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High and low sensation seeking adolescents show distinct patterns of brain activity during reward processing

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ABSTRACT

Previous research has shown that personality characteristics, such as sensation seeking (SS), are strong predictors of risk-taking behavior during adolescence. However, the relationship between levels of SS and brain response has not been studied during this time period. Given the prevalence of risky behavior during adolescence, it is important to understand neurobiological differences in reward sensitivity between youth with high and low SS personalities. To this end, we used functional magnetic resonance imaging (fMRI) to examine differences in brain activity in an adolescent sample that included 27 high (HSS) and 27 low sensation seekers (LSS), defined by the Impulsive Sensation Seeking scale of the Zuckerman–Kuhlman Personality Questionnaire (Zuckerman et al., 1993). In the scanner, participants played a modified Wheel of Fortune decision-making task (Cservenka and Nagel, 2012) that resulted in trials with monetary Wins or No Wins. We compared age- and sex-matched adolescent HSS and LSS (mean age = 13.94 ± 1.05) on brain activity by contrasting Win vs. No Win trials. Our findings indicate that HSS show greater bilateral insular and prefrontal cortex (PFC) brain response on Win vs. No Win compared to LSS. Analysis of simple effects showed that while LSS showed comparable brain activity in these areas during Wins and No Wins, HSS showed significant differences in brain response to winning (activation) vs. not winning (deactivation), with between-group comparison suggesting significant differences in brain response, largely to reward absence. Group differences in insular activation between reward receipt and absence may suggest weak autonomic arousal to negative outcomes in HSS compared with LSS. Additionally, since the PFC is important for goal-directed behavior and attention, the current results may reflect that HSS allocate fewer attentional resources to negative outcomes than LSS. This insensitivity to reward absence in HSS may lead to a greater likelihood of maladaptive choices when negative consequences are not considered, and may be an early neural marker of decreased loss sensitivity that has been seen in addiction. This neurobiological information may ultimately be helpful in establishing prevention strategies aimed at reducing youth risk-taking and suggests value in further examination of neural associations with personality characteristics during adolescence.

Introduction

Adolescence is a developmental period during which pubertal, cognitive, and affective maturation take place (Casey and Jones, 2010; Ernst and Fudge, 2009; Ernst et al., 2006; Scherf et al., 2012). This transitional period is marked by changes in physical (Susman et al., 2010) and brain (Sowell et al., 2002) maturity, as well as alterations in personality characteristics and behavior (Pharo et al., 2011). In particular, adolescence is considered a period of increased risk-taking, reflected by elevated alcohol and drug experimentation, unsafe sexual activity, and reckless driving (Eaton et al., 2010). While many risk factors are believed to increase susceptibility for engaging in maladaptive behavior, sensation seeking is one personality characteristic that is a strong predictor of such risk (Steinberg, 2004; Wills et al., 1994).

Sensation seeking has been defined as a trait that leads individuals to seek out novel and intense sensations and experiences (Zuckerman and Kuhlman, 2000). From an evolutionary perspective, sensation seeking during adolescence may be viewed as an adaptive mechanism for learning to gain independence from parents (Steinberg and Belsky, 1996); however, risky adolescent behaviors lead to especially high mortality rates (Institute of Medicine and National Research Council, 2011). High sensation seekers view novel activities as less risky compared to low sensation seekers (Horvath and Zuckerman, 1993), and thus, may be more prone to seek out exciting experiences without recognition/

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awareness of their potential adverse consequences (Zuckerman and Kuhlman, 2000). Along these lines, longitudinal analysis has shown that the increase in sensation seeking during adolescence, accompanied by concomitant rise of risk-taking behavior, is a significant predictor of elevated alcohol use (MacPherson et al., 2010). Other longitudinal studies have shown that sensation seeking predicts binge drinking onset and smoking behavior during adolescence, making this personality characteristic a potentially useful target for prevention strategies aimed at reducing the incidence of alcohol and substance abuse during this critical developmental period (Sargent et al., 2010). Given that sensation seeking is strongly associated with approach motivation (Zuckerman and Kuhlman, 2000), laboratory paradigms have begun to investigate the relationship between sensation seeking and risk-taking as they relate to reward/loss sensitivity in young adults. Results suggest that reward sensitivity may be an important marker for the relationship between personality and risk-taking, as individuals high in sensation seeking and impulsivity do not reduce the number of risky decisions they make in the face of high reward/loss magnitude trials (Bornovalova et al., 2009). This suggests that sensation seeking may modulate sensitivity to reward, and that studying the neural correlates of this trait as a marker for reward sensitivity could help identify how this personality characteristic relates to risk-taking in adolescents.

To understand the underlying neural mechanisms of heightened approach behavior during adolescence, neuroimaging studies have been conducted to examine the relative rate of neural development across reward-related and higher-order cognitive control brain regions. These neurobehavioral models of adolescence propose that heightened approach behavior during this period, in the face of weak avoidance and still immature regulatory capacity by higher-order cognitive control systems, leads to the elevated risk-taking seen during this time (Ernst and Fudge, 2009; Ernst et al., 2009). For example, the triadic model of adolescent neurodevelopment (Ernst et al., 2006) has proposed that heightened approach behavior during adolescence may be linked to the earlier development of subcortical systems, such as the basal ganglia, relative to the more protracted maturation of prefrontal cognitive control brain regions (Casey and Jones, 2010). Some theories argue that heightened motivational drive is linked to increased ventral striatal response to rewards during adolescence (Galvan et al., 2006). However, others have proposed that it is a hyporesponsive subcortical system that leads adolescents to seek out exciting and novel experiences, a phenomenon that has been termed the reward deficiency hypothesis (Bjork et al., 2004). A number of different hypotheses have been reviewed that may explain discrepancies in the results of adolescent reward processing studies (Galvan, 2010). Differences in task design and analysis (including contrast specification) and variation in adolescent age samples are just a few examples that may account for disparate findings (Bjork et al., 2004, 2010b; Ernst et al., 2005; Galvan, 2010; Galvan et al., 2006). Furthermore, individual variability in personality traits, such as sensation seeking, may be an important determinant of reward response that could have clouded past results. To identify youth who may be at greatest risk for maladaptive behavior, examining the neural correlates of sensation seeking during adolescence may hold promise.

Previous research investigating the contribution of personality differences on brain structure and function has begun to examine the neurobiological basis of sensation seeking in adults. Using a probabilistic monetary reward task, Abler et al. (2006) found that thrill and adventure seeking was positively correlated with ventral striatal blood oxygen level-dependent (BOLD) response during the expectation of reward. Novelty seeking is another trait that has been closely associated with approach behavior and was found to correlate with medial prefrontal cortex activity during expectation of emotional relative to neutral pictures (Bermpohl et al., 2008). Furthermore, this trait has been examined in relation to brain morphology, with studies suggesting positive correlations between novelty seeking and grey matter volume in both prefrontal and parietal regions (Gardini et al., 2009; Van Schuerbeek et al., 2011).

While previous research has correlated personality traits with brain structure and function, few studies have stratified sensation seekers into high and low groups to examine differences in brain activity in relation to distinct sensation seeking profiles. Joseph et al. (2009) grouped young adults into high and low sensation seekers and measured BOLD response when viewing high- or low-arousing emotional pictures. The authors found that high sensation seekers showed greater brain response to highly arousing stimuli compared to low sensation seekers in the insula and inferior frontal gyrus. Given other work implicating insular activity in response to appetitive stimuli (Ray et al., 2010), these results suggest an overactive approach system in high sensation seekers (Joseph et al., 2009). To date, only one study has examined neural response to monetary rewards in high and low sensation seekers and showed greater reward sensitivity in high sensation seeking adults in regions including the insula and nucleus accumbens (Kruschwitz et al., 2012). To our knowledge, no studies have examined the neural correlates of sensation seeking during adolescence, a period during which peak levels of this personality trait have been observed in the majority of individuals (Steinberg et al., 2008).

To this end, the current study stratified adolescents into those with above and below average sensation seeking profiles, using the Impulsive Sensation Seeking Scale of the Zuckerman–Kuhlman Personality Questionnaire (Zuckerman et al., 1993). Adolescents performed a probabilistic monetary reward-based decision-making task during functional magnetic resonance imaging (fMRI) (Cservenka and Nagel, 2012; Ernst et al., 2004b). Since we were interested in how personality may relate to reward sensitivity, we examined brain response during the reward feedback phase of the task. Overall, we hypothesized that adolescents would show a hyperresponsive pattern of brain activity in the ventral striatum in the presence vs. the absence of monetary rewards, in support of previous studies of adolescent reward sensitivity. In addition, based on the adult literature, we predicted that personality would further exacerbate this hyperresponsive pattern such that high sensation seeking youth would show greater activation to rewards compared with low sensation seeking youth in brain regions related to approach behavior and autonomic arousal, including the nucleus accumbens and insula.

Material and methods

Participants

Inclusionary and exclusionary criteria

Participants included healthy adolescents, ages 12 to 16 years. All participants were recruited from the community and underwent comprehensive screening interviews as part of an ongoing study of adolescent neurodevelopment. Exclusionary criteria for youth included left handedness [Edinburgh Handedness Inventory (Oldfield, 1971)], DSM-IV psychiatric diagnoses (Lucas et al., 2001), inability of a parent to provide family history, serious medical problems, significant head trauma, mental retardation or learning disabilities, psychotic illness in a biological parent (e.g. schizophrenia or bipolar I), prenatal exposure to drugs or alcohol, MRI contraindications (e.g., irremoveable metal in the body), or pregnancy. In addition, all youth were free of heavy alcohol or substance use {$\geq$10 lifetime alcoholic drinks or $>$2 drinks on any occasion, $>$5 uses of marijuana, any other drug use, or $>$4 cigarettes per day [Brief Lifetime version of the Customary Drinking and Drug Use Record (Brown et al., 1998)]}. Only participants who were classified as either a high or low sensation seeker, as defined below (Classification of sensation seeking groups), were included. The study was approved by the Oregon Health & Science University (OHSU) Institutional Review Board.

Classification of sensation seeking groups

94 adolescents (60 males) were administered the Impulsive Sensation Seeking (ImpSS) Scale of the Zuckerman–Kuhlman Personality Questionnaire (Zuckerman et al., 1993). This scale consists of 19 true–