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Age-related changes in reappraisal of appetitive cravings during adolescence

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ABSTRACT

The ability to regulate temptation and manage appetitive cravings is an important aspect of healthy adolescent development, but the neural systems underlying this process are understudied. In the present study, 60 healthy females evenly distributed from 10 to 23 years of age used reappraisal to regulate the desire to consume personally-craved and not craved unhealthy foods. Reappraisal elicited activity in common self-regulation regions including the dorsal and ventral lateral prefrontal cortex (specifically superior and inferior frontal gyri), dorsal anterior cingulate cortex, and inferior parietal lobule. Viewing personally-craved foods (versus not craved foods) elicited activity in regions including the ventral striatum, as well as more rostral and ventral anterior cingulate cortex extending into the orbitofrontal cortex. Age positively correlated with regulation-related activity in the right inferior frontal gyrus, and negatively correlated with reactivity-related activity in the right superior and dorsolateral prefrontal cortices. Age-adjusted BMI negatively correlated with regulation-related activity in the predominantly left lateralized frontal and parietal regions. These results suggest that the age-related changes seen in the reappraisal of negative emotion may not be as pronounced in the reappraisal of food craving. Therefore, reappraisal of food craving in particular may be an effective way to teach teenagers to manage cravings for other temptations encountered in adolescence, including alcohol, drugs, and unhealthy food.

Adolescence presages dramatic increases in autonomy and exposure to temptations, such as unhealthy food, alcohol, and drugs. Learning how to manage appetitive cravings and resist these temptations is a vital aspect of healthy adolescent development (Davidson et al., 2000; Gross, 1998; Gross and Munoz, 1995). However, little is known about how the adolescent brain regulates these cravings. Recently, we and others have leveraged the considerable work done in the field of emotion regulation to better understand the cognitive regulation of craving. Like emotions, cravings are affective states that motivate behavior, in ways that are not always desirable or appropriate — and may thus benefit from being regulated.

One useful regulation strategy is reappraisal, the cognitive reinterpretation of an event or stimulus so as to change its affective meaning (Giuliani and Gross, 2009). Reappraisal can be used to significantly reduce cravings for personally-craved unhealthy foods by, for example, focusing on the negative consequences of indulging in that food (Giuliani et al., 2013). In adults, reappraisal of the craving for food stimuli recruits a network of brain regions quite similar to those recruited during the reappraisal of other affective states, including the dorsolateral prefrontal cortex (DLPFC), the inferior frontal gyrus (IFG), and the dorsal anterior cingulate cortex (dACC; Buhle et al., 2013; Giuliani et al., 2014; Hollmann et al., 2011). Recruitment of this network often modulates or overrides activity in regions like the ventral striatum (VS), whose activity often reflects the anticipation of reward (e.g. Buhle et al., 2013; Hare et al., 2009; Martin Braunstein et al., 2014).

The ability to use reappraisal to regulate affective states begins to emerge as early as age 5 (DeCicco et al., 2012). Increases in reappraisal ability and usage throughout adolescence have been noted in some samples (Garnefski et al., 2002; McRae et al., 2012; Silvers et al., 2012), but not all (Gullone et al., 2010; Silvers et al., 2014). Several studies have interrogated the neural correlates of emotion reappraisal in adolescence, using stimuli including sad pictures, disgusting pictures, negative pictures from the International Affective Picture System, and sad film clips (Belden et al., 2014; Lévesque et al., 2004; McRae et al., 2012; Pitskel et al., 2011). Across all of these studies, using reappraisal to reduce negative affect (measured by the difference in self-reported affect between passive viewing and reappraisal) commonly recruited aspects of lateral prefrontal cortex (PFC). However, only two of these studies investigated age-related effects on the behavioral and neural correlates of emotion reappraisal, and the findings were conflicting. Pitskel et al. (2011) found that age was associated with less reappraisal-related activity in the orbitofrontal cortex (OFC), medial PFC, left IFG, and left amygdala, and McRae et al. (2012) found that age had a positive linear relationship with reappraisal-related activity in the left IFG and a positive quadratic relationship with activity in the posterior cingulate cortex (PCC). Additional well-powered investigations of

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the neural correlates of reappraisal across adolescence may help to resolve this inconsistency.

While most of the extant work on reappraisal has focused on the reappraisal of negative affective states, other affective motivational states are also useful and important targets of cognitive regulation (e.g., Giuliani et al., 2008; Kober et al., 2010a; Parrott, 1993). In particular, reappraisal is an effective way of reducing cravings such as those elicited by cigarettes and junk food (Giuliani et al., 2013; Kober et al., 2010a). Although much of the work on reward and appetitive motivation in adolescence has focused on secondary rewards like money, some studies have begun to investigate how primary, non-monetary rewards like food are processed in the adolescent brain (e.g., Holsen et al., 2005; Luking et al., 2014; Silvers et al., 2014). This is an especially important question during this phase of development, when experimentation with rewarding appetitive substances like alcohol or drugs often begins (Eaton et al., 2012).

The transient peak in approach and exploratory behaviors during adolescence is thought to be adaptive, as it biases the adolescent to pursue experiences that are essential for developing adult independence (Luciana and Collins, 2012). However, adolescents encounter many situations in which regulation of these approach behaviors is preferable or even necessary for survival. Unfortunately, little work exists on the cognitive regulation of affective states beyond negative emotion (e.g., Giuliani et al., 2014; Hollmann et al., 2011; Kober et al., 2010b; Siep et al., 2012), and even less exists on the adolescent regulation of the desire for non-monetary rewards like food. One recent study investigated the neural bases of food craving reappraisal in adolescence, comparing reappraisals focusing on the costs of eating an unhealthy food with ones focusing on the benefits of not eating the unhealthy food. Both strategies elicited activity in the left medial superior frontal gyrus (SFG) and IFG, which was not moderated by body mass index (BMI; Yokum and Stice, 2013). However, this study (N = 21; *M* age = 15.2, SD = 1.18) did not investigate whether or how food craving reappraisal ability develops from childhood into adulthood. Another recent study of the neural bases of food craving reappraisal examined neural activity in participants across a much wider age range (N = 105, ages 6–23 years), and asked them to focus more or less on the appetizing features of unhealthy foods (Silvers et al., 2014). This study mentioned only one age effect specific to reappraisal strategy, in the putamen; it also found that leaner (age-adjusted BMI) individuals recruited left ventrolateral and parietal regions more during regulation trials, especially at younger ages. Taken together, it remains unclear from the limited literature whether activity in neural circuitry supporting appetitive reappraisal should increase, decrease, or remain stable across adolescence.

More generally, several models of adolescent neurobiological development have combined the literature on regulation and reactivity to better understand risk-taking behavior in adolescence. For example, dual-systems and imbalance models (e.g., Casey, 2015; Somerville and Casey, 2010; Steinberg, 2010) contrast non-linear patterns of incentive motivation and reward seeking (uniquely heightened in adolescence) with linear age-related increases in cognitive regulation to account for the transient peaks in approach behaviors and risk-taking seen during this time. These models have been generative and useful, but the existing neuroimaging evidence in human adolescents relies primarily upon affective faces and money to represent the vast array of stimuli motivating approach (or avoidance) behavior encountered in everyday life. It is presently unknown how well these models apply to other stimuli, and thereby represent the full complexity of the changes taking place (Bjork et al., 2012; Crone and Dahl, 2012; Pfeifer and Allen, 2012).

Therefore, in the present study, we sought to investigate the behavioral and neural correlates of food craving reappraisal and reactivity in a large sample of healthy adolescents across a wide age range. Specifically, we hypothesized that, across all subjects, cognitive reappraisal would effectively moderate the desire to consume personally-craved unhealthy foods. Neurally, our a priori regions of interest were based on the expectations that reappraisal of food cravings would elicit regulation-related activity in the DLPFC, IFG, and dACC, and food reactivity would elicit reward-related activity in the VS and OFC. We were also interested in whether and how individual differences in age, BMI, and self-reported reappraisal usage related to the behavioral and neural correlates of food reappraisal and reactivity. In light of the neurobiological imbalance models discussed above, it may be expected that reappraisal ability and related neural activity would exhibit a linear association with age in adolescence, whereas cravings and related neural activity would exhibit a nonlinear pattern (such as an adolescent-specific peak). However, due to the mixed findings in the literature thus far regarding the relationship between the neural correlates of reappraisal and age, we did not have an a priori hypothesis as to the predicted direction of the relationship (if any) between age and brain activity during reappraisal.

Methods

Participants

Participants were 60 females between the ages of 10 and 23 (*M* = 16.66, SD = 3.68, range 10.16–22.89 years) recruited from the Eugene, OR metropolitan area. The sample was distributed across the age range; in one-year increments, Ns ranged from 3 to 6 (*M* = 4.62, SD = .77). There was no overlap between this sample and those from previous studies using this task (Giuliani et al., 2013, 2014). Potential participants were excluded if they were left-handed, under 10 or over 23 years of age, non-native English speakers, had a current or past diagnosis of neurological or psychological disorder, had a history of head trauma, were pregnant, currently used psychoactive medication, or had any non-MRI compatible conditions (e.g., metal in body). All gave informed consent in accordance with the University of Oregon Institutional Review Board.

Task

Details of the task are outlined in our previous work (Giuliani et al., 2013) and shown in Fig. 1. Briefly, images of two types of palatable foods were included as stimuli: low energy density foods (“Neutral”), and energy-dense (ED) foods of the participants' choosing. The total stimulus set consisted of 14 pictures of low energy-density food (carrots, corn, cucumber, beans, broccoli, Brussels sprouts, eggplant, lettuce, squash, tomatoes; pre-tested desirability *M* = 2.51, SD = .23), and 28 pictures in each of the following categories of ED food (pre-tested desirability *M*s = 3.46–3.53, SDs = .16–.37): chocolate, cookies, donuts, fries, ice cream, pasta, and pizza. Importantly, images were chosen such that the mean desirability ratings of the ED food categories were not significantly different from each other (all paired-samples *p*-values > .2), and that the mean of each ED food category was significantly greater than the mean of the Neutral stimuli (*p*-values < .001). All participants saw the same set of 14 Neutral stimuli. For the ED stimuli, participants chose from the above list of seven food types the one that they craved the most (“Craved”) and the one they craved the least (“Not Craved”), and saw only images within those two categories in addition to the Neutral stimuli during the task. Craving was defined as the desire and tendency to consume the target food, even in the absence of hunger.

There were two types of instructions: Look or Regulate. The Look instruction directed participants to focus on the pictured food, imagine it was actually in front of them, and think about consuming it. The Regulate instruction directed participants to focus on the food, imagine it was in front of them, and think about the short- or long-term negative consequences of eating a large quantity of the food (e.g., stomachache, weight gain). Participants chose one specific strategy before the task and were directed to use that same strategy on every Regulate trial. For the rating period, we instructed participants to report their craving honestly at the end of each trial. To minimize the demand characteristics of the task regarding regulation success (i.e., reduced desire ratings