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Neural Correlates of Conflicting Social Influence on Adolescent Risk Taking

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Adolescence is often characterized by heightened risk-taking behaviors, which are shaped by social influence from parents and peers. However, little is understood about how adolescents make risky decisions under conflicting influence. The valuation system in the brain may elucidate how adolescents differentially integrate conflicting social information. Twenty-eight adolescents (M_{age} = 12.7 years) completed a social influence task during a functional magnetic resonance imaging scan. Behaviorally, adolescents took more risks only when their parent endorsed risky decisions but not when their peers endorsed risky decisions. At the neural level, adolescents showed enhanced vmPFC–striatum functional connectivity when they made risky decisions that followed their parents' risky decisions. Results suggest that parents' decisions may guide youths' risk-taking behavior under conflicting influence.

One defining feature of adolescence is an increase in risk-taking behaviors (e.g., Arnett, 1992). Adolescents' negative risk-taking behaviors (e.g., substance abuse and unprotected sex) have serious implications on many aspects of youth's immediate lives such as impeded educational achievements and disrupted interpersonal relationships (e.g., Newcomb & Bentler, 1988) and also have lasting impacts into adulthood including unemployment and compromised psychological well-being (e.g., Kandel, Davies, Karus, & Yamaguchi, 1986). Coinciding with these heightened risky behaviors is a social reorientation of the brain whereby adolescents become especially sensitive to socially salient stimuli (Nelson, Jarcho, & Guyer, 2016). Indeed, social influence from parents and peers is among the most powerful predictors of adolescents' engagement in risk-taking behavior (e.g., Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Telzer, Ichien, & Qu, 2015).

Social Influence of Parents and Peers

Peer influence. As they transition into adolescence, youth gradually spend more time with peers and less time with parents (Larson, Richards, Moneta, Holmbeck, & Duckett, 1996). Simultaneously, adolescents begin to form closer and more supportive friendships (Furman & Buhrmester, 1992), and become more interdependent with peers over time (Brown & Larson, 2009). A wealth of research on the effect of peers on youth's risky behavior has demonstrated that adolescents are more likely to engage in risk-taking and deviant behaviors, and substance use if their peers do (e.g., Loke & Mak, 2013). Moreover, experimental studies demonstrate that adolescents engage in significantly greater risky behaviors when their peers are present, which is paralleled by heightened activation in the ventral striatum, ventromedial prefrontal cortex, and orbitofrontal cortex, brain regions involved in valuation and reward processing, suggesting that risk taking may be more rewarding and socially reinforcing in the presence of their peers than alone (Chein et al., 2011).

Parent influence. Adolescence is also characterized by increasing individuation from parents (Grotevant & Cooper, 1986) and greater egalitarian parent–adolescent relationships (De Goede, Branje, & Meeus, 2009). Contrary to popular beliefs that peers are the primary source of social influence on adolescent risk-taking behavior, parents maintain a consistent presence in adolescents' lives and exert a significant influence on adolescents' risky behaviors (see Telzer, Rogers, & van Hoorn, 2017). For instance, adolescents are more likely to engage in substance use if their parents do, or even if they merely perceive that their parents do (Pisinger, Holst, Bendtsen, Becker, & Tolstrup, 2017). Yet,

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parents also have a buffering effect, such that parental support, parental monitoring, and even the presence of parents in risky contexts are associated with reduced risky behaviors and attenuated ventral striatum activation when taking risks (e.g., Telzer, Ichien, & Qu, 2015; Qu, Fuligni, Gálvan, & Telzer, 2015).

Conflicting social influence. Although significant research has investigated the independent effects of parent and peer influence, little research has directly examined the simultaneous and potentially conflicting social influence from parents and peers (i.e., when parents and peers endorse different or opposing attitudes or behaviors). Social influence from parents and peers rarely occurs in isolation but is incredibly interdependent such that the effect of one context is often contingent on that of the other (Sentse, Lindenberg, Omvlee, Ormel, & Veenstra, 2010). In particular, social norms endorsed by parents and peers may conflict such that parents and peers disagree on various behaviors, especially risky behaviors (e.g., Soh, Chew, Koay, & Ang, 2018). However, little is known about how adolescents make risky decisions under conflicting influence. It is thus crucial to examine parent and peer contexts in tandem in order to capture a more holistic representation of adolescents' complex social environment.

Conformity to peers tends to increase across adolescence, whereas conformity to parents decreases (Utech & Hoving, 1969). While some empirical research suggests that peers are a more robust influence on adolescents than are parents and adults with respect to risky behaviors and perceptions (e.g., Knoll et al., 2015), other research indicates that parents may act as a buffer against risky peers (e.g., Crosnoe, Erickson, & Dornbusch, 2002), and the effect of parents can even outweigh that of peers with respect to attitude formation (Welborn et al., 2016) and intentions against substance use (Sawyer & Stevenson, 2008). When youth themselves are in direct conflict with their parents and peers, youth are more likely to agree with their parents' perspectives while invalidating their peers', thereby demonstrating that youth may take the perspectives of their parents over those of their peers (Komolova, Wainryb, & Recchia, 2017). Different forms of conflicting influence from parents and peers have different effects on adolescents' attitudes and behaviors, and it is therefore unclear as to who—parents versus peers—will have a stronger pull with respect to risky behaviors.

Social Identity Theory

Social identity theory provides a framework for understanding how adolescents navigate conflicting social influence. Social identity theory posits that an individual's sense of self depends on the social group to which they belong (Tajfel & Turner, 1979). In turn, one's social group membership impacts how they internalize norms from their environment and consequently behave according to the established group norms (Tajfel & Turner, 1979). Therefore, adolescents will adhere to the social norms of particular groups as a means to enhance their sense of social connection and group identity (e.g., Deutsch & Gerard, 1955). Because adolescents are part of multiple different social groups including their family and friendship groups, different social identities and norms are activated across different social contexts (McDonald, Fielding, & Louis, 2013). When adolescents are a member of multiple social groups, stronger group affiliation leads to a greater social influence from that specific group and thus a greater norm representation of the group (e.g., Terry & Hogg, 1996).

In line with social identity theory, individuals are often challenged with conflicting social norms when there are inconsistencies between different group identities (McDonald, Fielding, & Louis, 2013), such as when peers endorse social norms that align with risk taking but parents endorse social norms that align with safety. When more than one social identity is activated, norm conflict arises and individuals must reconcile the conflicting social norms by aligning with the group identity that is more personally relevant or salient (McDonald, Fielding, & Louis, 2013). That is, norm conflicts may trigger the more salient set of beliefs and attitudes held by one group over the other. However, little is understood about how adolescents make risky decisions in the face of conflicting social norms from parents and peers. Examining the effects of conflicting social norms has implications for understanding how adolescents reconcile diverging social information and choose to behave.

Valuation in the Brain

Understanding the neural processes involved in reconciling diverging social information may shed light on how adolescents make decisions under such conflicting social norms. Conflicting social influence may involve an effort to weigh and integrate the relative value of subjective information, which may assist with youth's decision-making and whether they conform to a particular social group. In line with social identity theory, adolescents may differentially weigh information from one group identity (e.g., parents) against the other group (e.g., peers). This will lead to greater activation and representation of one group over the other, depending on which group adolescents more closely identify with. As such, the valuation system in the brain may differentially evaluate and compute the social norms endorsed by parents and peers that may ultimately contribute to internalizing the social norm and subsequently modeling the behaviors of one over the other in a conflicting situation.

The ventromedial prefrontal cortex (vmPFC) is involved in computing subjective reward valuation, reward expectancies of one's actions, and value-based decision-making (e.g., Bartra, McGuire, & Kable, 2013). The vmPFC also responds to values related to external aspects of the self, such that the vmPFC is activated to stimuli of high personal value such as close others (D'Argembeau, 2013). In a social context, the vmPFC is linked to social norm computation (Zaki, Schirmer, & Mitchell, 2011), moral judgments (van den Bos & Güroglu, 2009), and social conformity (Klucharev, Hytönen, Rijpkema, Smidts, & Fernández, 2009). Additionally, a recent meta-analysis identified the vmPFC as one of the regions robustly involved in adolescent decision-making in a social context (van Hoorn, Shablack, Lindquist, & Telzer, 2019).

Brain regions dynamically interact with one another such that two regions may coactivate during the same psychological process and thus temporally correlate with one another. Indeed, interactions between the vmPFC and other regions have been shown in various valuation processes in decision-making. For example, the ventral striatum and vmPFC make up the core of the valuation system (Bartra et al., 2013), and coupling between the two is associated with reward processing (e.g., Cauda et al., 2011). vmPFC connectivity with the dorsolateral prefrontal cortex is observed when individuals make context-dependent valuations (Rudorf & Hare, 2014), and vmPFC connectivity with the posterior cingulate cortex is observed in magnitude changes in social reward valuation (Smith, Clithero, Boltuck, & Huettel, 2014). Therefore, the interaction between the vmPFC and other regions may underlie the specific valuation experience through which youth make risky decisions in the context of conflicting social information from parents and peers.

The Present Study

In the current study, we sought to examine the neural correlates of conflicting social influence on adolescent risk-taking behavior. Here, we focus on 12- to 14-year-old adolescents since this age range has been shown to be the most sensitive to socially salient stimuli (e.g., Pfeifer et al., 2011). Furthermore, early adolescence is a key developmental period of transitioning from childhood to adolescence that parallels changes in relationships with parents and peers, such that early adolescents spend increasingly more quality time with peers and begin to turn toward peers to fulfill attachment needs (e.g., Nickerson & Nagle, 2005). Finally, early adolescents relative to later adolescents are particularly sensitive to social influence in both prosocial and risky contexts (e.g., Foulkes, Leung, Fuhrmann, Knoll, & Blakemore, 2018; Knoll et al., 2015).

Adolescent participants completed a behavioral session during which we measured baseline risk-taking behavior. Following this, adolescents returned for a functional magnetic resonance imaging (fMRI) scan during which they completed the same risk-taking task, this time with conflicting social influence. Given that parents and peers represent two of the most important social identities for adolescents and that these social groups often endorse diverging norms, our goal was to explore how adolescents' risky decisions change in the face of conflicting social norms from parents and peers (e.g., when parent endorses risky behavior whereas peer endorses safe behavior, and vice versa). At the neural level, we examined whether vmPFC functional connectivity is involved during this decision-making process when adolescents are faced with such conflicting social norms.

METHODS

Participants

Twenty-nine adolescents completed a social influence task (described below) at both a behavioral and fMRI session. One participant was excluded due to insufficient behavioral data during the scan (less than 80% response rate on task). Thus, the current study included 28 participants (N = 14 female) in our final sample for analyses (M_{age} = 12.7 years, SD = 0.62 years, range = 12–14). Participants were from diverse ethnic backgrounds (19 White, 5 African American, 1 Asian and Pacific Islander, 2 Latinx, and 1 multiethnic). Parental education was as follows: 1 high school degree, 2 trade or vocational school, 7 some college, 13 college degree, and 5 advanced degree. Participants were recruited via flyers, referrals, listserv mailings, and outreach at local events. All participants provided informed consent and assent, and the University's Institutional Review Board approved all aspects of the study.

Procedures

Participants completed a baseline session and an fMRI session. As part of a larger study, adolescent participants completed questionnaires, a personal profile page, biological measures (e.g., hair sampling), and behavioral tasks during the behavioral session. Parents also completed questionnaires, biological measures, and behavioral tasks during the behavioral session. Approximately two weeks later, adolescent participants returned for an fMRI session. When they arrived, participants were told that there was a peer present at the testing site who would be involved in the task and was currently completing their own scan. Participants were shown a profile page of the peer with a picture and basic information (e.g., name, age, grade, and two things they like to do for fun) that was similar to the profile they had completed during their behavioral session. Participants also spoke to the peer over a speakerphone as part of a separate task (van Hoorn, McCormick, Rogers, Ivory, & Telzer, 2018). Here, the experimenter called down to the scanner where the peer was ostensibly in the scan and had the participant read a script saying that they were watching the peer play the task, which may have further enhanced the credibility and saliency of this unfamiliar peer via this virtual interaction. In reality, the peer was a confederate. All peer confederates were age-, gender-, race-, and grade-matched with the participant. A number of prior studies have utilized unknown peer confederate as a peer manipulation and have shown significant peer effects (e.g., Peake, Dishion, Stormshak, Moore, & Pfeifer, 2013), and some have used unfamiliar peers to contrast parent and peer effects on adolescents (e.g., Saxbe, Del Piero, Immordino-Yang, Kaplan, & Margolin, 2015). Indeed, known and unknown peers tend to have comparable effects on adolescent risk-taking behavior (Weigard, Chein, Albert, Smith, & Steinberg, 2014). Participants then completed an fMRI scan that lasted approximately 1.5 hr, during which they completed the social influence task (described below), as well as four other tasks that are not the focus of the current study. The same peer confederate was used in two different tasks during the scan, including the current task. Following the scan, participants completed post-scan assessments and several self-report measures, which included questions about their decision-making strategies in order to see whether or not they had any doubts about the task and the peer manipulation. Based on these responses, no participant indicated they did not believe the social influence manipulation. At the end of the study, participants were fully debriefed about the deception. Adolescents and their parent were compensated with a monetary remuneration and prizes for participation (e.g., gift card to movies).

Social Influence Task

Participants completed a novel risk-taking task with simultaneous social influence. Participants completed the task twice: once during a behavioral session during which there was no social influence in order to obtain baseline performance on the task, and once again during the fMRI session where the conflicting social influence was added.

Behavioral session. Participants were presented with ponds of 12 fish and told to choose to either "Fish" or "Pass" for each pond. Each pond consisted of green fish, red fish, and gold fish (see Figure 1a). If the participant chose to "Fish" in a given pond, the task randomly selected one of the 12 fish; if a green fish was selected, the participant obtained 2 points, if a red fish was selected, the participant lost 1 point, and if a gold fish was selected, the participant gained 5 points. Points were added or subtracted to a running total, which was shown during the feedback throughout the task (described further below). If the participant chose to "Pass," then there was no gain nor loss in points and hence no change in overall score. "Fish" decisions are considered risky as participants have an uncertain outcome of winning and losing points, whereas "Pass" decisions are considered safe as participants are not taking the risk to win or lose points. The goal of the task was to accumulate as many points as possible in order to obtain a prize at the end of the study. Although participants believed that their performance on the task would determine the size of the prize, all participants received a small prize at the end of the study session regardless of their performance for human subject's purposes to ensure the same renumeration across participation.

The baseline task consisted of 72 ponds in total, 24 of which contained one gold fish. In ponds that did not contain a gold fish (48 trials), the pond of

12 fish was composed of a combination of green and red fish, with 3 possible combinations of green:red fish: 7:5, 6:6, and 5:7. The proportion of green:red fish was included to increase variability in participants' responses and decrease heuristic responding but were not separately analyzed. In the event that there was a gold fish, one green fish was replaced, and there was an equal likelihood of a gold fish appearance across all pond types. Given that adolescents are especially sensitive to rewards, we added gold fish trials to keep participants engaged and motivated in the task and therefore expected performance on these trials to be near ceiling (i.e., selecting to "Fish" the majority of the time). Thus, we did not include gold fish trials in our primary analyses (see Supplementary Materials for analyses involving the gold fish trials). The actual feedback provided to the participants was based on these probabilities for each pond, and the outcome was predetermined for each trial depending on their decision. On each trial, the pond with 12 fish appeared for 3,000 ms, within which the participants made their decision to either "Fish" or "Pass". Next, there was a jitter for 250 ms, during which the participant viewed a fixation cross. This was followed by feedback for 1,500 ms. Feedback presented the fish that was selected and indicated either "Win", "Lose", or "No-Gain", depending on the decision and the fish that was chosen, as well as the total running points. Finally, there was an intertrial jitter of 250 ms.

Adolescents and parents each completed the task during the behavioral session. Baseline performance was obtained during the behavioral session from adolescents in order to account for their initial propensities to take risks. Baseline performance was obtained during the behavioral session from parents, which was ostensibly used in the fMRI session for the social influence component (see below).

fMRI session. The fMRI task followed a very similar procedure as the baseline task, but with conflicting social influence added. Prior to seeing each pond, participants were shown how their peer and parent made decisions on that pond. Social influence was ostensible and was comprised of 4 conditions, two of which were congruent social influence (both parent and peer ostensibly decided to fish, here on referred to as: "No Conflict–Risk"; both parent and peer ostensibly decided to pass: "No Conflict–Safe"), and two of which were conflicting social influence (parent ostensibly decided to fish while peer passed: "Conflict–Parent Risk";

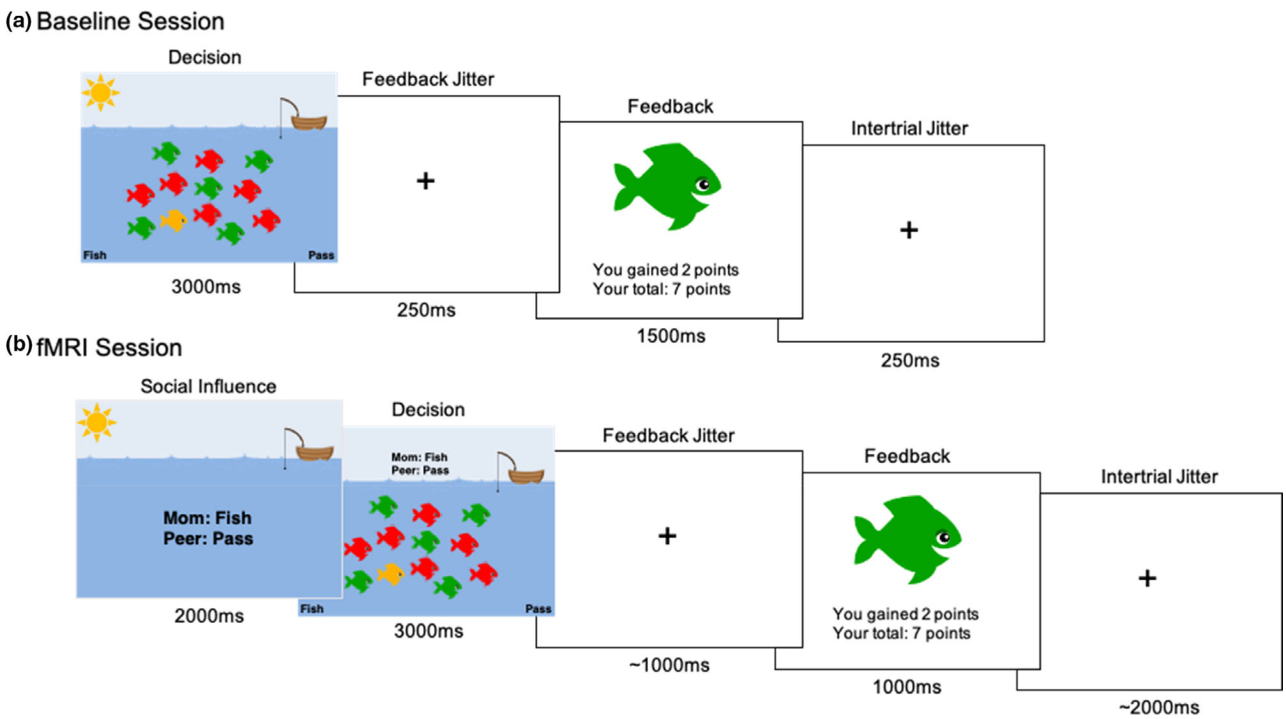

FIGURE 1 (a) Example trial of social influence task in baseline session. (b) Example trial of social influence task in the fMRI scanner with conflicting social influence from parent and peers. [Color figure can be viewed at wileyonlinelibrary.com] parent ostensibly decided to pass while peer fished: “Conflict–Peer Risk”). The latter two possibilities are conflicting social influence given that the parent and peer are providing incongruent behavior and represent our conditions of interest. Social influence was ostensible in order to ensure that we had sufficient manipulations of each type of social influence. We included four different types of social influence in order to increase variability in adolescents’ behaviors as well as increase believability in the decisions of their parent and peer. However, the nonconflict trials were not of interest in the current study, as we specifically focused on the two conflict types. The four types of social influence conditions were randomized, and within each condition, parent and peer’s decisions were presented simultaneously. There was an equal distribution of pond types and equal likelihood of gold appearance across the four types of social influence. After viewing the social influence, participants saw the pond of fish, made their own decision, and received feedback, which was similar to the behavioral session (see Figure 1b).

The fMRI task consisted of 108 trials, 42 of which included a gold fish. Two thirds of the total trials were conflicting social influence (72 trials), half of which were Conflict–Parent Risk and half were Conflict–Peer Risk. The remaining one third of trials (36 trials) were congruent social influence (i.e., No Conflict–Risk and No Conflict–Safe). There was an equal chance of a gold fish appearing across all 4 social influence contexts. Like the behavioral session, each pond consisted of 12 fish with the same possible ratios of green:red fish, and these various probabilities were equated across the four social influence conditions. On each trial, parent and peer social influence appeared for 2,000 ms, followed by the pond with 12 fish for 3,000 ms. Within this 3,000 ms, participants made their decision to either “Fish” or “Pass” while the social influence remained on the slide. Next, there was a jitter that averaged 1,000 ms, followed by feedback for 1,000 ms. Like the behavioral session, feedback presented the fish and either “Win”, “Lose”, or “No-Gain”, depending on the decision and the fish that was chosen as well as the total running points. The trial ended with a jitter that was randomly selected from gamma distribution centered at 2,000 ms.

fMRI Data Acquisition and Analysis

Imaging data were collected using a 3 Tesla Siemens MAGNETOM Trio MRI scanner. The task consisted of T2*-weighted echoplanar images (EPI; 300 volumes; slice thickness = 3 mm; 38 slices; TR = 2 s; TE = 25 ms; matrix = 92x92; FOV = 230 mm; voxel size = 2.5 × 2.5 × 3 mm^3). Structural scans, including a T1* magnetization-prepared rapid-acquisition gradient echo (MPRAGE; 192 slices; TR = 1.9 s; TE = 2.32 ms; FOV = 230 mm; matrix = 256 × 256; sagittal acquisition plane; slice thickness = 0.9 mm) and a T2*-weighted, matched-bandwidth (MBW), high-resolution anatomical scan (38 slices; TR = 4 s; TE = 64 ms; FOV = 230 mm; matrix = 192 × 192; slice thickness = 3 mm), were also acquired. To maximize brain coverage and reduce dropout in orbital and temporal regions, MBW and EPI images were acquired at an oblique axial orientation.

Preprocessing steps, utilizing FSL FMRIB Software Library (FSL v6.0; https://fsl.fmrib.ox.ac.uk/fsl/), included the following steps: skull stripping of all images using BET; slice-to-slice motion correction of EPI images using MCFLIRT; sequential co-registration of EPI images to standard stereotactic space defined by the Montreal Neurological Institute (MNI) and the International Consortium for Brain Mapping through the MBW and MPRAGE images using FLIRT; application of a 128-s high-pass temporal filter to remove low-frequency drift within the time series; and spatial smoothing with a 6-mm Gaussian kernel, full width at half-maximum. Individual-level independent component analysis (ICA) using MELODIC was applied and combined with an automated component classifier (Tohka et al., 2008; Neyman–Pearson threshold = 0.3) in order to remove artifact signal (e.g., physiological noise, motion; an average of 27.07 components or 28.10 % was removed) from the functional data. Quality check during preprocessing and analyses ensured adequate signal coverage.

The task was modeled using an event-related design within the Statistical Parametric Mapping software package (SPM8; Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK). Each social influence event was modeled using the onset of the social influence and a duration equal to the participants’ response time within the 3000-ms decision period (i.e., how long it took the participant to decide to “Fish” or “Pass”). In the event that the participant did not respond in a given trial, then the trial was removed from analysis. Each outcome event was also modeled at the onset of the feedback and equal to the full outcome duration (1,000 ms); however, this was an event of noninterest given our study focused on the decision-making phase. Individual-level fixed-effects models were created for each participant using the general linear model in SPM with regressors for the following conditions: trials for each of the four social influence conditions in the absence of gold fish (e.g., No Conflict–Risk, No Conflict–Safe, Conflict–Parent Risk, and Conflict–Peer Risk), trials containing gold fish, and trials for each outcome (e.g., green fish, red fish, and gold fish). A parametric modulator was included for the social influence conditions to model participants' decisions (e.g., "Fish" or "Pass"; i.e., risky and safe decision). The parametric modulator was binomial (-1 = "Pass", 1 = "Fish") and served to examine how neural activation and connectivity differed when making risky versus safe decisions in the presence of conflicting social influences. Trials in which participants did not respond and volumes containing motion in excess of 2 mm slice to slice were modeled in a separate regressor of no interest. Jittered intertrial periods (e.g., fixation) were not explicitly modeled and therefore served as the implicit baseline for task conditions.

To examine neural connectivity, we conducted psychophysiological interaction (PPI) analyses using a generalized form of the context-dependent PPI from the automated generalized PPI (gPPI) toolbox in SPM (McLaren, Ries, Xu, & Johnson, 2012). Given its role in value-based decision-making, we utilized the vmPFC as our seed region, which was defined structurally from the Harvard-Oxford Atlas (utilizing Frontal Medial Cortex: $-12 < x < 12$; $-2 < z < -32$; see Figure 3a). Time series were extracted from the vmPFC seed region and served as the physiological variable. Trials were then convolved with the canonical HRF to create the psychological regressor. Finally, the physiological and psychological variables were multiplied in order to create the PPI term. This interaction term was then used to identify regions that covary with the vmPFC seed region in a task-dependent manner. As such, each participant's individual gPPI model included a deconvolved BOLD signal alongside the psychological and interaction term for each event type.

Random-effects, group-level analyses were run using GLMFlex (http://mrtools.mgh.harvard.edu/index.php/GLM_Flex). GLMFlex offers several advantages, including removing outliers and sudden activation changes in brain, corrects for variance–covariance inequality, partitions error terms, and analyzes all voxels containing data. Group-level analyses were performed by first testing for associations at the whole brain with neural activation followed by vmPFC functional connectivity. Our analyses focused on Conflict–Parent Risk > Conflict–Peer Risk contrast with the parametric modulator representing adolescents' risky decisions. This contrast allowed us to examine differences in the neural correlates of conflicting social influence (i.e., when parent endorsed risky behavior versus when peer endorsed risky behavior) when adolescents decide to make risky relative to safe decisions.

To correct for multiple comparisons at the neural level, we conducted a Monte Carlo simulation using the updated (April 2016) 3dFWHMx and 3dClustSim programs from the AFNI software package (Ward et al., 2000) and the group-level brain mask. Smoothness was estimated with the -acf option of this method. For neural activation, this simulation indicated that a $p < .05$ family-wise error (FWE) corrected would be achieved with a voxel-wise threshold of $p < .005$ and a minimum cluster size of 48 voxels. For neural connectivity, this simulation indicated that a $p < .05$ family-wise error (FWE) corrected would be achieved with a voxel-wise threshold of $p < .005$ and a minimum cluster size of 58 voxels. All reported results are available on NeuroVault (Gorgolewski et al., 2015; see https://neurovault.org/collections/6033/).

RESULTS

Behavioral Results

Behavioral analyses of risk-taking behavior across conflicting social influence. To investigate the effect of conflicting social influence on adolescent risk-taking behavior, we conducted a repeated-measures analysis of variance with one within-subjects variable with five levels (condition: Baseline, Conflict–Parent Risk, Conflict–Peer Risk, No Conflict–Risk, and No Conflict–Safe). Results show a significant social influence effect, $F(4,108) = 3.69$, $p = .007$, $\eta p^2 = .12$. To probe this effect, we first conducted paired samples t-tests comparing each conflict condition to baseline. As shown in Figure 2, adolescents significantly increased their risky decisions from baseline by 7.65% when their parent endorsed the risk but their peer did not (i.e., Conflict–Parent Risk; $t(27) = -2.89$, $p = .007$, $d = .56$), whereas adolescents did not change their behavior when their peer endorsed the risk but their parent did not (i.e., Conflict–Peer Risk; $t(27) = .86$, $p = .400$). Moreover, adolescents were significantly more risky when their parent endorsed risk than when their peer did by 10.56% (i.e., Conflict–Parent

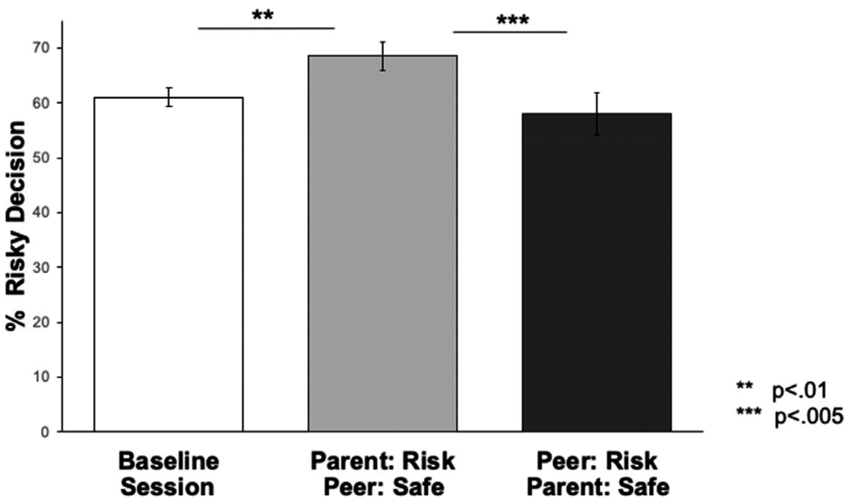

FIGURE 2 Behavioral effects on risk-taking behavior. Adolescents took more risks when parents endorsed risk despite their peers deciding to be safe (i.e., Conflict–Parent Risk) but did not increase their risk taking when their peer endorsed risk (i.e., Conflict–Peer Risk).

TABLE 1
Behavioral Performance Across All Conditions

Condition	*Mean*	SE
Baseline session		
Gold fish	74.19	2.12
No gold fish	60.88	1.72
fMRI session		
Gold fish	80.01	2.87
Conflict (All)	77.51	3.66
Conflict-MomRisk	77.87	3.9
Conflict-PeerRisk	77.14	4.13
No Conflict (All)	84.27	2.29
No Conflict-Risk	84.33	2.51
No Conflict-Pass	84.24	3.48
No gold fish	65.13	2.67
Conflict (All)	63.48	2.83
Conflict-MomRisk	68.54	2.61
Conflict-PeerRisk	57.98	3.76
No Conflict (All)	69.06	3.11
No Conflict-Risk	72.47	4.52
No Conflict-Pass	66.24	4.32

Note. Gold fish indicates the presence of a gold fish in the pond. No gold fish indicates ponds with no gold fish. Conflict (All) and No Conflict (All) represent all conflict (i.e., Conflict-Mom Risk and Conflict-Peer Risk) and no conflict (No Conflict-Risk and No Conflict-Pass) trials collapsed, respectively.

Risk compared to Conflict–Peer Risk; $t(27) = 3.43$, $p = .002$, $d = .65$). These results underscore the greater influence parents have on youth's risk-taking behavior and show that adolescents become riskier when their parents endorse risk but not when their peers do. In addition to the significant pairwise differences described above, other significant differences emerged between Baseline and No Conflict, $t(27) = -2.45$, $p = .021$, $d = .64$, Conflict-Peer Risk and No Conflict-Risk, $t(27) = -2.73$, $p = .011$, $d = .66$, and Conflict-Peer Risk and No Conflict-Safe, $t(27) = -2.57$, $p = .016$, $d = .39$. Further, adolescents took more risks in the nonconflicting social contexts than baseline by 8.18%, $t(27) = -2.56$, $p = .017$, as well as more risk in the nonconflicting social contexts than in conflicting social context by 5.58%, $t(27) = -2.2$, $p = .037$. Table 1 shows the descriptive statistics for all conditions.

fMRI Results

We first conducted a whole-brain *t*-test that compared the two conflicting social influence conditions (Conflict–Parent Risk > Conflict–Peer Risk) when participants chose to make risky relative to safe decisions, as measured with the parametric modulator. Main effects of neural activation are shown in Table 2. No regions involved in valuation were recruited at the main effect level.

Next, we examined functional connectivity for this contrast with the vmPFC as the seed. For PPI analyses, 1 participant was more than five standard deviations above the mean in connectivity strength; the model was re-estimated after excluding this 1 participant; and our reported neural results are based on this re-estimation with $N = 27$. PPI analyses yielded greater coupling with the bilateral striatum for Conflict–Parent Risk > Conflict–Peer Risk

TABLE 2
Brain Activation Patterns for Neural Activation and Functional Connectivity

Anatomical Region	x	y	z	t	k
Conflict–Parent Risk > Conflict–Peer Risk					
L Fusiform Gyrus	−38	−52	−14	4.27	103
L Somatosensory Cortex	−48	−26	18	−4.12	93
L Premotor Cortex	−30	−14	54	−3.46	56
PPI (vmPFC seed): Conflict–Parent Risk > Conflict–Peer Risk					
L Striatum	−12	24	4	3.90	107

Note. No significant regions were identified for the contrast Conflict–Peer Risk> Conflict–Parent Risk. L and R refer to left and right hemispheres; *x*, *y*, and *z* refer to MNI coordinates; *t* refers to the peak activation level in each cluster; *k* refers to the number of contiguous voxels in each significant cluster. All regions are based on whole-brain mask (minimum 48 voxels) and are significant at $p < .005$.

when participants chose to make risky relative to safe decisions (see Figure 3b and Table 2). For descriptive purposes, we extracted parameter estimates of signal intensity from the striatum representing its functional connectivity with the vmPFC and plotted parameter estimates for each condition, separated by participants' decisions. As shown in Figure 3c, when adolescents' decisions matched their parents' decisions in a risky context (i.e., deciding to be risky in the Conflict–Parent Risk condition), there was heightened coupling between the vmPFC and striatum. In contrast, there was no heightened vmPFC–striatum coupling when adolescents' decisions matched their peers' decisions in a risky context (i.e., deciding to be risky in the Conflict–Peer Risk condition)—during which adolescents' risky decisions were incongruent with their parents' endorsement of safe behavior. When adolescents chose to make safe decisions, there was a heightened vmPFC–striatum connectivity in both conflicting contexts; however, this coupling was enhanced when adolescents' and parents' decisions were congruent in the safe context (i.e., deciding to be safe in the Conflict–Peer Risk condition). These findings suggest that there is heightened connectivity within the valuation system when youth make decisions that are congruent with their parent (i.e., making safe decisions when parents endorse safe behavior) relative to their peers in both risky and safe contexts.

DISCUSSION

The aim of the current study was to examine how adolescents make risky decisions under conflicting social influence from parents and peers and how the valuation system in the brain interacts during this process. Our results suggest that adolescents take more risks when their parent chose to be risky but did not take more risks when their peer chose to be risky. At the neural level, there was a heightened vmPFC–striatum functional connectivity when adolescents decided to take a risk, but only if their parent also endorsed the risky decision despite their peers' safe decision. This coupling within the valuation system was also present when adolescents decided to be safe, particularly when adolescents' safe decision was in line with their parents' safe decision. Taken together, these results indicate that parents may have a more prominent role in shaping young adolescents' risk-taking behavior as elucidated by greater changes in their risk-taking propensities as well as by increased vmPFC–striatum functional connectivity.

Behaviorally, adolescents took more risks when their parent endorsed the risky decision despite their peer choosing to be safe. Interestingly, adolescents did not become riskier when their peers endorsed the risky decision, during which their parent chose to be safe, which is in contrast to the popular stereotype and research that peers alone push adolescents to be riskier (e.g., Knoll et al., 2015). Our findings reveal that parents' conflicting influence outweighs peers' decisions in risky contexts, which is consistent with some prior research that parents have a stronger influence on adolescents' decision-making than peers (Welborn et al., 2016). Perhaps parents' decisions to be risky acts as a permission or gateway for adolescents to take the risk and thereby override their peers' safe decision in conflicting social contexts. Parents serve as role models for youth, such that adolescents learn from their parents' decisions and behaviors (e.g., Wiese & Freund, 2011). Adolescents are more likely to engage in risky and antisocial behaviors if parents also participate in these negative behaviors (e.g., Chassin, Curran, Hussong, & Colder, 1996), which reinforces how adolescents can learn and imitate their parents during this key developmental stage.

In line with prior research findings that parents may be protective against deviant peers (e.g., Crosnoe et al., 2002), our results demonstrate that parents' safe decisions may act as a buffer against risky peers since adolescents' risky decisions did not significantly increase when their peers chose to be risky in conflicting social contexts where their parents endorsed the safe decision. Prior research has highlighted how adolescents significantly increase their risk-taking behaviors and attitudes in

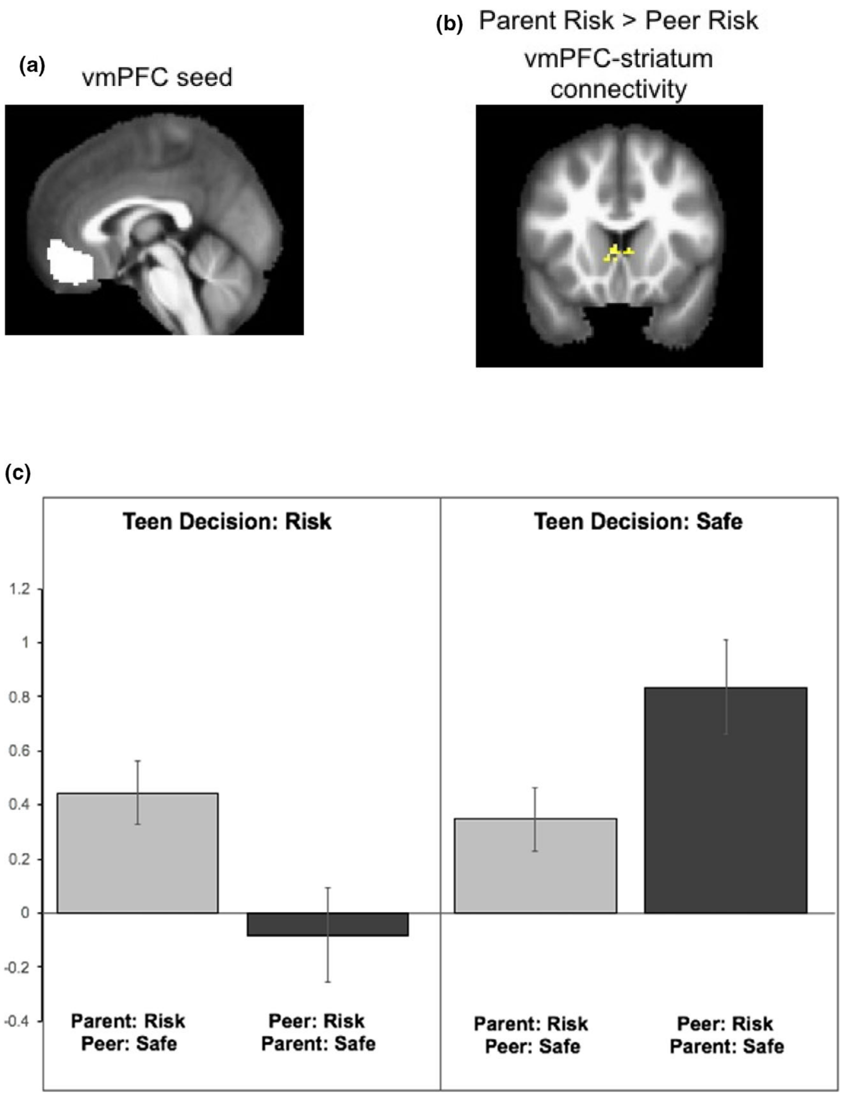

FIGURE 3 (a) vmPFC seed. (b) The Conflict–Parent Risk > Conflict–Peer Risk contrast yielded vmPFC functional connectivity with the bilateral striatum. (c) Parameter estimates of connectivity strength were extracted for each decision for both conflicting social contexts for illustrative purposes. [Color figure can be viewed at wileyonlinelibrary.com]

the presence of peer norms that support risks (e.g., Knoll et al., 2015). Thus, our results suggest that the conflicting influence from parents may override peers' risky decisions and consequently shield youth from conforming to their peers' risky behaviors. These results underscore the salience of family norms in conflicting social contexts, as evidenced both by greater conformity to parents' risky decisions and by the potential buffering role of parents against risky peers. In a conflicting social context, norm conflict may indicate that adolescents identify more with their parents than with their peers, thereby causing greater norm activation to risk-taking information delivered from their parents than that from their peers. While adolescents increasingly rely on peers for attachment, parents are still reported to be their primary secure base in early adolescence for youth to turn to for guidance (Nickerson & Nagle, 2005), and young adolescents may still have a stronger reliance on parents than peers (e.g., Utech & Hoving, 1969). As a result, both positive (e.g., "safe") and negative (e.g., "risky") social information from parents, relative to peers, may be more instrumental in shaping and regulating early adolescents' risk-taking behaviors in conflicting social contexts.

Further, our results evince a behavioral effect that is unique to the conflicting social influence from parents and peers since the same pattern is not observed under nonconflicting social influence.

One likely reason for this is that parental norms might be especially more salient to adolescents when they conflict with peers' norms, leading adolescents to be more sensitive to parents' decisions when they are placed in conflicting situations. Thus, parental influence on adolescents' risky and safe behaviors might appear different had parental endorsement been presented alone in the current task. Future studies should test various types of social influences within the same task in order to generalize the importance of parental influence on adolescents' risky and safe behaviors to other social contexts.

At the neural level, we found interaction within the valuation system as characterized by vmPFC–striatum functional connectivity during conflicting social influence. In particular, when adolescents decided to take the risk in line with their parents' risky decision but against their peers' safe decision, vmPFC–striatum connectivity was enhanced. However, this connectivity was not present when adolescents decided to take the risk in line with their peers' risky decision but against their parents' safe decision. When adolescents decided to be safe, they showed enhanced vmPFC–striatum connectivity especially when adolescents decided to be safe in line with their parents' safe decision. These connectivity results during safe decisions corroborate prior findings that connectivity within the vmPFC–striatum circuit is associated with less impulsive behaviors in adolescents (Christakou, Brammer, & Rubia, 2011). Stronger coupling between the vmPFC and striatum may entail a more adaptive incorporation of social information that may guide adolescents to integrate, calculate, and consider all aspects of their actions (Christakou et al., 2011). Furthermore, enhanced coupling between the vmPFC and striatum is linked to greater reward processing (e.g., Cauda et al., 2011). From a neurodevelopmental lens, younger relative to older adolescents show enhanced vmPFC–striatum connectivity to learned high-value cues (Insel, Charifson, & Somerville, 2019). Thus, when their parent endorses a risk, adolescents may recruit vmPFC–striatum connectivity as they integrate the social norm set by their parent, engage in value-based learning, and subsequently behave in line with their parent. Connectivity within this circuit is also associated with greater saliency to socially affective cues in adolescence (van Duijvenvoorde, Achterberg, Braams, Peters, & Crone, 2016). Therefore, coupling between the vmPFC and striatum when adolescents' decisions follow their parents' decisions may not only emphasize conformity to parents as value-based learning, but also the saliency of parents' choices in guiding adolescents' future decisions and behavior. This vmPFC–striatum functional connectivity result provides a possible biological explanation as to why adolescents take notably more risks when parents make risky decisions despite their peers' safe decisions via strengthened connectivity within the valuation system.

There are some limitations to our study. First, our sample size is small. Future research should examine these same questions using a larger sample size to test whether the effects replicate. In addition, we did not examine any age-related differences. Future investigations should examine how the behavioral and neural effects of conflicting influence differ between various age-groups (e.g., younger vs. mid vs. older adolescents) or how these effects change longitudinally across the adolescence years given that the saliency of parents and peers continues to shift across this developmental period. Although our current findings oppose the popular conception that peers are more influential than parents, these results may change in older adolescent samples. While peer influence and conformity to peers increase across adolescence, parental influence and conformity to parents decrease (e.g., Utech & Hoving, 1969). We may therefore see differences in risk-taking propensity and neural connectivity in the later adolescent years as peers become increasingly influential. Moreover, our peer condition may be conflated by using an unfamiliar peer whom the participant had no expectation to physically meet or interact with. This may have introduced a new social stimulus into our design and therefore confound the familiarity of the two social contexts, especially since adolescents knew that their parent did indeed participate in the study. Nevertheless, based on prior research, we expect the results to be largely similar had familiar peers participated (see Weigard et al., 2014). Additionally, prior work has found strong social influence effects by utilizing confederate peers (e.g., Peake et al., 2013) and has also used unfamiliar peers to contrast parent against peer effects in adolescents (e.g., Saxbe et al., 2015). It is possible that using an unfamiliar peer, as opposed to actual peers, may be a truer representation of adolescents' complex social environment where they meet and interact with new peers. Future studies should examine the effects using a real-life peer or an unfamiliar adult. Further, we did not have a control condition for the fMRI condition, which limits us from probing vmPFC–striatum connectivity when adolescents make risky decisions in the absence of social information. Lastly, both vmPFC and striatum are in regions vulnerable to susceptibility artifacts due to potential signal dropout as well as to movement, and thus, the functional connectivity between vmPFC and striatum might be especially prone to these artifacts.

To our knowledge, this is the first study to explore adolescent risk-taking behavior when there is conflicting social influence from parents and peers, and how the valuation system interacts during this process. Our study lends preliminary support to the idea that parents continue to serve as powerful role models for youths in conflicting situations, as observed by changes in risky decisions and functional connectivity within the valuation system in the developing brain. Our results underscore that early adolescents may have a stronger bias toward their parents' safe and risky decisions than toward their peers, and as such, there may be a continued importance of parental influence on guiding and shaping young adolescents' behaviors.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Supplementary Material.

Table S1. Brain Activation Patterns for Neural Activation.

Figure S1. When making decisions, adolescents showed heightened activation in the VS in ponds with gold fish relative to ponds without gold fish.

Figure S2. VS activity when adolescents make risky and safe decisions in the presence and absence of gold fish.