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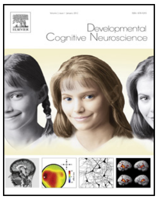

Age differences in the impact of peers on adolescents' and adults' neural response to reward

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A B S T R A C T

Prior research suggests that increased adolescent risk-taking in the presence of peers may be linked to the influence of peers on the valuation and processing of rewards during decision-making. The current study explores this idea by examining how peer observation impacts the processing of rewards when such processing is isolated from other facets of risky decision-making (e.g. risk-perception and preference, inhibitory processing, etc.). In an fMRI paradigm, a sample of adolescents (ages 14–19) and adults (ages 25–35) completed a modified High/Low Card Guessing Task that included rewarded and un-rewarded trials. Social context was manipulated by having participants complete the task both alone and while being observed by two, same-age, same-sex peers. Results indicated an interaction of age and social context on the activation of reward circuitry during the receipt of reward; when observed by peers adolescents exhibited greater ventral striatal activation than adults, but no age-related differences were evinced when the task was completed alone. These findings suggest that, during adolescence, peers influence recruitment of reward-related regions even when they are engaged outside of the context of risk-taking. Implications for engagement in prosocial, as well as risky, behaviors during adolescence are discussed.

1. Introduction

One hallmark of adolescent risk taking is that, more often than not, it occurs in the presence of peers (for recent review, see Albert et al., 2013). Although the customary explanation of this phenomenon assumes that it arises from explicit peer pressure to engage in risky behaviors, experimental studies of the "peer effect" on adolescent risk taking have demonstrated that the mere presence of peers can increase adolescents' risk taking even when the adolescents are prohibited from directly communicating with each other (Chein et al., 2011; Smith et al., 2014), an effect that is not seen among adults. This finding suggests that a process other than explicit encouragement to behave recklessly explains why adolescents, but not adults, are more likely to take risks when with their friends.

One explanation suggested by prior work is that, during adolescence, the presence of peers affects the way in which rewards are valuated and processed. In behavioral studies, for example, adolescents who are being watched by peers are more oriented toward immediate than delayed rewards (O'Brien et al., 2011; Weigard et al., 2013), and more inclined to pursue rewards even in the face of likely negative outcomes (Smith et al., 2014). Prior neuroimaging work further shows that during a risk-taking task, being

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observed by peers produces heightened activation selectively in brain areas associated with reward processing (e.g., the ventral striatum, VS), and not in other brain regions engaged by the task (e.g., lateral prefrontal cortex, lPFC) (Chein et al., 2011). Consistent with the behavioral evidence, this increased activation during peer observation is found among adolescents, but not among adults.

These findings suggest that adolescents' relatively stronger inclination to behave recklessly in the presence of peers is due specifically to the impact of peers on reward sensitivity, which is likely mediated by engagement of reward processing regions, specifically the VS. However, the paradigms previously used to investigate this effect conflate reward processing with other facets of risky decision making, such as risk preference and self-regulation, making it difficult to determine whether reward processing per se is specifically impacted by the presence of peers, or whether some more complex interaction between self-regulatory and affective processes operative during risky decision making might underlie this effect. In the present study, we therefore examine the peer effect on reward processing using a task in which no explicit risk is involved.

There are no prior studies investigating how peers impact age differences during reward processing, but there have been several studies of age differences in reward sensitivity when individuals are alone (e.g., Bjork et al., 2004; Galvan et al., 2006; Padmanabhan, Geier, Ordaz, Teslovich, & Luna, 2011; Van Leijenhorst et al., 2009). Several such studies report age differences in striatal engagement during reward processing. The majority of studies show that relative to both children and adults, adolescents are more sensitive to rewards and show greater striatal activation in brain regions typically associated with reward processing (Barkley-Levenson and Galvan, 2014; Christakou et al., 2011; Galvan et al., 2006; Galvan and McGlennen, 2013; Geier et al., 2010; Hoogendam et al., 2013; Jarcho et al., 2012; Padmanabhan et al., 2011; Van Leijenhorst et al., 2009). There are also several studies, however, reporting a dampened striatal response to reward during adolescence (Bjork et al., 2004, 2010; Hoogendam et al., 2013; Lamm et al., 2014) and others that do not find any effect of age on striatal response (Benningfield et al., 2014; Krain et al., 2006; Teslovich et al., 2013; Van Leijenhorst et al., 2006). Despite these inconsistencies in the literature, which are likely due to differences in the specific tasks employed and the specific stages of reward processing under investigation (e.g., anticipation or receipt) (for recent review, see Richards et al., 2013), the weight of the available evidence seems to indicate increased striatal responding to rewards during adolescence. Whether this age difference in the activation of reward circuitry is moderated by the presence of peers, and whether any such moderating influences arise during reward anticipation, reward receipt, or both, is unknown.

The current study uses functional magnetic resonance imaging (fMRI) to examine age differences in neural engagement during peer observation when participants perform a reward-processing task that involves no risk taking (i.e., there is no response that can be thought of as inherently more “safe” or more “dangerous”). We tested three hypotheses. First, we hypothesized that adolescents would show greater activation than adults in the VS during the anticipation and receipt of reward. Second, we hypothesized that adolescents' activation of this region (either during the anticipation or receipt of reward) would be greater in the presence of peers than when alone. And third, we hypothesized that the impact of peers on activation of the VS would be seen among adolescents, but not adults.

2. Method

2.1. Participants

Twenty adolescent participants (ages 14–19 years, $M = 16.7$, $SD = 1.5$, 10 females), and 20 adult participants (ages 24–32 years, $M = 26.7$, $SD = 2.3$, 10 females) provided data for the study. The demographics were as follows: 43% Caucasian, 25% African American, 20% Asian, and 12% Unknown. The two age groups did not differ with respect to race, $X^2(3,40) = 5.48$, $p = 0.14$. Informed consent was obtained from each participant aged 18 and older, and parental consent and youth assent were obtained from each participant aged 17 and younger. All procedures were reviewed and approved by the university's Institutional Review Board. Participants received monetary compensation ($35) for their participation. To keep participants motivated throughout the experiment, they were informed that an additional bonus payment (up to $15) would be provided based on their overall task performance. In actuality, all participants received the bonus.

2.2. Procedure

The current study was part of a larger fMRI experiment in which we systematically varied the social context (i.e., alone versus peer observation, as described below) under which individuals were tested. While in the scanner, participants completed 6, 8-min rounds of the High/Low Card Guessing Task (described below) and 2, 5-min rounds of a Delay Discounting Task. The order of tasks was the same for all participants: 3 runs of the Card Guessing Task, followed by 2 runs of Delay Discounting, then the social condition was switched and 3 additional runs of the Card Guessing Task (but no additional runs of Delay Discounting) were completed. Only the results of the Card Guessing Task are presented in this manuscript, since the Delay Discounting task was not administered with a within-subjects social context manipulation.

2.3. Task design

The current study employed a modified version of the High/Low Card Guessing Task (adapted from Delgado et al., 2003) administered on a computer inside the scanner (Fig. 1a). This reward processing task required participants to make a series of uninformed guesses about whether a number hidden on the reverse side of each card in a virtual stack of cards would be higher or lower than 5. It is important to note that although the task does involve a simple decision (a guess) that may encourage some degree of internal deliberation, it does not involve *risky* decision making, because the guesses made by the participants are