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Original article

Neural Responses to Exclusion Predict Susceptibility to Social Influence

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A B S T R A C T

Purpose: Social influence is prominent across the lifespan, but sensitivity to influence is especially high during adolescence and is often associated with increased risk taking. Such risk taking can have dire consequences. For example, in American adolescents, traffic-related crashes are leading causes of nonfatal injury and death. Neural measures may be especially useful in understanding the basic mechanisms of adolescents' vulnerability to peer influence.
Methods: We examined neural responses to social exclusion as potential predictors of risk taking in the presence of peers in recently licensed adolescent drivers. Risk taking was assessed in a driving simulator session occurring approximately 1 week after the neuroimaging session.
Results: Increased activity in neural systems associated with the distress of social exclusion and mentalizing during an exclusion episode predicted increased risk taking in the presence of a peer (controlling for solo risk behavior) during a driving simulator session outside the neuroimaging laboratory 1 week later. These neural measures predicted risky driving behavior above and beyond self-reports of susceptibility to peer pressure and distress during exclusion.
Conclusions: These results address the neural bases of social influence and risk taking; contribute to our understanding of social and emotional function in the adolescent brain; and link neural activity in specific, hypothesized, regions to risk-relevant outcomes beyond the neuroimaging laboratory. Results of this investigation are discussed in terms of the mechanisms underlying risk taking in adolescents and the public health implications for adolescent driving.

IMPLICATIONS AND CONTRIBUTION

Adolescents who show the greatest neural reactivity to exclusion may be most susceptible to risk taking in the presence of peers. Neural responses provided information that was not evident from self-reports of susceptibility to peer pressure or participants' distress during exclusion, lending new insight into the mechanisms of peer influence and risk.

Adolescence is a period characterized by heightened responsivity to social influence across domains [1–4], including increased risk taking in the presence of peers [5–7]. This can have dire consequences. For example, in U.S. adolescents, traffic-related crashes are the leading causes of nonfatal injury and death [8]. Evidence is strong that adolescents drive in a more risky fashion compared with adults [9]. Furthermore, adolescents drive in a more risky fashion in the presence of passengers

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[10], with fatal crash rates being higher among adolescent drivers carrying young passengers [11,12].

Neural measures may be especially useful in understanding the basic mechanisms of adolescents' vulnerability to peer influence and risk taking. For example, well-established theories suggest that the imbalance between relatively more rapid development of affective processing systems than cognitive control systems leaves adolescents more vulnerable to risk taking than those in other developmental groups [5,6]. However, adolescents are not uniformly susceptible to risk [7,13–15]; recent empirical work and reviews highlight the likely importance of social context and motivational salience [7,14,16,17], among other factors [13], in affecting adolescent responses to social-cognitive and social-affective cues, as well as in resulting risk-taking behavior. However, current understanding of the neural mechanisms of peer influence on risk taking and knowledge of how neural responses to social cues might interact with context and motivation in adolescents are extremely limited (c.f., [18]).

One form of sensitivity to social cues is the cognitive ability to consider and make sense of the contents of other people's minds (termed mentalizing). Primary brain regions associated with mentalizing include the dorsomedial prefrontal cortex (DMPFC) [19], right temporal parietal junction (rTPJ) [20,21], and posterior cingulate cortex (PCC) [22,23]. Individual differences in the sensitivity of this system may also be associated with broader susceptibility to social influence.

A second form of sensitivity to social cues includes affective responses to being accepted or rejected by others [7]. Prior research has demonstrated that heightened reward activity in the presence of peers is associated with risk taking in adolescents [24]. Conversely, sensitivity to "social pain" [25] has not been examined as a predictor of susceptibility to risky influence and is the focus of the present investigation. Social pain is associated with increased neural activity in the anterior insula (AI) and subgenual anterior cingulate cortex (subACC) in adolescents [26], as well as in the dorsal anterior cingulate cortex (dACC) in adults [25,27,28]. Activity within this system is thought to signal that one may not be in line with the group, among other things, and is associated with restoring normative behavior [29,30]. The social pain system may serve to promote learning that keeps individuals in harmony with the group [26,31].

Hypotheses

Consistent with theories that focus on social monitoring during exclusion as a means of remaining or being included as part of the group [32–34], to the extent that individuals are more sensitive to social cues and experience greater physiological reactivity to exclusion, they might be more inclined to behave in ways that pre-emptively avoid exclusion and promote bonding during social interactions [35]. Given that risk taking in adolescence can be a means of gaining social acceptance [36], those who are more responsive to acute social threats might pre-emptively adjust their behavior to fit in with group norms across situations. More specifically, we hypothesized that increased activity in neural systems associated with social-cognitive sensitivity (mentalizing: DMPFC [19], rTPJ [20,21], and PCC [22,23]) as well as social-affective sensitivity ("social pain": AI, subACC [26]) during exclusion would be associated with differences in risk taking in the presence of peers in a separate simulated driving session, controlling for solo risk-taking behavior. It is also possible that the dACC might play a role, given prior findings regarding social pain in adults [25,27,28].

To test these hypotheses, we conducted a two-appointment study in which neural responses were recorded using functional magnetic resonance imaging (fMRI) during social exclusion in an especially at-risk group for fatal crash: recently licensed male adolescents [11,37]. Individual differences in neural sensitivity to exclusion during the initial fMRI scan were then used to predict individual differences in risk taking in the presence of peers, controlling for solo risk behavior, in a separate driving simulator session approximately 1 week later (Figure 1). Driving simulation is consistently associated with a number of real-world driving behaviors [38] and is a safe method for investigating the effect of peer influences on risky driving behavior while maintaining a high degree of both experimental control and external validity [39].

Materials and Methods

Participants

Thirty-six neurotypical adolescent males aged 16–17 years ($M = 16.8$, SD = .47) were recruited through the Michigan state driver registry database (driver history record) as part of a larger study on peer influences on adolescent driving [40]. These participants successfully completed both an fMRI session and a separate driving simulator appointment approximately 1 week later (Figure 1; see Supplementary Data for full recruitment and simulator details). Within the 4–9 months prior to the scan, all participants had obtained a Level 2 (intermediate) Michigan driver license allowing them to drive independently but with passenger and night driving restrictions. In addition, participants met standard MRI safety criteria (Supplementary Data). Legal guardians provided written informed consent, and adolescents provided written assent.

Procedure

Session 1: fMRI. At their first (fMRI) session, participants were introduced to two gender-matched peer confederates. Participants were told that they would be playing some computer games on their own, as well as in a group with the other "participants." Research assistants then took them to separate private rooms where the real participant completed the online prescan questionnaires and was given further instructions about the fMRI tasks; the confederates were not involved further in study procedures. Participants next completed a series of tasks within the fMRI scanner, including a game called Cyberball. Cyberball has been validated in a number of behavioral and neuroimaging studies as a reliable way of simulating the experience of social exclusion [27,41]. A fair game of Cyberball was always played first, in which the participant and two virtual players received the ball equally often. This was followed by an unfair game, in which the participant and virtual players started out receiving the ball equally often, but where the participant was left out after a few throws, simulating exclusion. Order of the rounds was held constant to preserve the psychological experience across participants (see Supplementary Data). After the scan, participants completed a second set of questionnaires, including all the questionnaires that are the focus of this investigation.