence

During the adolescent years, drastic development occurs in both brain structure and function, and this is thought to underlie changes in adolescents' behaviours including social contextual risk taking[5,19,21–25]. Key brain systems that are particularly relevant are those involved in affective-salience, cognitive control and social cognition (BOX 1; FIG. 2). Functional brain activation and connectivity (co-activation between brain regions) in these specific systems might elucidate how adolescents are motivated, execute goal-directed behaviours, and mentalize (the process of thinking and understanding) about others. Although no studies have drawn direct parallels between the adolescent brain and the three theories discussed above, the theories are used as theoretical guides for contextualizing the neural correlates of social contextual risk taking[40–42]. We now provide a brief overview of some brain regions within the affective-salience, cognitive control and social cognition systems that provide a neurobiological basis for social contextual risk taking in adolescence.

Affective-salience processing in the brain involves heightened sensitivity to salient positive (reward) and negative (punishment) cues. Adolescents undergo a social reorientation during this period of development that tunes their brain to socially salient cues[19,43]. Here, this social reorientation of the brain renders adolescents hypersensitive to both salient-positive and -negative social cues, such as peer acceptance and peer rejection, respectively[44]. Further, these elevated sensitivities are thought to support adolescents' risk-taking behaviours by motivating them to approach social rewards and to avoid social punishments[45]. The ventral striatum (VS), the amygdala, the anterior insula (AI) and the dorsal anterior cingulate cortex (dACC) are key brain regions in the affective-salience system[46,47]. The VS is involved in reward processing such as valuing, anticipating and gaining rewards, and is thought to modulate reward-seeking behaviours[48]. The amygdala is involved in salience and threat detection, and is thought to modulate threat-avoiding behaviours[48,49]. The AI and the dACC are involved in salience detection by integrating relevant cognitive and emotional information, thereby

Box 1 | Risk versus non-risk behaviours

Brain regions in the affective-salience, cognitive control and social cognition systems that are implicated in social contextual risk-taking also subserve adolescents' social contextual behaviours that are not related to risk-taking such as interpersonal decisions to share with, give to, punish and forgive others, as well as moral decisions that rely on societal norms[99,100,135–138]. For instance, imagine that you are tired so you decided to take the last seat on the bus you just caught. At the next stop, a person on crutches gets on the bus (example taken from Sommer et al.[137]). Here, will you adhere to the societal norm and thereby give up your seat to the injured person? Or, will you adhere to your personal desires and thus decide to stay in your seat? Although adults make more socially normative decisions than adolescents, adolescents show greater activation in the ACC, the dlPFC, the mPFC and the TPJ than adults when they make socially normative relative to personal decisions[137]. In conclusion, neurodevelopmental changes during the adolescent years gear adolescents to weigh up the self (personal values) versus others (societal norms) in social contextual decision-making, regardless of whether it involves risk-taking behaviour. Despite the widespread misconception that adolescent risk-taking is inherently impulsive and detrimental, these shared neural patterns between risk and non-risk behaviours reveal social contextual risk taking to be a form of biologically normative decision.

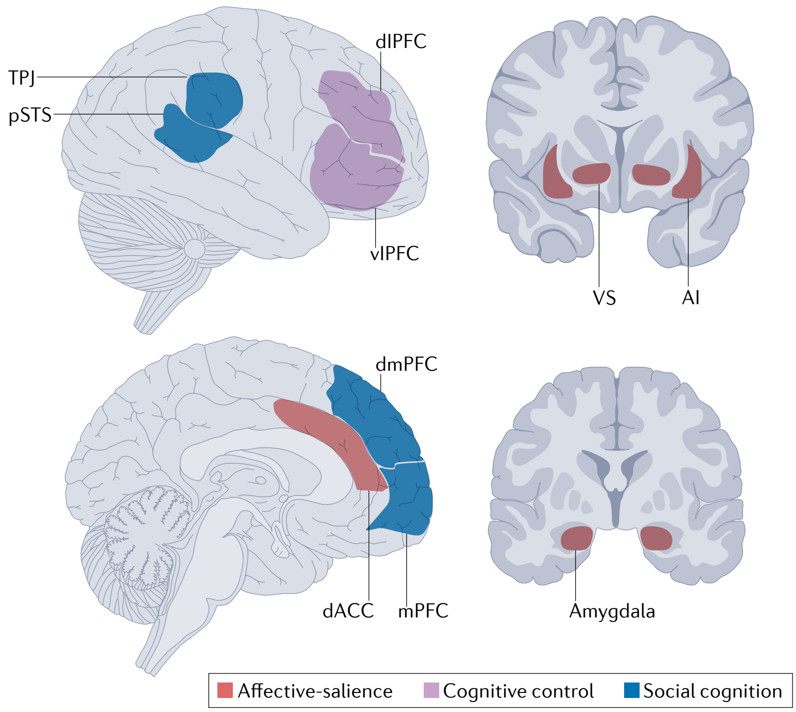

Fig. 2 | **Key brain systems in adolescence.** Neural regions implicated in affective-salience, cognitive control and social cognition systems that are relevant to adolescents' social contextual risk taking. Regions in the affective-salience system include the ventral striatum (VS), the dorsal anterior cingulate cortex (dACC), the anterior insula (AI) and the amygdala; in the cognitive control system the dorsolateral and ventrolateral prefrontal cortex (dlPFC and vlPFC, respectively); and in the social cognition system the medial prefrontal cortex (mPFC), the dorsomedial prefrontal cortex (dmPFC), the temporoparietal junction (TPJ) and the posterior superior temporal sulcus (pSTS). Adapted with permission from REF.[129], Elsevier.

resolving potential conflicts when multiple items of information are present[50,51]. Neural processing in these brain regions is consistent with social identity theory by suggesting a neurobiological basis for heightened response to salient social information, and is also consistent with social learning theory by providing a neurobiological basis for evaluating gains and losses of rewards and punishments as differential reinforcements.

Cognitive control involves regulating intrinsic thoughts and behaviours to elicit appropriate or adaptive responses[52,53]. Cognitive control is essential for basic processes such as working memory maintenance and manipulation, and is also crucial for higher-level processes such as behavioural inhibition — inhibition of inappropriate behaviours but facilitation of appropriate ones — goal-directed behaviour and learning[52,53]. Developmentally, cognitive control dramatically improves from childhood to adulthood, so adolescence is a critical window for maturing cognitive control abilities[52,53]. During adolescence, the inability to regulate impulsive behaviours is thought to render individuals vulnerable to negative risks[54]. Alternatively, successful cognitive control capacities allow adolescents to enact reasoned, strategic risks[55,56]. Brain regions that are often linked to cognitive control include specialized areas of the prefrontal cortex, namely the dorsolateral and ventrolateral prefrontal cortex (dlPFC and vlPFC, respectively)[57–59]. Activation in the dlPFC and vlPFC may represent neural correlates during the facilitation or inhibition of risk-taking behaviour in various social settings[58,60]. These cognitive control areas may have a role in social identity theory by providing a neurobiological basis for intentionally overriding one social agent's risk norms with another's, and is also consistent with the social information processing theory by providing a neurobiological basis for clarifying pertinent social goals.

Social cognition involves mental processes that support other-oriented behaviours, and these mental processes include empathy, perspective-taking and self–other overlap (the merging of the self and the other; for example, thinking about oneself through the eyes of others). Social-cognitive abilities advance during adolescence, and these developing abilities are particularly important during this time since adolescents are hypersensitive to their social surroundings, form new types of social relationships and behave in more socially complex ways[18]. Moreover, social-cognitive skills regulate risk taking, particularly social contextual risk taking, by understanding others' intentions as well as how adolescents' own actions affect others[61]. Brain regions linked to social cognition — often referred to as the 'social brain' — include the medial prefrontal cortex (mPFC), the dorsomedial prefrontal cortex (dmPFC), the temporoparietal junction (TPJ), the posterior superior temporal sulcus (pSTS) and the precuneus[18]. Indeed, all these regions of the social brain system are implicated in facilitating adolescent risk taking that involves incorporating into their decision-making process how they construe others' emotions, intentions and thoughts[61,62]. The social brain system may provide a neurobiological basis for encoding others' perspectives and internalizing these perspectives into one's own behaviours, which is relevant to both social information processing theory and social learning theory.

All in all, employing a developmental neuroscience approach is crucial for understanding the development of social contextual risk taking, by elucidating how the developing brain functions set the stage for social contextual risks to occur. However, one important limiting factor is that these studies are mostly cross-sectional, which inhibits the ability to probe individual differences in development. Understanding the function of a brain region also often relies on reverse inference, which refers to making assumptions about what cognitive processes a task-related neural activation corresponds to[63]. A pitfall of reverse inference, however, is that the same brain region is involved in a number of cognitive processes, and so it is challenging to determine specifically why such activation is observed during a task[63]. However, regardless of these considerations, neuroimaging methods are able to identify biological correlates of adolescent-specific behaviours.

Self-oriented risks

Given that neural patterns of brain regions involved in affective-salience, cognitive control and social-cognition processes are thought to subserve adolescents' risk taking, the following section will explore how the same brain regions extend to a specific social contextual risk: self-oriented risks. Here we focus on the neural correlates of self-oriented risks in adolescence. Self-oriented risks refer to risks that consequently gain rewards or incur costs to oneself, as a result of using information obtained from the social surroundings. These risks can be measured using a variety of paradigms, including the 'stoplight task' and the 'self-disclosure task', in which adolescents make risky decisions in the presence of others or adolescents reveal personal information to others, respectively[64,65]. In the following section, we discuss socially influenced and socially motivated risks to probe how explicit and implicit social information in a given context informs adolescents' self-oriented risk-taking behaviour. Although this is a distinction not clearly made in the literature, it is important to explore the tiers of social contextual information that can infiltrate adolescents' risky behaviours.

Socially influenced risks. One type of self-oriented risk is a socially influenced risk, which refers to direct situations where the social context explicitly shapes adolescents' self-oriented risk taking. A number of studies have examined how adolescents take self-oriented risks when others are in the same room and are actively observing them, compared to when others are absent, as well as how adolescents change their self-oriented risk taking or their own risk attitudes after learning about those of others.

One of the most ubiquitous findings from these studies is that adolescents take more risks in the presence of their peers than in the absence of their peers[64,66,67]. Consistent with these risk-taking behaviour findings, adolescents taking risks in their peers' presence elicit greater VS activation than adolescents taking risks when alone[64]. However, one study shows the opposite pattern — that peer presence does not change adolescents' risk taking behaviours — however, these differences in findings are attributable to how the peer presence was manipulated, which reaffirms the idea that adolescents are sensitive to how social information is delivered (explicitly versus implicitly) during risk taking[67]. By contrast, risk-taking adults recruit the VS similarly in their peers' presence and when alone[64]. Furthermore, when adults take risks, they show greater activation than do adolescents in regions involved in cognitive control such as the lateral PFC, regardless of the social context[64]. These neurobiological differences indicate that adolescents' risk taking may be more incentivized by their peers whereas adults' risk taking may be more deliberate and independent.

Moreover, adolescents' neural sensitivity to their peers is non-uniformly related to their risk-taking behaviours, depending on the type of peer[68]. For instance, greater activation in cognitive control regions involved in behavioural inhibition — the basal ganglia and the inferior frontal gyrus (IFG) — is linked to more risk taking in the presence of risk-promoting peers, whereas activation in the same cognitive control regions is linked to less risk taking in the presence of risk-averse peers[68]. This study's findings are consistent with social learning theory. It posits that an adolescent's cognitive control is sufficiently modified from passively viewing peers' risky behaviours, which leads to adolescents imitating their peers' risk norms during their own risk taking[68]. Therefore, the same cognitive control system in the brain may boost or constrain risk taking depending on the risk norm of the peer present (risk-promoting versus risk-averse). This context-dependent effect during risk taking, as indicated by differences in both behaviour and neural patterns, demonstrates that adolescents are sensitive to a range of risk norms embodied by their peers and that they are able to strategically employ cognitive control to best fit the demands of various social circumstances[55,69].

Whereas adolescents take more risks in the presence of their peers than in their absence, they take fewer risks in the presence of their parents than in their absence[70]. As proposed by social identity theory, boosted risk-taking behaviour with their peers present but dampened risk-taking behaviour with their parents present may be due to adolescents flexibly switching between two different social identities, depending on the identity that is most pertinent to the given context. In line with this interpretation, their parents' presence elicits attenuated VS activation in adolescents taking risks, but their parents' presence results in heightened vlPFC activation and greater VS–vlPFC functional connectivity in adolescents when making safer decisions[70]. On the one hand, taking risks is thought to be less rewarding in their parents' presence, but on the other hand being safe is thought to be better regulated, whereby these regulated behaviours (for instance, playing it safe) are the ones that are particularly motivating and rewarding in their parents' presence[70].

Importantly, these behavioural and neural effects are unique to their parents' presence, given that adolescents choose safer options in their parents' presence but not in an unknown adult's presence[71]. Consistent with social identity theory, the more salient parents' identities better modulate adolescents' risk-taking behaviour than do the less salient unknown adult's identities, perhaps because adolescents are unfamiliar with unknown adults' risk norms. The safe behaviour in their parents' presence relative to an unknown adult's presence is paralleled by increased activation in cognitive control regions such as the IFG[71]. By contrast, risky behaviour in their parents' presence relative to in an unknown adult's presence is paralleled by increased activation in social brain regions such as the dmPFC and the TPJ as well as weaker subcortico-cortical connectivity, an endophenotype that is thought to be more developmentally mature and adult-like[71–73]. Overall, the neurobiology is consistent with the idea that when adolescents take risks in the presence of their parents, they may be required to mentalize to a greater degree than when in the presence of an unknown adult. This increased activity may be due to adolescents thinking more about their parents' risk norms during risk taking and consequently identifying more strongly with their parents, which may be a process that is absent or weaker in an unknown adult's presence[71].

Adolescents also alter their risk-taking behaviours or attitudes (a set of beliefs about a particular thing) towards risk after learning about others' risk-taking behaviours or attitudes towards risk in the same situation[74,75]. Adolescents show increased activation in the AI and the dACC when their attitudes towards risk conflict with others' attitudes towards risk, compared to when their attitudes are consistent with others' attitudes towards risk[76]. This activation of the AI and the dACC is linked to the detection of incongruences in social norms that may propel adolescents to activate the others' social identity and then modify their behaviour to conform to the others' social norms[77,78].

Whereas most research has examined how an incongruence with a single social identity affects adolescents' risk taking, adolescents are more likely to be simultaneously affected by the risk attitudes of multiple social agents in their daily lives, such as their parents and peers[79]. Indeed, in line with social identity theory, multiple identities may concurrently come online in any given context, in which case adolescents are able to activate risk norms of the more salient social identity[32]. Further, multiple social identities, such as those related to parents and peers, can contradict each other when activated in tandem. In this case, adolescents conform similarly to their parents and peers when they conflict in their risk attitudes, but conform more to their parents when they conflict in their risk-taking behaviours[40,80]. These findings suggests that their parents' social identity may be more strongly activated in adolescents when risk-taking behaviours but not risk attitudes conflict. Brain activation and functional connectivity within affective-salience (in the dACC and in vmPFC–striatum coupling), cognitive control (the dlPFC) and social cognition (the TPJ) systems support this differential conformity to conflicting attitudes and risk-taking behaviours[40,80]. For example, for risk attitudes, adolescents show greater dlPFC activation when conforming to the risk attitudes of their peers relative to those of their parents. For risk-taking behaviours, adolescents show greater vmPFC–striatum functional connectivity when their risk taking aligns with their parents' risk taking, but not when their risk taking aligns with their peers' risk taking[40].

Together, these findings show that social information can explicitly manipulate adolescents' self-oriented risks, by having other individuals physically present in the space where risks occur or by informing adolescents of others' risky choices. Yet, whether the social information is explicit does not necessarily change adolescents' risk-taking behaviour. That is, how much explicit social information or social influence shapes risk taking is contingent on how much adolescents identify with social figures who are associated with this information and influence; and these varying degrees of identification are manifested at both behavioural and neural levels, and also in a context-dependent manner.

Socially motivated risks. Self-oriented risks can also be socially motivated, referring to indirect and subtle situations where the social context implicitly drives adolescents' self-oriented risk taking[81,82]. In other words, unlike socially influenced risks in which social information is directly offered to adolescents, socially motivated risks may occur when adolescents have an underlying social goal in that particular context. Adolescents may indeed become goal-oriented in the presence of others (socially influenced risks); however, here we focus on self-oriented risks that occur even in the absence of external social influences. Such self-oriented risks include risky behaviours that seek social status and connection, such as self-disclosure.

Adolescents' self-oriented risks are often linked to social status, for risks can result in being excluded or humiliated by others[83]. For instance, adolescents may spend time with someone their friends do not like or defend an unpopular opinion. These are risky decisions that ultimately affect the adolescent themselves and hence are classified as self-oriented risks[84]. The above examples of risks can affect the adolescent in a negative way (for instance, peers not liking the adolescent for hanging out with someone they do not like), as well as in a positive and beneficial way by creating opportunities to fulfill other social needs (for instance, expanding their social circle by being inclusive of disliked peers)[85]. These status-related risks are a greater concern for adolescents than for adults because of adolescents' elevated sensitivities to social goals and motivations during risk taking[83,85]. Additionally, adolescents take more risks when their peers actively observe them, but not just in the mere presence of their peers; so perhaps adolescents are being selective with their risk-taking behaviours in order to make them known and impress their peers[82]. Indeed, social information processing theory postulates that adolescents evaluate their most relevant goals when engaging in risk-taking behaviour, and so status-related goals such as being accepted by others may be particularly pertinent in social circumstances and result in adolescents taking risks[35]. Thus, the potential of reaping social benefits or avoiding social harms encourages adolescents to engage in risky behaviours.

Neuroimaging findings are consistent with adolescents' risk-taking behaviours being socially motivated and sensitive to social status. Risk taking after receiving social rank feedback (participants were shown what their performance rank was compared to all participants) recruits greater activation in the AI than after receiving monetary feedback (participants earned money based on their performance), which suggests that risks related to social goals may be more emotionally evocative to adolescents than non-social goals, consequently generating risky behaviours[82]. In this study, taking risks after receiving social rank feedback was a socially motivated risk since there was no risk information associated with the social rank feedback. In other words, while adolescents may reflect on their peers' risk norms when their peers are present, social rank feedback does not necessarily mirror other participants' risk norms. The developing adolescent brain is thus responsive to the mere experience of knowing one's own social standing and this motivates risk-taking behaviours.

Additionally, intense experiences in changes in social standing or connection modulate adolescents' self-oriented risks. For example, greater activation and functional connectivity in the affective-salience and social cognition systems during experimental social exclusion predict greater subsequent risk taking, and chronically victimized adolescents engage in more risk taking than non-victimized adolescents and they recruit brain regions implicated in reward processing (the VS) and mentalizing (the TPJ and the mPFC) during this risk taking[86–89]. These studies collectively demonstrate that socially rejected adolescents may be driven to subsequent risk taking in order to regain social acceptance and peer approval, which are adolescents' relevant goals according to social information processing theory. By contrast with adolescents who are socially rejected, adolescents who self-classify as bullies also recruit greater activation in brain regions of the affective-salience (the VS), cognitive control (the IFG) and social cognition (the mPFC) systems when viewing the social exclusion of others relative to social inclusion[90]. Bullying includes socially excluding others, spreading rumours about others, name-calling others and showing unprovoked aggression towards others[90]. This neural activation during social experiences indicates that having a history of bullying others, which is a form of antisocial behaviour with strong links to negative risk-taking behaviours, may also be goal-directed and sensitive to social hierarchy in situations where social standing is salient[90,91]. In summary, adolescents who self-classify as bullies may also be engaging in negative risks as a form of social strategy[90].

Self-disclosure is when individuals share intimate or superficial information about themselves with others. This behaviour involves risk taking since it is associated with uncertainties regarding how the shared personal information will be perceived by others, which is particularly salient in the teenage years when adolescents are hypersensitive to social acceptance and popularity[29,92]. Corresponding with social information processing theory, adolescents' risk-taking behaviour in disclosing personal information may be prompted by the socially motivated objective of connecting with others or gaining status. For example, in a task where adolescents share or withhold personal information with their close friend at a cost, adolescents were willing to spend money to disclose personal information to their friend, and disclosing such personal information elicited greater activation in the VS than evaluating that personal information (prior to disclosure)[65]. Thus, sharing information about themselves with their friend may be inherently rewarding for adolescents. Moreover, during that task, adolescents spent more money to share superficial ("sometimes I burn my toast") over intimate ("sometimes I can be awkward") information with their friend[65]. At the neural level, sharing intimate information with their friend resulted in stronger activation in regions implicated in cognitive control (the dlPFC) and social cognition (the dmPFC, the TPJ and the precuneus) than when sharing superficial information[65]. In summary, sharing intimate information with others may involve risks that affect oneself, rendering self-disclosure of intimate information as a more deliberate and thoughtful, and subsequently a less frequently executed form of socially motivated risks than sharing superficial information.

Together, these findings show that social context can also implicitly govern adolescents' self-oriented risks, since adolescents reflect on their social aims in a given setting. Even in the absence of clear social information, adolescents are able to consider the social aims that emerge in that particular landscape and take these into account when taking risks. Some notable objectives during adolescence include attaining social status and making connections. Indeed, experiences related to social status and connections, such as being excluded or actively excluding others, are linked to changes in risky behaviours and in neural processing during risk taking in adolescence.

Other-oriented risks

Risk taking in adolescents' everyday lives can affect not only themselves but also others around them. Other-oriented risks are risks that consequently gain rewards for or incur costs to others, and in which the social figure for whom the risky behaviour is intended is the social contextual information (FIG. 3). Like

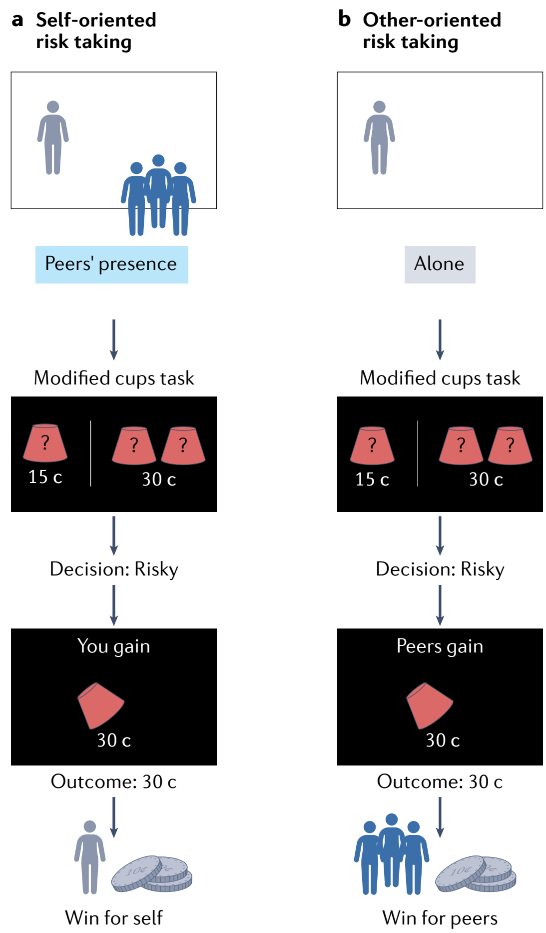

Fig. 3 | **Illustrative example of self-oriented and other-oriented risk-taking.** In the modified 'cups task'[94,95], participants are presented with two scenarios of overturned cups. Choosing the left side equates to making a safe decision, since the outcome is a guaranteed gain of 15 cents, and choosing the right side equates to making a risky decision, since the outcome may be a higher amount of 30 cents or may be a lower amount of 0 cents. **a** | This task can be used to measure self-oriented risk taking if adolescents complete this task in their peers' presence in order to win money for themselves. **b** | This task can be used to measure other-oriented risk-taking if adolescents complete this task, whether that be alone or in their peers' presence, in order to win money for their peers. Panels **a** and **b** adapted with permission from REF.[40], OUP.

self-oriented risks, other-oriented risks can also be socially influenced by taking place in others' presence and socially motivated by being driven by status-seeking motivations, but these risks ultimately affect others and are therefore classified as other-oriented risks. Other-oriented risks can be measured using a number of paradigms such as the 'cups task', in which adolescents make risky decisions to earn money for others such as their parent and best friend[93,94] (FIG. 3b). Although research on adolescents' other-oriented risks is limited, this type of risk-taking behaviour is particularly pertinent to adolescents as their social world becomes increasingly complex and they encounter increased opportunities for making decisions that affect others. Below, we discuss neural correlates of other-oriented risks in adolescence.

Adolescents take risks differentially for themselves and strangers, taking more risks for themselves than for a stranger, with this difference diminishing over time[61]. In addition, adolescents are able to cater to the preferences of the other person; they take more other-oriented risks affecting strangers who they perceive as 'high risk-takers' than those perceived as 'low risk-takers'[61]. Consistent with social learning theory, adolescents adopt others' definitions of risks during other-oriented risk taking, such that they boost their risk-taking behaviour when it affects others who define risks as desirable and diminish their risk-taking behaviour when it affects others who define risks as undesirable. Thus, adolescents understand others' mental states at multiple levels: they are able to comprehend that their risk-taking behaviour directly affects others, and are also able to internalize the perspectives of others and adhere to others' risk norms during other-oriented risk taking.

Other-oriented risk taking relies on the nature of the social target and on how much adolescents relate to these targets. From early to late adolescence, adolescents consistently take fewer risks affecting a stranger than risks affecting themselves, which demonstrates that early adolescents are already able to think about how their own risk-taking behaviours affect others, even if that behaviour involves an unknown individual[61]. By contrast with taking risks for a stranger, early adolescents take risks similarly for themselves and their parents[94]. This effect, however, depends on relationship factors. For instance, early adolescents with high family conflict take more risks involving their parents than do early adolescents with low family conflict[94]. Furthermore, adolescents take a similar level of adaptive risks involving their parents from early to mid-adolescence[95]. In this study, adaptive risk taking was defined as sensitivity to the 'expected value' of reward during risk taking, whereby it is economically advantageous to take risks when the expected value of the reward is high and to avoid risks when the expected value of the reward is low. This consistency in adaptive risk taking for one's parent demonstrates that reward computations involving intimately connected others are already in place by early adolescence (while such computations involving unfamiliar others may still be developing[61]), thereby allowing early adolescents to capitalize on expected value information to take risks strategically for close others[95].

Developmentally, the tendency to take other-oriented risks is similar for adolescents and adults. However, the strategies and motivation behind other-oriented risk taking differ with age[96]. First, for other-oriented risks involving peers, adolescents become more attuned to the consequences of the risk taking for their peers because adolescents increasingly incorporate prior performance feedback into their subsequent expected value computations with age, and take more other-oriented risks if peers might benefit but fewer other-oriented risks if peers might suffer[96]. Next, in other-oriented risk taking, an opposite pattern to self-oriented risk taking appears, in which adolescents but not adults are sensitive to the social landscape. Adolescents take similar other-oriented risks involving their peers regardless of whether they are alone or in their peers' presence, whereas adults are sensitive to the social surroundings and selectively take more other-oriented risks when being actively observed[96]. This developmental shift in other-oriented risk taking may be due to an individuals' changing social needs. That is, in accordance with social information processing theory, adults may be seeking to maximize gains for their friends to impress them when they are watching, whereas adolescents may be seeking to maximize gains for their friends regardless of any recognition they might receive[96]. These results highlight the importance of understanding the primary target of an adolescent's risk-taking behaviours, given that adolescents may interpret the information available from their surroundings differentially. Information about adolescents' social targets may override other competing information and serve as a powerful tool for regulating their risk-taking behaviour[35].

Few developmental neuroimaging studies have examined the neural substrates of other-oriented risk taking. Despite this scarcity, brain regions within the affective-salience, cognitive control and social cognition systems are promising candidates. These regions provide a neurobiological basis for reward-approaching and punishment-avoiding processes that are needed for prioritizing others. For example, there are longitudinal changes in the VS when adolescents obtain monetary rewards for their parents and their peers, indicating that the VS is implicated in processing vicarious experiences[97]. Affective-salience regions, such as the VS, may therefore be recruited during other-oriented risk taking to compute the expected reward values that an adolescent may obtain for others. Further, the lateral PFC and the TPJ are activated when helping and forgiving others, which suggests that the lateral PFC and the TPJ have a role in making decisions that are intended to affect others[98–100]. Cognitive control and social cognition systems may therefore be recruited during other-oriented risk taking to facilitate deliberate risk taking while thinking about others' best interests. Indeed, VS–TPJ/pSTS and VS–mPFC functional connectivity during an individual's self-oriented risk taking longitudinally predict that individual's other-oriented risk taking[95]. Consequently, maturational changes in the crosstalk between the affective-salience and social cognition systems are necessary for promoting strategic risk-taking behaviours that can benefit others during adolescence.

Contrary to the popular conception that adolescents are unaware of how their own actions are affecting those around them, adolescents are able to flexibly switch their risk-taking behaviours depending on who these behaviours act on. As is shown by adolescents taking self-oriented risks differently when others are present compared to absent but taking other-oriented risks similarly in the two contexts, self-oriented and other-oriented risks indeed rely on distinct psychological mechanisms. Yet both types of social contextual risks are supported by the same brain networks. Information about the social target is therefore a pivotal factor that influences adolescents' risk taking and may be leveraged to guide risk taking in a positive direction.

Integrated risks

Adolescents' risk-taking behaviours can occur within a social context, primarily affecting themselves, and their risk-taking behaviours can also primarily affect others around them. However, the self and the other are both also involved in other-oriented and self-oriented risks, respectively. We next discuss how the self and the other are intertwined in social contextual risk taking and the impacts of this integration across the adolescent years.

It is difficult to identify the multitude of motivations behind social contextual risk taking. Perhaps adolescents take other-oriented risks (winning rewards or avoiding losses for others) for self-oriented reasons such as climbing the social ladder and gaining popularity from their peers by impressing them. Similarly, perhaps adolescents at times resist social influence because they more strongly value their own risk norms and not necessarily because they were not socially influenced. Risk-taking behaviours may therefore have a number of diverging or competing motivations undergirding a single decision-making process. Indeed, motivations behind social contextual decision-making vary, suggesting that it is imperative to identify a wide range of adolescents' goals in order to understand how they prioritize themselves and others in various risk circumstances[101,102]. Consequently, regardless of the primary target of their risk-taking behaviour, adolescents are balancing both the self and the other during social contextual risk taking and so the two motivating agents should be considered in tandem (BOX 2).

The self and the other may also be used to construe one another. In adults, the self serves as a proxy for making sense of the social world[103–106]. That is, adults think about others' thoughts and feelings by using their own experiences in a similar situation, and imagining themselves in the other person's shoes[107]. Using the self as the basis for normative social reasoning also paves the way for a greater self–other overlap, bolstering successful social behaviours such as other-oriented decisions[108–110]. This integration of the self and the other is also observed in adolescence: a clearer understanding of the self, such as greater self-concept clarity, predicts better social interactions with intimately close others, such as a better self-reported relationship quality with parents[93,111,112]. Indeed, self-referential processes such as self-evaluation elicits unique adolescent-specific neural patterns in the VS, the mPFC, the dmPFC, the TPJ and the pSTS[113–116]. Neural activity in the social brain system indicates that the maturing brain tunes adolescents to engage in other-referential processes during self-referential processes. In other words, behavioural and neurobiological underpinnings of the self set the stage for adolescents to be other-oriented.

Adolescence is a critical window of opportunity for establishing the self as a foundation for construing others. Over time, adolescents improve at overriding the currently provided social information with previously experienced social information to make decisions[117–119]. Thus, when their previously experienced information is inconsistent with the information currently provided from the environment, adolescents increasingly rely on themselves by drawing from their own perceptions and learned information to take risks in a social context. Adolescents therefore increasingly trust themselves as a source of information during decision-making. At the neural level, functional connectivity during self-oriented risk taking predicts other-oriented risk taking for one's parents, demonstrating that neural substrates associated with the self can serve as a predictor of social behaviours[95]. In conclusion, establishing a stable sense of self in the adolescent years may promote healthy social sensitivity and susceptibility during social contextual risk taking.

The meaning of the self, the other and the self–other overlap are all reconstructed during the adolescent years. As self-concept and the meaning of the self develop, so does an adolescent's ability to use themselves as a means of construing and taking the perspectives of others[120,121]. That is, adolescents improve at using themselves as a reference point for judging others during perspective-taking[121,122]. In turn, enhanced perspective-taking shapes an adolescents' ability to

Box 2 | **Example of risk-taking behaviour that affects both the self and the other**

Trust refers to a two-person exchange where one individual forgoes a certain present value in exchange for an uncertain future benefit. The propensity to trust others is usually studied using economic exchange paradigms where one player ('the investor') shares money with another ('the partner') in hopes for a profitable return, but with the simultaneous risk of no return[139]. Trust behaviours are both self-oriented and other-oriented because the investor's risk-taking behaviour in an economic setting benefits themselves in the event of their partner's reciprocation, but also affects the partner by earning the investor's trust and future cooperative interactions when they decide against non-reciprocation (thereby not harming the investor)[140]. Corroborating the importance of social targets in social contextual risk-taking, adolescents exhibit trust in partners who are known to be 'good' by investing more money in 'good' partners than in 'neutral' or 'bad' partners, even though all partners reciprocated similarly in actuality[117]. This biased propensity to trust others based on known social information indicates that information about social targets (for instance, believing that the partner is 'trustworthy') may be overpowering actual experiences with social targets (such as a 'trustworthy' partner not being as trustworthy as expected), particularly in early adolescence[117]. At the neural level, there are age-related decreases in striatum activation during exchanges with trustworthy partners, in contrast to increases in ACC activation during those with untrustworthy partners[141]. Thus, expectations of trustworthiness may increase, as evidenced by activation decreases in the striatum, and conflict monitoring may increasingly adjust subsequent behaviours, as evidenced by activation increases in the ACC from early adolescence to adulthood[141]. In summary, developmental changes in key brain systems are necessary to up- and down-regulate risk-taking behaviours that affect both the self and the other, and hence to facilitate successful social interactions.

use others as a means of construing themselves and solidifying their own sense of self[114,116]. The feedback loop between self-referential and other-referential processes such as establishing self-concept and improving perspective-taking, respectively, consequently fortifies the self–other integration.

These developmental changes in self-referential and other-referential processes during adolescence may lead researchers to question the reliability of the self as a baseline when studying social contextual risk taking. A large body of studies utilizes the self as an adolescent's baseline risk-taking propensity, for example, when unobserved in order to examine how this tendency changes in other contexts such as when peers are actively observing the adolescent[64]. However, one concern with such a method is that older adolescents may be accounting for others' risk norms more automatically than younger adolescents during their risk taking, even in the absence of an external social stimulus. That is, perhaps older adolescents are able to take risks based on how they think others expect them to behave in that scenario, even when they are alone, resulting in older adolescents taking risks similarly in others' presence and absence (FIG. 4). Indeed, older adolescents increasingly incorporate others' risk norms into their risk-taking behaviours[123–125]. From a social identity perspective, perhaps an adolescent's identity becomes increasingly similar to their peers' identity late in adolescence, such that the adolescents' own risk norms and their peers' risk norms may become indistinguishable. This development in risk norms — increasingly incorporating 'how I think about others' and 'how I think others think about me' — brings into question whether the difference between the self and the other in social contextual risk taking in early adolescence is comparable to that in late adolescence.

These considerations highlight the challenge of truly separating the self and the other in social contextual risk taking — whether that be self-oriented or other-oriented risk taking — in adolescence. Adolescents incorporate both self-oriented and other-oriented processes into both types of social contextual risk, whether that be in the form of motivation or neural patterns. Moreover, adolescence is a crucial time for changes in self–other integration, which is also supported by key brain systems that mature during this period. Lastly, changes in self–other integration query how future research can better capture adolescent risk taking in the absence of external social stimuli.

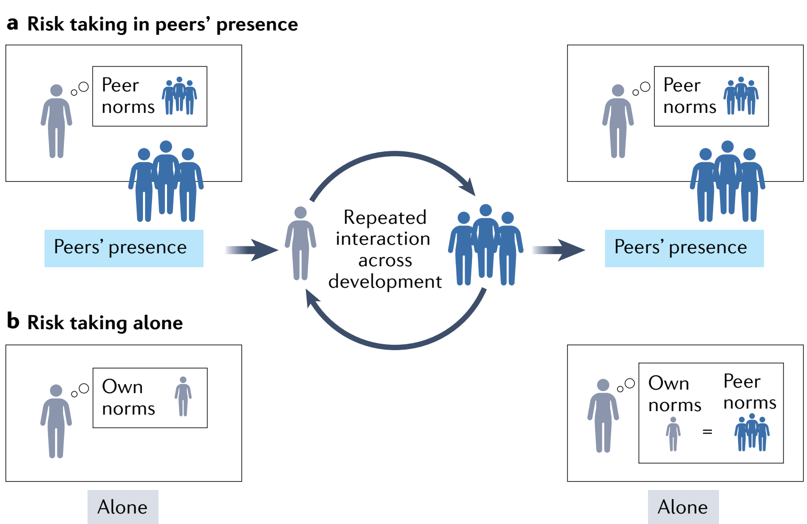

Fig. 4 | **Integration of the self and other across adolescence. a** | During risk taking where adolescents take risks in their peers' presence, adolescents may similarly think about their peers' risk norms across development since this information about peers' risk norms is actively delivered via their peers' presence. **b** | As self-related and other-related processes develop across adolescence with repeated social interactions with peers, there is stronger integration of the self and the other (peers, in this example) and adolescents more automatically incorporate peers' risk norms into their own risk norms. As a result, older adolescents may be tapping into their peers' risk norms when they try to think about their own risk norms, even in the absence of external social stimuli (peers' presence, in this example). Hence, risk-taking behaviour when alone may be different in early adolescence compared to in late adolescence.

Summary and future directions

In this Review, we have discussed social contextual risk taking in adolescence with a specific focus on the primary target of the risks. We explored how adolescents use social contextual information to take risks that primarily affect themselves and also how adolescents take risks that primarily affect others, wherein the risk's target serves as the social contextual information. We also highlighted key neurodevelopmental changes that take place during the formative adolescent years that have an essential role in modulating social contextual risk taking. Yet, in the field of developmental psychology, there has been little consideration of social contextual changes in risk-taking behaviours or of longitudinal methods that could better capture the neurodevelopmental changes that underpin social contextual risk taking. Below, we provide some suggestions for future investigations.

Adolescents become increasingly closer to and interdependent with their peers as they grow older[28,29]. In addition to this social shift towards their peers, adolescents diversify the types of peer they engage with as their peer landscape becomes highly complex and hierarchical[28,29,126]. As adolescents transition into high school, new peer groups become more common and accessible, consequently making adolescents socially salient to an increased range of peers in a potentially domain-specific way[127,128]. These groups might be encountered through extracurricular activities, specialized upper-level classes or jobs outside the home, for example. Given the importance of the social target in social contextual risk taking, future research should explore the roles of different types of peer over time. For instance, friends from classes and from extracurricular groups might boost academic and social risk taking in different ways. Future longitudinal fMRI work should investigate how risk information from different types of peer affects adolescents' various risk-taking behaviours over time in order to examine neurodevelopmental changes in domain-specific social influences on risk taking. Furthermore, leadership roles at school might also influence adolescents' other-oriented risks for a group of people by requiring them to make executive decisions on behalf of others. Future work should investigate adolescents' other-oriented risk taking for groups, in which several people are affected as opposed to a single target.

In addition to examining adolescents' ever-evolving social relationships, neural evidence should also be brought to bear on the question of risk taking in adolescence. As previously mentioned, one limiting factor in interpreting neuroimaging research is the frequent reliance on reverse inference. To address this, future research should take a formal approach to understanding a link between brain function and its parallel psychological mechanism, by using multi-voxel pattern analysis (MVPA) and computational models[63]. Another consideration for future research is the need for longitudinal functional magnetic resonance imaging (fMRI) research that captures social contextual risk taking during adolescence, for instance from late childhood to early adulthood (see Telzer et al.[129]). Longitudinal modelling captures within-person changes in both brain and behaviour, acknowledging that every individual develops at their own rate and thereby identifying individual growth trajectories. Moreover, the more data points a longitudinal model has, the better it can estimate complex forms of development such as quadratic and cubic trajectories[130]. These non-linear functional forms of trajectories are important tools that can characterize neural peaks or inflection points and can therefore pinpoint sensitive periods, which can then be leveraged to help to deflect negative adolescent behaviours and instead promote better social contextual risk-taking practices[131]. Although there are practical constraints to longitudinal modelling, such as cost and participant retention, future longitudinal research should also probe neural patterns of social contextual risk taking beyond the adolescent years, given that both structural and functional brain changes persist into adulthood[132–134].

Adolescents are able to subsume complex social information from their environment, integrate information into their risk-taking decision-making process, and can therefore selectively decide when to make riskier choices. We have stressed the importance of social targets for risk-taking behaviours, but the self and the other are difficult to disentangle because most social contextual risk taking affects both the self and the other simultaneously. Adolescents integrate both the self and the other in their motivations or risk norms during social contextual risk taking, but future fMRI work is needed to investigate the neurodevelopment of this process. Adolescence is an impressionable time of socio-emotional, cognitive and neurobiological transformations; an increasing understanding of the behavioural and neural trajectories of the self during social contextual risk taking may set the stage for better interventions that optimize social behaviours and promote positive adolescent development.

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