Development and Psychopathology **28** (2016), 277–291

doi:10.1017/S0954579415000449

Neural responses to monetary incentives among self-injuring adolescent girls

COLIN L. SAUDER,[a] CHRISTINA M. DERBIDGE,[b] AND THEODORE P. BEAUCHAINE[c]
[a]*Stony Brook University;* [b]*University of Washington; and* [c]*Ohio State University*

Abstract

Rates of self-inflicted injury among adolescents have risen in recent years, yet much remains to be learned about the pathophysiology of such conduct. Self-injuring adolescents report high levels of both impulsivity and depression behaviorally. Aberrant neural responding to incentives, particularly in striatal and prefrontal regions, is observed among both impulsive and depressed adolescents, and may mark common vulnerability to symptoms of anhedonia, irritability, and low positive affectivity. To date, however, no studies have examined associations between central nervous system reward responding and self-injury. In the current study, self-injuring ($n = 19$) and control ($n = 19$) adolescent females, ages 13–19 years, participated in a monetary incentive delay task in which rewards were obtained on some trials and losses were incurred on others. Consistent with previous findings from impulsive and depressed samples, self-injuring adolescents exhibited less activation in both striatal and orbitofrontal cortex regions during anticipation of reward than did controls. Self-injuring adolescents also exhibited reduced bilateral amygdala activation during reward anticipation. Although few studies to date have examined amygdala activity during reward tasks, such findings are common among adults with mood disorders and borderline personality disorder. Implications for neural models of impulsivity, depression, heterotypic comorbidity, and development of both self-injury and borderline personality traits are discussed.

Self-inflicted injury (SII), including suicide attempts and nonsuicidal self-harm (see Crowell et al., 2008; Nock, 2010), portends a wide range of adverse outcomes among affected adolescents, including social problems, academic underachievement, and poor psychological adjustment (for reviews, see Crowell, Derbidge, & Beauchaine, 2014; Crowell, Kaufman, & Lenzenweger, 2013; Derbidge & Beauchaine, 2014; Nock, 2010). Most adolescents who engage in SII meet criteria for one or more psychiatric disorders, with risk dispersed roughly evenly across the internalizing and externalizing spectra (Crowell et al., 2005; Nock, Joiner, Gordon, Lloyd-Richardson, & Prinstein 2006). Perhaps of more importance, SII is the single best predictor of eventual completed suicide (Hamza, Stewart, & Willoughby, 2012).

Although some correlates of suicidal behavioral and nonsuicidal self-harm appear to be distinct, such as levels of hopelessness, perceived burden others, and reported goals of the behavior, most if not all self-injurers experience negative/irritable mood states, a desire to reduce/avoid emotional distress, and high levels of impulsivity (see Brown, Comtois, & Linehan, 2002; Glenn & Klonsky, 2010; Horesh et al., 1997; Joiner et al., 2002; Minkoff, Bergman, Beck, & Beck, 1973; Rudd, Joiner, & Rajad, 1996).

The research reported in this article was supported by Grants MH86198 and MH63699 from the National Institute of Mental Health.

Address correspondence and reprint requests to: Theodore P. Beauchaine, Department of Psychology, Ohio State University, 225 Psychology Building, 1835 Neil Avenue, Columbus, OH 43210; E-mail: beauchaine.1@osu.edu.

Obtaining accurate prevalence estimates of SII and related behaviors is difficult for a number of reasons, yet rates of self-injury appear to have increased over the past two decades, especially among adolescents (Centers for Disease Control [CDC], 2008; Nock, 2008). Even in community samples, up to 45% of adolescents report having engaged in some form of self-harm (Lloyd-Richardson, Perrine, Dierker, & Kelley, 2007). In clinical samples, prevalence rates of SII are higher still (Darche, 1990). Furthermore, roughly 400,000 individuals in the United States receive medical attention for self-injury each year (CDC, 2006). Given the level of functional impairment associated with SII, and the risk it confers for psychiatric morbidity and mortality (Klonsky, May, & Glenn, 2013), it is recognized by both the National Center for Injury Prevention and Control (CDC, 2009), and the US Public Health Service (1999) as an urgent public health problem.

For at least some adolescents, SII is also a developmental precursor to borderline personality disorder (BPD; see Beauchaine, Klein, Crowell, Derbidge, & Gatzke-Kopp, 2009; Crowell, Beauchaine, & Linehan, 2009; Crowell et al., 2013). In our own research on SII among 14- to 18-year-old adolescent girls (Crowell et al., 2005, 2008, 2012), a plurality already meet criteria for BPD, even though they are recruited based solely on endorsement of three or more episodes of self-injury in a 6-month interval, and not any other symptoms of the disorder. Even among adolescents who engage less frequently in self-injury, about 50% meet criteria for BPD (Nock et al., 2006). Moreover, roughly two-thirds of adults with BPD report initiating self-injury before age

18 (American Psychiatric Association, 2004). Thus, despite a paucity of longitudinal research on the development of BPD, SII appears to be an important etiological factor, at least for some individuals. Nevertheless, much remains to be learned about the development of SII and BPD. Of importance, furthered understanding of etiology may be a prerequisite of earlier identification, prevention, and more effective treatment for vulnerable individuals (see, e.g., Beauchaine, Neuhaus, Brenner, & Gatzke-Kopp, 2008).

For most of the past two decades, etiological models of BPD have focused on emotion dysregulation as the principle, if not defining, feature of the disorder. According to Linehan's (1993) theory, SII emerges as a means of coping with persistent emotional distress (see also Crowell et al., 2009; Kuo & Linehan, 2009). Self-injury is therefore reinforced and maintained because it is effective, at least sometimes, in dampening emotional discomfort (see Johnson, Hurley, Benkelfat, Herpertz, & Taber, 2005; Nock, 2009). Over time, the emotion regulatory function of self-harm becomes canalized, perhaps in part through endogenous opioid release (see Bresin & Gordon, 2013).

Literature addressing the emotion dysregulation hypothesis of SII and BPD is voluminous and cannot be reviewed here. However, support for the hypothesis is extensive (see, e.g., Klonsky & Muehlenkamp, 2007), based on self-report (e.g., Nock, 2008, 2009, 2010), peripheral psychophysiological (e.g., Crowell, Baucom, et al., 2014; Crowell et al., 2005, 2008; Kuo & Linehan, 2009), and neuroimaging data (Hazlett et al., 2012; Lis, Greenfield, Henry, Guile, & Dougherty, 2007). Nevertheless, we have argued that emotion dysregulation, in and of itself, is insufficient to account for the development of SII and BPD. Many if not most forms of psychopathology are characterized by emotion dysregulation (see, e.g., Beauchaine, 2001; Beauchaine, 2015a, 2015b; Beauchaine, Gatzke-Kopp, & Mead, 2007; Beauchaine & Thayer, in press; Cole, Hall, & Hajal, 2013; Goldsmith, Pollak, & Davidson, 2008), but most are not characterized by self-injury.

Based on this observation, and on other considerations outlined below, we have advanced a developmental model of SII and borderline personality development that extends Linehan's (1993) theory in several important ways (see Beauchaine et al., 2009; Crowell et al., 2009; Crowell, Derbidge, et al., 2014; Derbidge & Beauchaine, 2014). Although space constraints preclude full articulation of our developmental model, it follows in large part from mounting empirical evidence for each of the following conjectures:

1. In childhood, vulnerability to development of SII and borderline pathology is conferred through trait impulsivity, a highly heritable individual difference (see, e.g., Krueger et al., 2002) that accounts for (a) overlap in biological correlates of BPD and other impulse control disorders (see Beauchaine et al., 2009), and (b) shared familial risk for BPD and antisocial personality among adult females and males, respectively (e.g., Goldman, D'Angelo, & DeMaso, 1993). The assertion that impulsivity confers vulnerability to later SII is consistent with recent findings indicating heightened risk for self-injury and suicide attempts among adolescent girls who were diagnosed with attention-deficit/hyperactivity disorder (ADHD) in middle school (Hinshaw et al., 2012), with well replicated associations between trait impulsivity and both self-injury and BPD in adulthood (see Beauchaine et al., 2009; Glenn & Klonsky, 2010), and with positive associations between impulsivity scores and greater likelihood and severity of self-injurious behaviors (Dougherty et al., 2009; Lynam, Miller, Miller, Bornovlova, & Lejuez, 2011). According to this perspective, trait impulsivity is *necessary but insufficient* for development of SII and BPD.
2. Trait impulsivity is conferred through heritable deficiencies is mesolimbic dopamine (DA) responding (see Beauchaine et al., 2009). Among other functions, the mesolimbic DA system is responsible for hedonic capacity (e.g., Ashby, Isen, & Turken, 1999; Gorwood, 2008), so blunted responding within the system results in anhedonia, or lower than normal levels of pleasure from pursuit of and consummation of incentives (see Neuhaus & Beauchaine, 2013; Sagvolden, Johansen, Aase, & Russell, 2005). Blunted reward responding also results in a chronically aversive, irritable mood, which motivates affected individuals to seek frequent and immediate rewards in order to increase mesolimbic DA levels and upregulate their mood state (see Laakso et al., 2003). It is important to note that mesolimbic DA dysfunction is not specific to impulsivity; attenuated reward responding is also characteristic of depression in adolescence and adulthood, and is a likely neural substrate of anhedonia and irritability among those with mood disorders (see, e.g., Forbes, & Dahl, 2005, 2011). Thus, reduced pleasure in response to incentives (i.e., anhedonia) and high levels of irritability characterize both depression and impulse control disorders. Attenuated tonic and phasic mesolimbic DA function are therefore *transdiagnostic substrates* of both impulsivity and depression (see Sauder, Beauchaine, Gatzke-Kopp, Shannon, & Aylward, 2012).[1] It follows that self-injuring adolescents, who are highly impulsive and often depressed, should exhibit (a) heterotypic comorbidity, which is the case empirically (see, e.g., Crowell, Baucom, et al., 2014; Crowell et al., 2005,

1. Increasingly well-replicated findings of a common neural substrate for impulsivity and depression raise obvious questions about neural processes that differentiate between disorders. Although such a discussion is beyond the scope of this article, other neurobiological systems must be considered. Most notable among these is the septo-hippocampal system, the neural substrate of trait anxiety. Sensitization of this largely independent neural network confers vulnerability to depression (but not impulsivity) when coupled with deficient mesolimbic DA function (see, e.g., Corr & McNaughton, in press; Neuhaus & Beauchaine, 2013). Thus, multiple neurobiological systems must be considered when differentiating between impulsivity and depression, given both common (mesolimbic) and specific (septo-hippocampal) vulnerabilities. Interested readers are referred elsewhere for further discussion (e.g., Sauder et al., 2012).

2008), and (b) deficiencies in mesolimbic responding to incentives (see below), which have not been demonstrated but which we evaluate in this study.

3. Emotional lability and emotion dysregulation develop *after* preexisting impulsivity in the ontogenesis of SII and borderline pathology through operant reinforcement mechanisms expressed within families, as articulated originally by Linehan (1993) and more recently by Beauchaine and Zalewski (in press). Invalidating and coercive family environments reinforce repeated escalation of anger, dyadic conflict, emotional lability, and emotion dysregulation (see Crowell, Baucom, et al., 2014; Crowell, Derbidge, et al., 2014). Although far less heritable than trait impulsivity (Goldsmith et al., 2008), emotional lability and emotion dysregulation assume traitlike qualities across development via protracted reinforcement (see also Beauchaine, 2015b; Beauchaine & Zalewski, in press; Linehan, 1993).
4. Enduring patterns of emotion dysregulation elicit failures of adaptive coping, interfere with healthy socioemotional development, and confer adverse evocative effects on extrafamilial interpersonal relationships. As a result of these mechanisms and others (see Derbidge & Beauchaine, 2014), affected individuals engage in maladaptive social behaviors, affiliate with deviant peers, and are at high risk for developing SII and borderline personality traits (Crowell, Baucom, et al., 2014; Crowell et al., 2009).

Our primary purpose in conducting this study was to test the second component of our developmental model (Item 2 above). Accordingly, we sought to (a) determine whether or not adolescent girls who engage in SII exhibit neural response patterns to reward that characterize impulsive and depressed samples, and (b) evaluate correlations between mesolimbic neural responses to incentives and symptoms of impulsivity and depression among adolescent girls with histories of SII.

Existing Neuroimaging Research on SII and Borderline Personality

To date, most empirical studies of SII and borderline personality development, whether behavioral or neurobiological, focus on the emotion dysregulation component of each. Although several neuroimaging studies of BPD have appeared in the literature, almost all have either evaluated structural compromises in brain regions involved in emotion regulation (e.g., Minzenberg, Fan, New, Tang, & Siever, 2008; Soloff et al., 2012) or examined patterns of functional activation while participants engaged in emotion evocation or emotion discrimination tasks (e.g., Hazlett et al., 2012; Koenigsberg et al., 2009; Kraus et al., 2010). Thus, few studies have evaluated structural or functional associations with impulsivity or depression among self-injuring or borderline participants (for exceptions, see Völlm et al., 2007; Wolf et al., 2012). Furthermore, almost none have been conducted with adolescents who are at risk for BPD, as evidenced by a history of SII and/or endorsement of full criteria for the disorder. In one exception, Plener, Bubalo, Fladung, Ludolph, and Lulé (2012) reported stronger neural responses in the amygdala, hippocampus, and anterior cingulate cortex during emotion evocation among self-injuring adolescent girls compared with controls. Although consistent with findings obtained from adults with BPD, this study also focused on the emotion dysregulation component of SII, not on impulsivity or depression.

Neural Correlates of Trait Impulsivity

As described briefly above, contemporary theories of trait impulsivity all focus at least in part on the mesolimbic DA system, within which aberrant reward responding is observed in many, if not most, forms of externalizing psychopathology (see Gatzke-Kopp, 2011; Sagvolden et al., 2005). Extensive neuroimaging research reveals reduced mesolimbic and/or mesocortical reactivity to monetary incentives among individuals with ADHD (see Bush, Valera, & Seidman, 2005; Carmona et al., 2011; Dickstein, Bannon, Castellanos, & Milham, 2006; Durston, 2003), conduct disorder (CD; e.g., Rubia et al., 2009), substance use disorders (see, e.g., Martin-Soelch et al., 2001; Volkow, Fowler, & Wang, 2004), and antisocial personality traits (e.g., Oberlin et al., 2012). Moreover, reduced mesolimbic DA transporter, D2 receptor, and/or D3 receptor binding are observed among adults with ADHD (Volkow et al., 2009) and alcoholism (e.g., Laine, Ahonen, Räsänen, & Tiihonen, 2001), and compromised functional connectivity between mesolimbic and mesocortical structures is observed among adolescents with ADHD and CD (e.g., Shannon, Sauder, Beauchaine, & Gatzke-Kopp, 2009). This latter finding is of particular interest given the importance of top-down control by mesocortical structures over mesolimbic activity and reactivity in effective modulation of behavior and emotion (see Beauchaine, 2015b; Goldsmith et al., 2008). However, despite consistently high scores across all indices of externalizing behavior among girls who engage in SII (e.g., Crowell et al., 2005, 2008, 2012), and common familial risk for borderline and externalizing symptoms among adult females and males, respectively (for a review, see Beauchaine et al., 2009), mesolimbic responding to incentives has yet to be evaluated among adolescent girls who engage in SII.

Neural Correlates of Depression and Heterotypic Comorbidity

As also noted above, adolescent girls who engage in SII are at exceedingly high risk for heterotypic comorbidity. Crowell et al. (2005) reported that girls who were recruited based solely on three or more self-harm episodes in the past 6 months, or five or more episodes in their lifetime, scored in the 83rd and 82nd percentiles on internalizing and externalizing behavior, respectively, vis-à-vis national norms. Two-thirds also met full diagnostic criteria for major depression.

In addition to its role in impulsivity and vulnerability to externalizing behaviors (see above), the mesolimbic DA

system is clearly implicated in adolescent depression (see, e.g., Forbes et al., 2006). This may help to account for high rates of heterotypic comorbidity of internalizing and externalizing disorders, in both self-injuring and other samples (see, e.g., Sauder at al., 2012). Similar to research outlined above conducted among externalizing samples, numerous studies demonstrate blunted mesolimbic responding to monetary incentives among depressed adolescents (see Forbes et al., 2006; Forbes & Dahl, 2011; Richards, Plate, & Ernst, 2013). Altered mesolimbic reward processing likely confers risk for heterotypic comorbidity through its effects on positive affectivity and hedonic capacity (see above; Forbes & Dahl, 2005; Neuhaus & Beauchaine, 2013). Blunted striatal responding to incentives is associated with lower self-reports of positive affect in naturalistic settings (Forbes et al., 2009), and low levels of striatal DA (assessed with positron emission tomography) predict trait irritability (Laakso et al., 2003), which characterizes both internalizing and externalizing disorders. In contrast, infusions of DA into mesolimbic structures produce pleasurable affective states (see Berridge, 2003; Berridge & Robindon, 2003). Finally, Internalizing × Externalizing Symptom interactions account for individual differences in gray matter densities in mesolimbic brain regions (Sauder et al., 2012). Observed heterotypic comorbidity of impulsivity and depression among self-injuring individuals, and an apparent common neurobiological substrate for internalizing and externalizing symptoms, provided an additional impetus for evaluating reward-related neural responding among self-injuring adolescent girls.

Following from the above discussion, we evaluated patterns of neural reactivity during anticipatory reward processing among self-injuring adolescent girls, compared to those observed among control adolescents. We focused specifically on anticipatory reward processing for several reasons. First, anticipatory and consummatory reward processing are separable processes, with distinct neural correlates (Liu, Hairston, Schrier, & Fan, 2011). Second, prominent etiological models link behavioral impulsivity to deficits in reward anticipation (e.g., Tripp & Wickens, 2008). Third, restricting analyses to only anticipatory reward processing increased our statistical power and reduced the familywise alpha error rate. Consistent with research outlined above, we predicted less neural reactivity in mesolimbic structures during anticipation of reward.

In addition, we predicted attenuated reward responding within both the orbitofrontal cortex (OFC) and the amygdala. Imaging studies indicate consistently that incentives activate the OFC, amygdala, and striatum, and that these regions all play important roles in evaluation of reward cues (Cardinal, Parkinson, Hall, & Everitt, 2002; McClure, York, & Montague, 2004). For example, the OFC represents stimulus reward values, and is critical in reward learning (Rolls, 2000). Furthermore, functional disruptions in this region are associated with impulsivity and suicidality (Oquendo & Mann, 2000), and aggressive children and adults with ADHD show alterations in OFC activity during reward processing (Rubia et al., 2009; Wilbertz et al., 2012). A number of studies also indicate that the amygdala links anticipation of reward with hedonic value (see Murray, 2007). Moreover, the amygdala is linked both anatomically and functionally to the OFC and the striatum (Baxter & Murray, 2002; Camara, Rodriquez-Fornells, & Münte, 2008; Cardinal et al., 2002; Holland & Gallagher, 2004), damage to the amygdala is associated with increased impulsivity among both animals and humans (Bechara, Damasio, Damasio, & Lee, 1999; Winstanley, Theobald, Cardinal, & Robbins, 2004), and functional activation within the amygdala correlates with impulsivity (Brown, Manuck, Flory, & Hariri, 2006). It is important to note that the OFC and amygdala are also implicated in mood regulation and aggression (Banks, Eddy, Angstadt, Nathan, & Phan, 2007; Davidson, Putnam, & Larson, 2000), and therefore may represent a second neural substrate of impulsivity and depression among self-injuring adolescents.

Method

Participants

Self-injuring ($n = 22$) and control ($n = 22$) adolescent females between ages 13 and 19 years were enrolled in the study. Among these, 3 participants from the self-injuring group and 2 participants from the control group were excluded due to motion-related functional magnetic resonance imaging (fMRI) artifacts and/or acquisition errors (see below). In addition, 1 participant from the control group was excluded because she was taking a selective serotonin reuptake inhibitor (SSRI) for depression, even though she did not report a current or lifetime mood disorder. Thus, 19 participants per group were included in all analyses. Twenty-four participants identified as Caucasian, 6 as Hispanic Caucasian, and 8 as biracial (4 mixed African American and Caucasian, 1 Filipino and Caucasian, 1 Japanese/Korean/Caucasian, and 2 Hispanic/non-Caucasian). Males were not included given lower prevalence rates of self-injury and an inadequate sample size for evaluating sex effects. Participants were recruited from previous studies, direct mailings to families, and advertisements/letters sent to mental health providers, community centers, and pediatrician's offices. Study procedures were approved by the Seattle Children's Hospital Institutional Review Board. Preliminary screening interviews with a trained research assistant took place by phone. Based on results of these interviews, selected respondents were invited to the lab for more extensive interviews, and then for a scanning session if they met inclusion criteria described below.

Phone screen

Callers completed the preliminary phone screen, which included questions that assessed lifetime and current self-injurious behavior; previous psychiatric diagnoses; current major depressive disorder (MDD); possible mental retardation; IV drug use; current medications; handedness; and MRI safety

screening. Potential control group participants were screened out if they endorsed DSM-IV (APA, 1994) criteria for a depressive disorder, or if they reported any lifetime self-injury event. Those who reported a history of bipolar disorder or schizophrenia, possible mental retardation, IV drug use, left-handedness, and/or MRI contraindications (e.g., metal implants or braces) were excluded from both groups.

Lab interview

Respondents who met preliminary phone screen criteria were evaluated during a subsequent lab visit. Current disorders, including CD, generalized anxiety disorder, panic disorder, obsessive–compulsive disorder, posttraumatic stress disorder, social phobia, schizophrenia, dysthymia, bipolar disorder, anorexia, and bulimia were assessed using the Youth's Inventory (YI; Gadow et al., 2002), a child self-report measure, and the Adolescent Symptom Inventory (ASI; Gadow & Sprafkin, 1997), a parent-report measure. Although the YI and ASI are not structured interviews, both assess full criterion sets for DSM-IV disorders, and yield screening cutoffs that are consistent with DSM-IV diagnoses (see below). Given high rates of comorbidity of self-injury, major depression, and substance use, both current and lifetime diagnoses of MDD and substance abuse/dependence were assessed using the Diagnostic Interview Schedule for Children—Computerized Version (DISC-C; Shaffer, Fisher, Lucas, Mina, & Schwab-Stone, 2000). To be considered for the self-injury group, respondents were required to report at least three self-injury episodes in the last year or five or more in their lifetime. At least one of these episodes had to have a lethality rating of 2 or higher on the Lifetime Suicide Attempt and Self-Injury Interview (L-SASI Count; Linehan & Comtois, 1996). Examples include taking 6–10 pills (or fewer if the medication is potentially lethal), cigarette burns, jumping from places up to 10 feet, taking heroin at ≥1.5 times the dependent dose, and combining drugs and/or alcohol. Potential self-injuring participants who were taking SSRIs ($n = 5$) were allowed to participate. Given the large number of self-injuring individuals who are prescribed SSRIs, excluding these respondents could have compromised generalizability. Qualifying participants were invited to participate in a more comprehensive lab visit screen to assess their eligibility more fully. Respondents who reported a lifetime history of SII and/or suicide attempts, or who met diagnostic criteria for any of the above disorders, as assessed by the ASI, YI, or parent or youth report on the DISC-C, were excluded from the control group. Among respondents who were invited to the lab, five were screened out based on their interview results.

Measures

L-SASI. The L-SASI (formerly the Lifetime Parasuicide Count; Linehan & Comtois, 1996) is a structured interview designed to collect information about lethality, suicidal intent, level of medical treatment received for, and specific circumstances surrounding adolescents' first, most recent, and most severe SII episode. With interviewer guidance, participants count lifetime events of different forms of self-injury, self-injury with intent to die, self-injury with ambivalence, self-injury without suicidal intent, and self-injury requiring medical treatment. In addition, the highest lethality event in each category of SII is assessed. Lethality rankings range from 1 = *very low* (e.g., head banging) to 6 = *severe* (e.g., asphyxiation). There are no psychometric studies of the L-SASI. However, items are identical to a subset of those on a longer measure, the Suicide Attempt Self-Injury Interview, which has very good interrater reliability and adequate validity (Linehan, Comtois, Brown, Heard, & Wagner, 2006). Although the L-SASI was designed for use with adults, it has since been used successfully with adolescents (e.g., Crowell et al., 2012, 2013).

Suicidal Ideation Questionnaire (SIQ). The SIQ (Reynolds, 1987, 1988) was used to screen adolescents at each study visit for levels of suicidal ideation. There are two versions of this measure based on grade level. The SIQ is composed of 30 items and is used for students in Grades 10–12. The SIQ-JR is composed of 15 items and is designed for use by students in Grades 7–9. In both versions, items are rated on 7-point scales (0 = *I never had this thought*, 6 = *I had this thought every day*), which are summed. Internal consistencies are high for both the SIQ ($\alpha = 0.97$) and the SIQ-JR ($\alpha =$ 0.93–0.94). Scale scores correlate moderately with constructs such as depression and hopelessness (0.52–0.70).

Structured Clinical Interview for DSM-IV Axis II. The Structured Clinical Interview for DSM-IV Axis II (First, Gibbon, Spitzer, Williams, & Benjamin, 1997) is a widely used semi-structured interview that assesses DSM-IV Axis II psychopathology. We used it only to assess BPD symptoms. The 15 BPD items evidence strong interrater reliability ($\kappa = 0.91$; Lobbestael, Leurgans, & Arntz, 2010; Maffei et al., 1997) and internal consistency ($\alpha = 0.71$–0.94; Maffei et al., 1997).

Youth Self-Report. The Youth Self-Report (Achenbach, 1991) is a widely used and well-validated self-report measure of internalizing and externalizing behaviors, designed for use with adolescents ages 11–18 years old. One-week test–retest reliabilities in the validation sample were 0.80 for the broadband internalizing factor, and 0.81 for the broadband externalizing factor. These scales served as primary independent measures in our imaging analyses (see below).

DISC-C. The DISC-C (Schaffer et al., 2000) is a commonly used, highly structured interview that assesses a wide range of DSM-IV psychiatric disorders. We used the computerized version for ease of administration and scoring. In the validation sample, the 1-year test–retest reliability for self-reported MDD was 0.92.

YI. The YI (Gadow et al., 2002) is a 120-item checklist of DSM-IV symptoms that yields both dimensional scores and diagnostic cut-offs. Items are rated on a 4-point scale (0 = *never*, 1 = *sometimes*, 2 = *often*, and 4 = *very often*). In the validation sample, 2-week test–retest reliabilities ranged from 0.54 to 0.92.

ASI. The ASI (Gadow & Sprafkin, 1997) is a 120-item parent report checklist of DSM-IV symptoms that yields both dimensional scores and diagnostic cutoffs. Items are rated on a 3-point scale (0 = *never*, 1 = *sometimes*, 2 = *often*, and 3 = *very often*). The ASI exhibits moderate to high concurrent validity with the Child Behavior Checklist, with correlations ranging from 0.41 to 0.80 for similar emotional and behavioral problems.

Kaufman Brief Intelligence Test, Second Edition. Adolescent's IQs were assessed using the Kaufman Brief Intelligence Test, Second Edition (Kaufman & Kaufman, 2004), a brief measure of verbal and nonverbal cognitive ability with excellent psychometric properties. Test–retest reliabilities range from 0.88 to 0.92, with strong internal consistencies for composite IQ scores (α = 0.89 to 0.96). Those with composite IQ scores less than 85 ($n = 0$) were excluded.

Mock scanning

Remaining participants, all of whom met inclusion/exclusion criteria, participated in a mock scanning session at the end of their lab visit in order to teach them the behavioral tasks (described below), and to assess their comfort level and ability to remain still during scanning. During mock scanning, a sticker was affixed to the forehead of participants. Next, participants were given an opportunity to practice the monetary incentive delay (MID) task (Knutson, Adams, Fong, & Hommer, 2001), which is described in detail below. Although no participants were excluded based on mock scanning, five were lost following the mock scanning session due to attrition (e.g., moving away, too busy, scheduling conflicts, etc.). Adolescents were paid $25 for participating in this first lab visit.

MRI scanning

Participants returned for a second lab visit to complete the MRI scanning protocol. Following safety screening by a trained MR technician, participants completed the anatomical MRI scan before completing two tasks during functional scanning. The procedure took about 60 min, including 3 min for the structural scan, 3 min for B0 fieldmap acquisition, and 17 min for the reward task, described below.

The MID task (Knutson, Adams, et al., 2001) requires participants to respond to stimuli on either the left or the right side of a screen. Prior to each trial, a visual cue is presented indicating whether participants can win or lose money in the subsequent trial. On "win" trials, participants see one of three circle cues indicating that they can win $0.20, $1.00, or $5.00 for responding correctly and within a time limit, with errors resulting in no monetary gain or loss. In "loss" trials, square cues indicate that errors will result in loss of $0.20, $1.00, or $5.00, with correct responses resulting in no monetary gain or loss. Participants are required to respond while target stimuli are present on the screen, and target duration is titrated to each individual's performance, to keep accuracy rates at approximately 66%. In addition, there are several control trials (triangle cues) in which participants neither win nor lose money, regardless of their responses. Following each trial, participants receive visual feedback regarding both their accuracy on the previous trial and the monetary outcome (gain, loss, or no change, reported numerically). During all phases of the task, with the exception of cue and target, total amount of money earned over the course of the task is displayed in the upper right-hand corner of the screen. At the end of the task, participants receive the actual dollar amount earned.

Three runs were completed by each participant, each of which consisted of 18 reward trials and 18 loss trials, split evenly among the three cue amounts ($0.20, $1.00, or $5.00). In addition, there were 12 control trials in which participants neither won nor lost money. Each trial lasted 6 s, consisting of one of seven cues (250 ms), fixation delay (2000–2750 ms), target (210–490 ms), a second delay (360–640 ms), and feedback (1650 ms). Intervals between cue presentations (5.5–8.75 s, M = 7 s), and intervals between cue and feedback (3.00–3.75 s, $M = 3.4$ s), were varied across trials to ensure optimal power to detect event-related signal differences during fMRI acquisition (Dale, 1999).

fMRI data acquisition, preprocessing, and analysis

Structural and functional MRI scans were performed on a 3 Telsa Philips Achieva MR System (version 2.63, Philips Medical Systems, Best, The Netherlands) with dual Quasar gradients (80 mT/m at a slew rate of 110 mT/m/s; or 40 mT/m at a slew rate of 220 mT/m/s) and an eight-channel SENSE head coil. High resolution three-dimensional FFE T1-weighted magnetization prepared–rapid gradient echo fast imaging sequences generated 200 contiguous axial slices spanning the entire brain (repetition time [TR] = 7.7 ms; echo time [TE] = 3.6 ms; flip angle = 8°; field of view [FOV] = 220 × 220 × 200; matrix size = 220 × 205; voxel dimension = 1 × 1.07 × 1 mm; SENSE factor = 1). Total scan time for anatomical images was approximately 3 min. Structural data were used for image registration. Whole-brain T2*-weighted images were acquired using a single-shot gradient-recalled echo-planar imaging (EPI) sequence (TR = 2000 ms; TE = 21 ms; flip angle = 76°; FOV = 210 mm; matrix size = 72 × 72; in-plane resolution = 3 × 2.92 mm, slice thickness = 3 mm). Forty-seven or 48 contiguous 3-mm axial slices were collected per image volume using an ascending slice acquisition. Three functional runs of 174 dynamics were collected for the MID task, with a total functional scan time of approximately 17 min. A matching B0 field map using a fast field echo sequence was acquired to correct for distortions

in the EPI data due to magnetic field nonhomogeneities (TR = 563 ms; TE = 2.8; flip angle = 90°; FOV = 210 × 210 × 141; matrix size = 72 × 72; in-plane resolution = 3 × 2.92; slice thickness = 3 mm). Forty-seven or 48 contiguous 3-mm axial slices spanning the entire brain were collected per image.

Data were analyzed using statistical parametric mapping software (SPM8; http://www.fil.ion.ucl.ac.uk/spm/software/spm8/). Initial preprocessing included slice time correction, motion correction, and deformation of field nonhomogeneity using SPM's unwarp procedure in conjunction with B0 field-maps. Subsequently, data were visually inspected and analyzed to detect excessive rapid motion using ArtRepair5, an artifact detection and repair tool (Mazaika, Hoeft, Glover, & Reiss, 2009). Two participants were excluded from the control group and three from the self-injuring group due to EPI acquisition artifacts and/or excessive inter-EPI motion of greater than 0.5 mm over more than 15% of EPI's collected. An additional eight functional runs were excluded (5 control and 3 self-injuring) under the same criteria. Remaining participants (n = 19 self-injury, n = 19 control) were normalized to the MNI template using diffeomorphic anatomical registration through expotentiated lie algebra (Ashburner, 2007), a high dimensional warping process. Finally, data were smoothed using an 8-mm Gaussian kernel.

To assess the effect of differing reward values, reward cues ($0.20, $1.00, or $5.00) were modeled separately. For each participant individually, reward cues were modeled relative to baseline (cues indicating no opportunity to win or lose) using a standard hemodynamic response function. First-level general linear models were created for each participant, and included the above described conditions of interest (e.g., reward cues) and noninterest (e.g., loss cue/feedback). Individual EPI scans with rapid motion of >0.5 mm were modeled as nuisance covariates, and data were detrended using an AR(1) model with a high-pass filter of 128 s.

To evaluate the within- and between-groups effects associated with anticipatory reward processes, a second-level mixed effects general linear model was performed using a Group (SII, control) × Reward Magnitude ($0.20, $1.00, $5.00) factorial design. Group × Reward Magnitude interaction effects were included. SSRI use was included initially as a covariate, but did not alter results and was subsequently removed from the final model.[2] A region of interest (ROI) analysis rather than whole-brain analysis was performed due to limited statistical power associated with the small sample size, the complexity of the task design, and clear a priori hypotheses regarding the regions implicated in reward processing. We selected ROIs based on theoretical considerations discussed above, and based on findings from previous publications in which the MID and related tasks were used (Knutson, Adams, et al., 2001; Knutson, Fong, Adams, Varner, & Hommer, 2001; Forbes et al., 2006; Liu et al., 2011). Specifically, we evaluated activation within the striatum (caudate+putamen) and OFC (orbital regions of the superior, middle, and frontal gyri), based on anatomical labels from the Automatic Anatomical Labeling Atlas (Tzourio-Mazoyer et al., 2002). In addition, we examined activation within the bilateral amygdalae. Main effects and interactions were modeled separately for each region, and corrected for multiple comparisons ($p < .05$) using a small volume correction based on the size of the ROI (ROIs were examined bilaterally, so there were three comparisons). Clusters of activation that did not exceed statistical thresholds or were less than 0.5 cm^3 were excluded. To evaluate effects for each participant separately, SPM's built-in principle eigenvariates approach was used to calculate average beta values across all voxels within each area of functional activation.

Results

Demographics and self-reports of psychopathology

As reported in Table 1, the self-injuring and control groups did not differ on age or IQ. However, consistent with previous research (e.g., Crowell et al., 2005, 2012), self-injuring participants scored higher on all self-report measures of internalizing and externalizing psychopathology. Although not reported, parent-report measures demonstrated similar between-groups differences. Given that agreement between adolescents and parents on measures of psychopathology is modest at best (e.g., Seiffge-Krenke & Kollmar, 1998; Sourander, Helstela, & Helenius, 1999), we analyzed data from both informants.

Behavioral responding to incentives

No group differences were observed during the reward task in reaction times ($M_{control}$ = 281.4 ms, M_{si} = 267.3 ms), t (36) = 1.75, d = 0.58; proportion of accurate responses ($M_{control}$ = 0.64, M_{si} = 0.64), t (36) = 0.74, d = 0.25; or amount of money earned ($M_{control}$ = $49.84, M_{si} = $46.22), t (36) = 0.86, d = 0.29.

Neural responding to incentives

Analyses of participants' neural responses yielded main effects of both group and reward magnitude (see Table 2). Compared to controls, self-injuring adolescents showed significantly less activation to reward cues in the striatum (putamen), amygdala, and OFC bilaterally (see Figure 1). There were no regions of greater activation for the SII group. Attenuated neural responding among SII participants was observed across all cue values and all ROIs. Nevertheless, both groups showed greater activation for higher cue values relative to lower cue values (see Figure 2). The main effect of reward magnitude predicted activation only in the striatum, specifically

2. The effects of SSRIs on striatal reward processing are inconsistent, with some studies finding attenuated responding (e.g., McCabe, Mishor, Cowen, & Reiss, 2010) and others finding increased responding (e.g., Stoy et al., 2012).

Table 1. *Demographic variables, reports of self-injury and suicidal ideation, and self-reported internalizing and externalizing scale score by group*

Variable	Control Mean (*SD*)	Self-Injury Mean (*SD*)	*t* or *z*[a]	Effect Size
Descriptive statistics				
Age	15.93 (2.03)	15.70 (1.77)	$t = 0.36$	$d = 0.11$
KBIT IQ	113.68 (9.73)	108.42 (10.17)	$t = 1.63$	$d = 0.52$
Self-Reported Self-Harm Behaviors and Borderline Personality Symptoms				
SIQ-Jr	1.63 (2.00) ($n = 8$)	14.88 (15.72) ($n = 8$)	$t = 2.36$*	$d = 1.26$
SIQ	2.54 (5.28) ($n = 11$)	49.63 (32.57) ($n = 11$)	$t = 4.73$***	$d = 2.12$
L-SASI				
SII	0.00 (0.00)	184.16 (262.05)	$z = 5.63$***	$r = .91$
Ambivalent attempts	0.00 (0.00)	1.32 (2.40)	$z = 2.62$**	$r = .42$
High intent attempts	0.00 (0.00)	20.42 (36.13)	$z = 3.81$***	$r = .62$
Total suicide attempts	0.00 (0.00)	21.74 (38.27)	$z = 4.04$***	$r = .66$
SCID-II BPD symptoms	0.00 (0.00)	3.00 (1.70)	$z = 5.66$***	$r = .92$
Self-Reported Symptoms of Psychopathology				
Youth Self-Report				
Externalizing	46.63 (8.50)	58.42 (9.84)	$t = 4.02$***	$d = 1.36$
Internalizing	38.68 (6.13)	61.26 (12.70)	$t = 6.98$***	$d = 2.36$
Youth's Inventory[b]				
Conduct disorder	0.00 (0.00)	0.53 (0.84)	$z = 2.05$*	$r = .34$
ADHD-combined[c]	0.31 (0.26)	0.59 (0.37)	$t = 2.64$**	$d = 0.88$
Major depression[c]	0.21 (0.19)	0.69 (0.30)	$t = 5.95$***	$d = 1.91$
Dysthymia[c]	0.15 (0.20)	0.63 (0.31)	$t = 5.64$***	$d = 1.84$
Generalized anxiety	0.00 (0.00)	2.05 (3.14)	$z = 2.64$***	$r = .43$
Schizophrenia	0.11 (0.32)	0.47 (0.77)	$z = 1.61$	$r = .26$
DISC diagnoses				
Major depression	0	9	—	—
Substance use disorder	0	3	—	—

Note: KBIT, Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman & Kaufman, 2004); SIQ, Suicide Ideation Questionnaire (Reynolds, 1987, 1988), standardized by grade level: SIQ-Jr (Grades 7–9) raw scores ≥ 31 and SIQ (Grades 10–12) raw scores ≥ 41 indicate significant clinical concern regarding suicide risk; L-SASI, Lifetime Suicide Attempt Self-Injury Count (Linehan & Comtois, 1996); SCID-II BPD, Structured Clinical Interview for DSM-IV Axis II (First et al., 1997) borderline personality disorder; SII, self-inflicted injury; SA, suicide attempt; ADHD-combined, attention-deficit/hyperactivity disorder–combined; DISC, Diagnostic Interview Schedule for Children.
[a]*t* tests were conducted on normally distributed data; Mann–Whitney U tests were conducted on skewed data.
[b]Due to technical difficulties with the computerized questionnaire, Youth's Inventory data were lost for one participant who had already been screened into the control group and completed the scanning procedure.
[c]Means, standard deviations, and *t* tests are reported for log-transformed data.
*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$.

the caudate nucleus. There were no significant Group × Reward Magnitude interactions.[3]

We conducted follow-up analyses to assess whether functional activation within regions that differentiated between SII and control participants was associated with symptoms of impulsivity (ADHD) and/or depression. Significant correlations were found across groups for symptoms of both ADHD and MDD in both the striatum and amygdalae bilaterally (see Figure 3). Activation within the striatum was correlated negatively with ADHD combined symptoms, as reported by both parents ($r = –.35$, $p = .03$) and adolescents ($r = –.42$, $p = .01$). Similar effects were found for symptoms of MDD for both parents ($r = –.31$, $p = .05$) and adolescents ($r = –.49$, $p = .002$). Amygdala activation was also correlated negatively with both ADHD combined symptoms (parent report, $r = –.41$, $p = .01$; adolescent report, $r = –.38$, $p = .02$) and MDD symptoms (parent report, $r = –.40$, $p = .01$; adolescent report, $r = –.46$, $p = .004$). There were no associations between OFC activation and either parent or self-reports of ADHD or MDD, all $ps > .23$.[4]

3. To ensure that group differences were not attributable to reduced responding among SII participants across all stimulus types, we also analyzed loss data. Although a group difference was observed in the OFC, no group differences were found in the striatum or amygdalae.

4. Correlations between functional activation within the OFC, striatum, and amygdala were largely specific to symptoms of ADHD and MDD. For example, no such relations were found for anxiety disorder symptoms.

Table 2. *Areas of significant activation for main effects of group and reward magnitude*

Region	MNI Coordinate	Cluster Size (mm^3)	*z*	*p*
Main Effect of Group				
Striatum				
Right putamen	33 –12 9	3375	−4.46	<.001
Left putamen	−27 –18 6	1242	−4.45	<.001
OFC				
Right	33 48 –3	8721	−4.82	<.001
Left	−3 63 –6	—	−4.05	<.001
Amygdala				
Right	30 –3 –27	1188	−3.46	<.001
Left	−18 –3 –12	297	−3.20	.001
Main Effect of Reward Magnitude				
Striatum				
Right caudate	12 12 0	3915	4.80	<.001
Left caudate	−6 15 –6	3024	5.24	<.001

Note: MNI, Standard Montreal Neurological Institute stereotaxic coordinates (*x, y, z*); OFC, orbitofrontal cortex. Negative *z* scores reflect greater activation for the SSI group relative to controls. Region of interest analyses were corrected for multiple comparisons using a false-discovery rate small volume correction for the spatial extent of the anatomical region of interest. Contiguous areas of functional activation that spanned hemispheres are italicized across adjacent rows.

Discussion

Our primary objective in conducting this study was to test the hypothesis that central nervous system reward dysfunction is observed among self-injuring adolescent girls, and is expressed similarly to that observed in both impulse control and depressive disorders. Such findings support our developmental theory of SII and borderline pathology in which mesolimbic DA dysfunction predisposes to trait anhedonia and trait irritability, which characterize both impulse control and depressive disorders, and likely underlie patterns of heterotypic comorbidity observed among those who self-injure (see Kaufman, Crowell, & Stepp, 2015). We evaluated neural responding in brain regions associated previously with reward processing during anticipation of incentives. Consistent with our hypotheses, self-injuring adolescents exhibited less neural responding to reward in the striatum (putamen), OFC, and bilateral amygdalae compared with controls. Furthermore, activation in both the striatum and amygdalae was correlated negatively with parent and adolescent reports of impulsivity (ADHD) and depression (MDD). We consider these findings in further detail below.

Trait impulsivity is highly heritable (Krueger et al., 2002) and is mediated by feedforward and feedback dopaminergic neural networks originating in the striatum and projecting to the prefrontal cortex (see Beauchaine & McNulty, 2013; Gatzke-Kopp & Beauchaine, 2007). Although early models of trait impulsivity assumed dopaminergic hyperactivity to reward (e.g., Quay, 1993), more recent empirical findings provide convincing evidence for both hypoactivation within and altered connectivity between these structures among those with impulse control disorders (see Beauchaine & Gatzke-Kopp, 2012; Gatzke-Kopp, 2011; Plichta & Scheres, 2014; Sagvolden et al., 2005; Shannon et al., 2009). According to prevailing contemporary theories, reduced tonic mesolimbic activity confers vulnerability to impulsivity because it is experienced as an aversive, irritable mood state (e.g., Laakso et al., 2003), which affected individuals are motivated to upregulate through reward-seeking behavior. However, because these individuals also exhibit reduced phasic mesolimbic responding to incentives, they experience limited hedonic value from ordinary rewards, and therefore engage in increasingly frequent reward-seeking behavior, including searches for larger and larger rewards (see Sagvolden et al., 2005). Consistent with this theory, neuroimaging studies demonstrate reduced reward responding in mesolimbic and/or mesocortical structures across impulse control disorders including ADHD, CD, substance use disorders, and gambling addiction

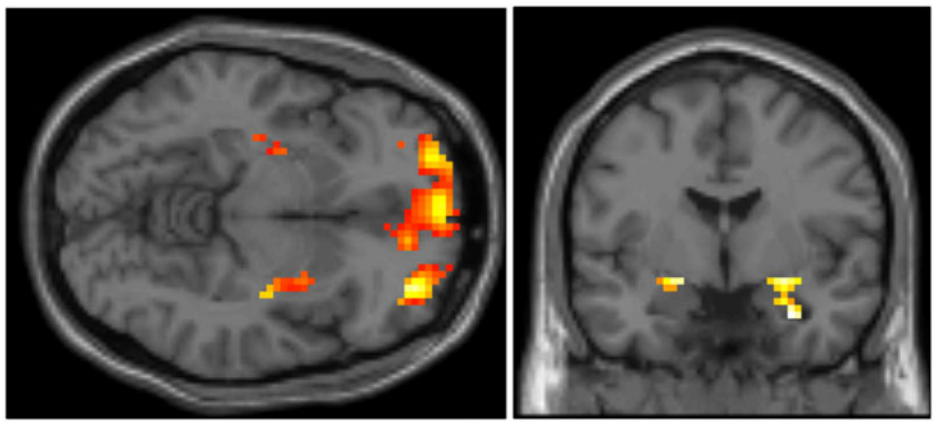

Figure 1. (Color online) Striatal, orbitofrontal, and amygdalar regions of interest in which controls exhibited greater neural reactivity to reward cues.

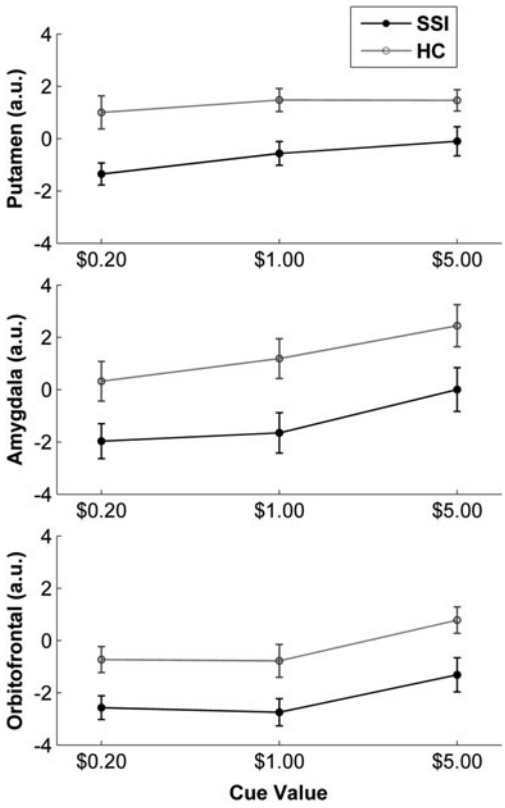

Figure 2. Neural responding among participants in the self-injury and control groups across all reward values and regions of interest. Values reflect beta weight estimates with arbitrary units of measurement.

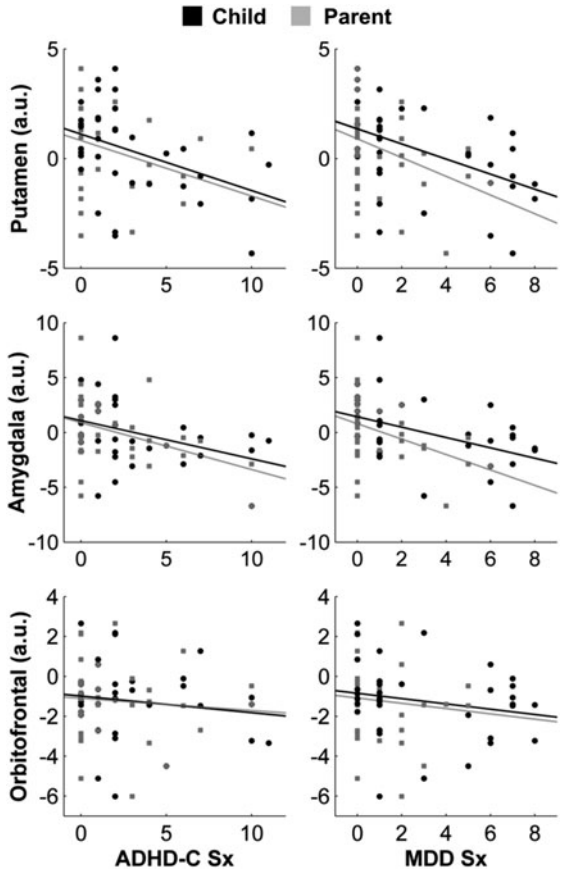

Figure 3. Correlations between neural reactivity in each region of interest and symptoms of (left) attention-deficit/hyperactivity disorder and (right) major depression across regions of interest. Values reflect beta weight estimates with arbitrary units of measurement. ADHD-C, attention-deficit/hyperactivity disorder, combined subtype; MDD, major depressive disorder; Sx, number of diagnostic symptoms met.

(see, e.g., de Ruiter et al., 2008; Dom, Sabbe, Hulstijn, & Van Den Brink, 2005; Rubia, 2011).

As noted above, abnormalities in DA-mediated reward function also play a role the etiology of depression (see Forbes & Dahl, 2011; Nestler & Carlezon, 2006). Until recently, most neurobiological models of depression focused on serotinergic neural networks. However, an ever growing number of studies point toward mesolimbic reward dysfunction as a neural substrate of anhedonia, irritability, and low positive affectivity in *both* depression and impulsivity. Among both healthy and depressed individuals, anhedonia is associated with hypoactivity within the ventral striatum (Gorwood, 2008). Moreover, blunted neural responding to incentives is observed among adolescents and adults with depression (Forbes et al., 2006; Knutson, Bhanji, Cooney, Atlas, & Gotlib, 2008; Smoski et al., 2009). Furthermore, increased neural activation in the striatum following treatment is associated with reduced depressive symptoms (Dichter et al., 2009, Schlaepfer et al., 2007).

To our knowledge, ours' is the first study to examine central nervous system reward processing among self-injuring adolescents, and only one study has done so among those with BPD. In that study, participants with BPD exhibited reduced prefrontal and striatal responding to monetary incentives, and prefrontal responding was correlated negatively with self-reported impulsivity (Völlm et al., 2007). However, not all individuals in the clinical group met criteria for BPD, and instead were diagnosed with antisocial personality disorder (ASPD). Although it may be tempting to eschew results of this study based on inclusion of ASPD, BPD and ASPD share a number of etiological influences, and may reflect sex-moderated manifestations of a single pathology (see Beauchaine et al., 2009). Accordingly, results are likely relevant to the present discussion.

Although sufficient evidence exists to suggest that anticipation and consummation of incentives are mediated by different neural processes (e.g., Dillon et al., 2008; Knutson, Fong, et al., 2001; Liu et al., 2011; Schultz, 2000), few studies have examined these processes separately in clinical populations. However, doing so may be particularly important when evaluating reward-related responding among impulsive children and adolescents, because anatomical regions associated with anticipation of reward and consummation of reward develop at different rates (Bjork et al., 2004; Geier & Luna, 2009; Geier, Terwilliger, Teslovich, Velanova, & Luna, 2010), and trait impulsivity may be mediated more by mesolimbic dysfunction in childhood but more by mesocortical

dysfunction by late adolescence and adulthood (see Beauchaine & McNulty, 2013). Although nearly all studies of anticipatory reward processing among externalizing adults and youth have found decreased reward-related activity, increased neural activity during consummatory processing, especially in prefrontal regions, is sometimes observed among adults with ADHD and alcohol dependence (Strohle et al., 2008; Wrase et al., 2007). In contrast, studies that parse anticipatory and consummatory reward processes among adolescent and adult depressed individuals are much more consistent, demonstrating hypoactivity across both phases (Forbes et al., 2006; Pizzagalli et al., 2009; Smoski et al., 2009). Finally, among externalizing samples, group differences in reward reactivity may also be associated more strongly with anticipation than with consummation (Strohle et al., 2008).

Given that comorbid externalizing problems are often observed in SII, we focused on the anticipatory phase of reward processing, which differentiates both internalizing and externalizing samples from controls. Our results are consistent with theoretical expectations and previous empirical work outlined above on reward processing among individuals with impulse control disorders and depression. Self-injuring adolescents showed less reactivity to reward cues in both striatal and OFC regions, and activation within the striatum was correlated negatively with internalizing and externalizing symptoms. These results may reflect a common neural vulnerability to impulsivity and depression, and provide insight into much higher than expected rates of heterotypic comorbidity (Sauder et al., 2012).

Self-injuring participants also exhibited less activation relative to controls in the amygdala, which is implicated in tracking hedonic value of reward (Baxter & Murray, 2002; Murray, 2007; Liu et al., 2011). Although etiological models implicate the amygdala in the pathogenesis of both depression and BPD, nearly all theoretical and empirical work on the amygdala has focused exclusively on its processing of emotion, not reward. Such studies typically find increased amygdala reactivity in depression and BPD, particularly to negative emotional stimuli. In the present study, self-injuring adolescents showed reduced reactivity that was reward specific, with no group differences to loss cues. Activation within the amygdala was also correlated negatively with symptoms of both ADHD and depression. Few studies have examined amygdala reactivity to reward among impulsive or depression samples (for exception, see Forbes et al., 2006; Stark et al., 2011). Results of the current study further implicate this region in development of SII and related disorders (e.g., BPD and MDD), and suggest that amygdala abnormalities among those with these disorders may extend beyond processing of negative emotion.

Recent work by Rubia and others suggests that the amygdala and orbital/medial PFC are part of a separable "hot" network of executive functioning responsible for decisions related to motivation and affective experience (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Rubia, 2011). Although dysfunction is observed in this network among children with ADHD, more severe deficits are observed among those with CD, which is characterized by greater mood lability, frequent displays of anger, and aggression (Cubillo, Halari, Smith, Taylor, & Rubia, 2012; Rubia, 2011; Rubia et al., 2009). Amygdala hyperactivation and corresponding reductions in OFC activity, and connectivity between these regions, is also associated with affective instability among adults with BPD, a disorder that is also marked by anger and aggression (Linehan, 1993; Lis et al., 2007; New et al., 2007; Soloff et al., 2003).

Although our findings are consistent with the hypothesis that impulsivity is an etiological factor in the development of SII, several caveats should be considered. First, only main effects are reported. Given the small sample and study design, statistical power was inadequate for testing Group × Condition interactions. The small sample size may also have affected our ability to detect associations between reward-related responding and self-reported internalizing and externalizing symptoms. Second, we did not have a depressed control group. Thus, we do not know what neural processes, if any, differentiate self-injuring adolescents, almost all of whom are depressed, from depressed adolescents who do not self-injure.

As is often the case in studies of SII, there was also considerable heterogeneity within the self-injuring sample. Numbers of self-injury episodes varied substantially, as did ratings of lethality and intent. Moreover, although a history of SII was required, current self-injury was not. In addition, our findings may not generalize to self-injuring males. Neurobiological correlates of externalizing psychopathology differ for girls versus boys (see Beauchaine, Hong, & Marsh, 2008), which illustrates why further research should be conducted to determine if reward-processing abnormalities observed among self-injuring adolescent girls extend to males who exhibit similar behaviors. Given the importance of developmental influences on the etiology and maintenance of nonsuicidal self-injuries (Beauchaine et al., 2009; Crowell et al., 2009; Crowell, Baucom, et al., 2014; Derbidge & Beauchaine, 2014), future longitudinal research is necessary to assess interrelations among impulsivity, depression, self-injury, and borderline personality development. Finally, future research is needed to address potential links between reward anticipation and emotion processing and regulation. Such research may be required to fully characterize relations among impulsivity, emotion deregulation, and self-injury.

Ours is the first study to examine neural correlates of reward responding among self-injuring adolescents. Reduced striatal and prefrontal activation were observed during reward anticipation in the self-injuring group, consistent with previous findings from those with impulse control disorders and depression. We hope future research with larger samples expands on our findings, toward disentangling what are clearly complex associations between neurobiological function, trait impulsivity, hedonic capacity, affectivity, and the development of debilitating conditions such as SII and borderline personality traits.

References

Achenbach, T. M. (1991). *Manual for the Youth Self-Report and 1991 profile*. Burlington, VT: University of Vermont, Department of Psychiatry.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

American Psychiatric Association (2004). *Practice guidelines for the treatment of psychiatric disorders*. Washington, DC: Author.

Ashburner, J. (2007). A fast diffeomorphic image registration algorithm. *NeuroImage*, *38*, 95–113.

Ashby, F. G., Isen, A. M., & Turken, A. U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review*, *106*, 529–550.

Banks, S. J., Eddy, K. T., Angstadt, M., Nathan, P. J., & Phan, K. L. (2007). Amygdala–frontal connectivity during emotion regulation. *Social Cognitive and Affective Neuroscience*, *2*, 303–312.

Baxter, M. G., & Murray, E. A. (2002). The amygdala and reward. *Nature Reviews Neuroscience*, *3*, 563–573.

Beauchaine, T. P. (2001). Vagal tone, development, and Gray's motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology*, *13*, 183–214.

Beauchaine, T. P. (2015a). Respiratory sinus arrhythmia: A transdiagnostic biomarker of emotion dysregulation and psychopathology. *Current Opinion in Psychology*, *3*, 43–47.

Beauchaine, T. P. (2015b). Future directions in emotion dysregulation and youth psychopathology. *Journal of Clinical Child and Adolescent Psychology*. Advance online publication.

Beauchaine, T. P., & Gatzke-Kopp, L. M. (2012). Instantiating the multiple levels of analysis perspective in a program of study on externalizing behavior. *Development and Psychopathology*, *24*, 1003–1018.

Beauchaine, T. P., Gatzke-Kopp, L., & Mead, H. K. (2007). Polyvagal theory and developmental psychopathology: Emotion dysregulation and conduct problems from preschool to adolescence. *Biological Psychology*, *74*, 174–184.

Beauchaine, T. P., Hong, J., & Marsh, P. (2008). Sex differences in autonomic correlates of conduct problems and aggression. *Journal of the American Academy of Child & Adolescent Psychiatry*, *47*, 788–796.

Beauchaine, T. P., Klein, D. N., Crowell, S. E., Derbidge, C., & Gatzke-Kopp, L. M. (2009). Multifinality in the development of personality disorders: A Biology × Sex × Environment interaction model of antisocial and borderline traits. *Development and Psychopathology*, *21*, 735–770.

Beauchaine, T. P., & McNulty, T. (2013). Comorbidities and continuities as ontogenic processes: Toward developmental spectrum model of externalizing behavior. *Development and Psychopathology*, *25*, 1505–1528.

Beauchaine, T. P., Neuhaus, E., Brenner, S. L., & Gatzke-Kopp, L. (2008). Ten good reasons to consider biological processes in prevention and intervention research. *Development and Psychopathology*, *20*, 745–774.

Beauchaine, T. P., & Thayer, J. F. (in press). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International Journal of Psychophysiology*.

Beauchaine, T. P., & Zalewski, M. (in press). Physiological and developmental mechanisms of emotional lability in coercive relationships. In T. J. Dishion & J. J. Snyder (Eds.), *Oxford handbook of coercive relationship dynamics*. New York: Oxford University Press.

Bechara, A., Damasio, H., Damasio, A. R., & Lee, G. P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *Journal of Neuroscience*, *19*, 5473–5481.

Berridge, K. C. (2003). Pleasures of the brain. *Brain and Cognition*, *52*, 106–128.

Berridge, K. C., & Robinson, T. E. (2003). Parsing reward. *Trends in Neuroscience*, *26*, 507–513.

Bjork, J. M., Knutson, B., Fong, G. W., Caggiano, D. M., Bennett, S. M., & Hommer, D. W. (2004). Incentive-elicited brain activation in adolescents: Similarities and differences from young adults. *Journal of Neuroscience*, *24*, 1793–1802.

Bresin, K., & Gordon, K. H. (2013). Endogenous opioids and nonsuicidal self-injury: A mechanism of affect regulation. *Neuroscience & Biobehavioral Reviews*, *37*, 374–383.

Brown, M. Z., Comtois, K. A., & Linehan, M. M. (2002). Reasons for suicide attempts and nonsuicidal self-injury in women with borderline personality disorder. *Journal of Abnormal Psychology*, *111*, 198–202.

Brown, S. M., Manuck, S. B., Flory, J. D., & Hariri, A. R. (2006). Neural basis of individual differences in impulsivity: Contributions of corticolimbic circuits for behavioral arousal and control. *Emotion*, *6*, 239–245.

Bush, G., Valera, E. M., & Seidman, L. J. (2005). Functional neuroimaging of attention-deficit/hyperactivity disorder: A review and suggested future directions. *Biological Psychiatry*, *57*, 1273–1284.

Camara, E., Rodriguez-Fornells, A., & Münte, T. F. (2008). Functional connectivity of reward processing in the brain. *Frontiers in Human Neuroscience*, *2*, 19.

Cardinal, R. N., Parkinson, J. A., Hall, J., & Everitt, B. J. (2002). Emotion and motivation: The role of the amygdala, ventral striatum, and prefrontal cortex. *Neuroscience & Biobehavioral Reviews*, *26*, 321–352.

Carmona, S., Hoekzema, E., Ramos-Quiroga, J. A., Richarte, V., Canals, C., Bosch, R., et al. (2011). Response inhibition and reward anticipation in medication-naïve adults with attention-deficit/hyperactivity disorder: A within-subject case-control neuroimaging study. *Human Brain Mapping*, *33*, 2350–2361.

Castellanos, F. X., Sonuga-Barke, E. J., Milham, M. P., & Tannock, R. (2006). Characterizing cognition in ADHD: Beyond executive dysfunction. *Trends in Cognitive Sciences*, *10*, 117–123.

Centers for Disease Control. (2006). *CDC injury fact book*. Atlanta, GA: National Center for Injury Prevention Control.

Centers for Disease Control. (2008). *Web-based injury statistics query and reporting system (WISQARS) nonfatal injuries: Nonfatal injury reports*. Atlanta, GA: National Center for Injury Prevention Control.

Centers for Disease Control. (2009). *CDC injury research agenda, 2009–2018*. Atlanta, GA: Author.

Cole, P. M., Hall, S. E., & Hajal, N. J. (2013). Emotion dysregulation as a risk factor for psychopathology. In T. P. Beauchaine & S. P. Hinshaw (Eds.), *Child and adolescent psychopathology* (2nd ed., pp. 341–373). Hoboken, NJ: Wiley.

Corr, P. J., & McNaughton, N. (in press). Neural mechanisms of low trait anxiety and risk for externalizing behavior. In T. P. Beauchaine & S. P. Hinshaw (Eds.), *Oxford handbook of externalizing spectrum disorders*. New York: Oxford University Press.

Crowell, S. E., Baucom, B. R., Yaptangco, M., Bride, D., Hsiao, R., McCauley, E., et al. (2014). Emotion dysregulation and dyadic conflict in depressed and typical adolescents: Evaluating concordance across psychophysiological and observational measures. *Biological Psychology*, *98*, 50–58.

Crowell, S. E., Beauchaine, T. P., Hsiao, R. C. J., Vasilev, C. A., Yaptangco, M., Linehan, M. M., et al. (2012). Differentiating adolescent self-injury from adolescent depression: Possible implications for borderline personality development. *Journal of Abnormal Child Psychology*, *40*, 45–57.

Crowell, S. E., Beauchaine, T. P., & Linehan, M. (2009). A biosocial developmental model of borderline personality: Elaborating and extending Linehan's theory. *Psychological Bulletin*, *135*, 495–510.

Crowell, S. E., Beauchaine, T. P., McCauley, E., Smith, C., Stevens, A. L., & Sylvers, P. (2005). Psychological, autonomic, and serotonergic correlates of parasuicidal behavior in adolescent girls. *Development and Psychopathology*, *17*, 1105–1127.

Crowell, S. E., Beauchaine, T. P., McCauley, E., Smith, C. J., Vasilev, C. A., & Stevens, A. L. (2008). Parent–child interactions, peripheral serotonin, and self-inflicted injury in adolescents. *Journal of Consulting and Clinical Psychology*, *76*, 15–21.

Crowell, S. E., Derbidge, C., & Beauchaine, T. P (2014). Developmental approaches to understanding self-injury and suicidal behaviors. In M. K. Nock (Ed.), *Oxford handbook of suicide and self-injury*. Oxford University Press. Advance online publication.

Crowell, S. E., Kaufman, E. A., & Lenzenweger, M. F. (2013). The development of borderline personality and self-inflicted injury. In T. P. Beauchaine & S. P. Hinshaw (Eds.), *Child and adolesscent psychopathology* (2nd ed., pp. 577–609). Hoboken, NJ: Wiley.

Cubillo, A., Halari, R., Smith, A., Taylor, E., & Rubia, K. (2012). A review of fronto-striatal and fronto-cortical brain abnormalities in children and adults with attention-deficit/hyperactivity disorder (ADHD) and new evidence for dysfunction in adults with ADHD during motivation and attention. *Cortex*, *48*, 194–215.

Dale, A. M. (1999). Optimal experimental design for event-related fMRI. *Human Brain Mapping*, *8*, 109–114.

Darche, M. A. (1990). Psychological factors differentiating self-mutilating and non-self-mutilating adolescent inpatient females. *Psychiatric Hospital*, *21*, 31–35.

Davidson, R. J., Putnam, K. M., & Larson, C. L. (2000). Dysfunction in the neural circuitry of emotion regulation—A possible prelude to violence. *Science*, *289*, 591–594.

Derbidge, C., & Beauchaine, T. P. (2014). A developmental model of self-inflicted injury, borderline personality, and suicide risk. In M. Lewis &

K. Rudolph (Eds.), *Handbook of developmental psychopathology* (3rd ed., pp. 521–542). New York: Springer.

de Ruiter, M. B., Veltman, D. J., Goudriaan, A. E., Oosterlaan, J., Sjoerds, Z., & van den Brink, W. (2008). Response perseveration and ventral prefrontal sensitivity to reward and punishment in male problem gamblers and smokers. *Neuropsychopharmacology*, *34*, 1027–1038.

Dichter, G. S., Felder, J. N., Petty, C., Bizzell, J., Ernst, M., & Smoski, M. J. (2009). The effects of psychotherapy on neural responses to rewards in major depression. *Biological Psychiatry*, *66*, 886–897.

Dickstein, S. G., Bannon, K., Castellanos, X. F., & Milham, M. P. (2006). The neural correlates of attention-deficit/hyperactivity disorder: An ALE meta-analysis. *Journal of Child Psychology and Psychiatry*, *47*, 1051–1062.

Dillon, D. G., Holmes, A. J., Jahn, A. L., Bogdan, R., Wald, L. L., & Pizzagalli, D. A. (2008). Dissociation of neural regions associated with anticipatory versus consummatory phases of incentive processing. *Psychophysiology*, *45*, 36–49.

Dom, G., Sabbe, B. G. C. C., Hulstijn, W., & Van Den Brink, W. (2005). Substance use disorders and the orbitofrontal cortex: Systematic review of behavioural decision-making and neuroimaging studies. *British Journal of Psychiatry*, *187*, 209–220.

Dougherty, D. M., Mathias, C. W., Marsh-Richard, D. M., Prevette, K. N., Dawes, M. A., Hatzis, E. S., et al. (2009). Impulsivity and clinical symptoms among adolescents with non-suicidal self-injury with or without attempted suicide. *Psychiatry Research*, *169*, 22–27.

Durston, S. (2003). A review of the biological bases of ADHD: What have we learned from imaging studies? *Mental Retardation and Developmental Disabilities Reviews*, *9*, 184–195.

First, M. B., Gibbon, M., Spitzer, R. L., Williams, J. B., & Benjamin, L. S. (1997). *User's guide for the Structured Clinical Interview for DSM-IV Axis II personality disorders*. Washington, DC: American Psychiatric Press.

Forbes, E. E., Christopher May, J., Siegle, G. J., Ladouceur, C. D., Ryan, N. D., Carter, C. S., et al. (2006). Reward-related decision-making in pediatric major depressive disorder: An fMRI study. *Journal of Child Psychology and Psychiatry*, *47*, 1031–1040.

Forbes, E. E., & Dahl, R. E. (2005). Neural systems of positive affect: Relevance to understanding child and adolescent depression? *Development and Psychopathology*, *17*, 827–850.

Forbes, E. E., & Dahl, R. E. (2011). Research review: Altered reward function in adolescent depression: What, when and how? *Journal of Child Psychology and Psychiatry*, *53*, 3–15.

Forbes, E. E., Hariri, A. H., Martin, S. L., Silk, J. S., Moyles, D. L., Fisher, P. M., et al. (2009). Altered striatal activation predicting real-world positive affect in adolescent major depressive disorder. *American Journal of Psychiatry*, *166*, 64–73.

Gadow, K. D., & Sprafkin, J. (1997). *Adolescent Symptom Inventory—4*. Stony Brook, NY: Checkmate Plus.

Gadow, K. D., Sprafkin, J., Carlson, G., Schneider, J., Nolan, E. E., Mattison, R. E., et al. (2002). A DSM-IV-referenced adolescent self-report rating scale. *Journal of the American Academy of Child & Adolescent Psychiatry*, *41*, 671–679.

Gatzke-Kopp, L. M. (2011) The canary in the coalmine: Sensitivity of mesolimbic dopamine to environmental adversity during development. *Neuroscience & Biobehavioral Reviews*, *35*, 794–803.

Gatzke-Kopp, L. M., & Beauchaine, T. P. (2007). Central nervous system substrates of impulsivity: Implications for the development of attention-deficit/hyperactivity disorder and conduct disorder. In D. Coch, G. Dawson, & K. Fischer (Eds.), *Human behavior, learning, and the developing brain: Atypical development* (pp. 239–263). New York: Guilford Press.

Geier, C., & Luna, B. (2009). The maturation of incentive processing and cognitive control. *Pharmacology Biochemistry and Behavior*, *93*, 212–221.

Geier, C. F., Terwilliger, R., Teslovich, T., Velanova, K., & Luna, B. (2010). Immaturities in reward processing and its influence on inhibitory control in adolescence. *Cerebral Cortex*, *20*, 1613–1629.

Glenn, C. R., & Klonsky, E. D. (2010). A multimethod analysis of impulsivity in nonsuicidal self-injury. *Personality Disorders: Theory, Research, and Treatment*, *1*, 67–75.

Goldman, S. J., D'Angelo, E. J., & DeMaso, D. R. (1993). Psychopathology in the families of children and adolescents with borderline personality disorder. *American Journal of Psychiatry*, *150*, 1832–1835.

Goldsmith, H. H., Pollak, S. D., & Davidson, R. J. (2008). Developmental neuroscience perspectives on emotion regulation. *Child Development Perspectives*, *2*, 132–140.

Gorwood, P. (2008). Neurobiological mechanisms of anhedonia. *Dialogues in Clinical Neuroscience*, *10*, 291–299.

Hamza, C. A., Stewart, S. L., & Willoughby, T. (2012). Examining the link between nonsuicidal self-injury and suicidal behavior: A review of the literature and an integrated model. *Clinical Psychology Review*, *32*, 482–495.

Hazlett, E. A., Zhang, J., New, A. S., Zelmanova, Y., Goldstein, K. E., Haznedar, M. M., et al. (2012). Potentiated amygdala response to repeated emotional pictures in borderline personality disorder. *Biological Psychiatry*, *72*, 448–456.

Hinshaw, S. P., Owens, E. B., Zalecki, C., Huggins, S. P., Montenegro-Nevado, A., Schrodek, E., et al. (2012). Prospective follow-up of girls with ADHD into young adulthood: Continuing impairment includes elevated risk for suicide attempts and self-injury. *Journal of Consulting and Clinical Psychology*, *80*, 1041–1051.

Holland, P. C., & Gallagher, M. (2004). Amygdala–frontal interactions and reward expectancy. *Current Opinion in Neurobiology*, *14*, 148–155.

Horesh, N., Rolnick, T., Iancu, I., Dannon, P., Lepkifker, E., Apter, A., et al. (1997). Anger, impulsivity, and suicide risk. *Psychotherapy and Psychosomatics*, *66*, 92–96.

Joiner, T. E., Pettit, J. W., Walker, R. L., Voelz, Z. R., Cruz, J., Rudd, M. D., et al. (2002). Perceived burdensomeness and suicidality: Two studies on the suicide notes of those attempting and those completing suicide. *Journal of Social and Clinical Psychology*, *21*, 531–545.

Johnson, P. A., Hurley, R. A., Benkelfat, C., Herpertz, S. C., & Taber, K. H. (2005). Understanding emotion regulation in borderline personality disorder: Contributions of neuroimaging. *Focus*, *3*, 478–483.

Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test* (2nd ed.). Circle Pines, MN: AGS Publishing.

Kaufman, E., Crowell, S. E., & Stepp, S. D. (2015). Self-injury, borderline personality development, and the externalizing spectrum. In T. P. Beauchaine & S. P. Hinshaw (Eds.), *Oxford handbook of externalizing spectrum disorders*. New York: Oxford University Press.

Klonsky, E. D., May, A. M., & Glenn, C. R. (2013). The relationship between nonsuicidal self-injury and attempted suicide: Converging evidence from four samples. *Journal of Abnormal Psychology*, *122*, 231–237.

Klonsky, E. D., & Muehlenkamp, J. J. (2007). Self-injury: A research review for the practitioner. *Journal of Clinical Psychology*, *63*, 1045–1056.

Knutson, B., Adams, C. M., Fong, G. W., & Hommer, D. (2001). Anticipation of increasing monetary reward selectively recruits nucleus accumbens. *Journal of Neuroscience*, *21*, 1–5.

Knutson, B., Bhanji, J. P., Cooney, R. E., Atlas, L. Y., & Gotlib, I. H. (2008). Neural responses to monetary incentives in major depression. *Biological Psychiatry*, *63*, 686–692.

Knutson, B., Fong, G. W., Adams, C. M., Varner, J. L., & Hommer, D. (2001). Dissociation of reward anticipation and outcome with event-related fMRI. *Neuroreport*, *12*, 3683–3687.

Koenigsberg, H. W., Siever, L. J., Lee, H., Pizzarello, S., New, A. S., Goodman, M., et al. (2009). Neural correlates of emotion processing in borderline personality disorder. *Psychiatry Research Neuroimaging*, *172*, 192–199.

Kraus, A., Valerius, G., Seifritz, E., Ruf, M., Bremner, J. D., Bohus, M., et al. (2010). Script-driven imagery of self-injurious behavior in patients with borderline personality disorder: A pilot FMRI study. *Acta Psychiatrica Scandinavica*, *121*, 41–51.

Krueger, R. F., Hicks, B. M., Patrick, C. J., Carlson, S. R., Iacono, W. G., & McGue, M. (2002). Etiologic connections among substance dependence, antisocial behavior, and personality: Modeling the externalizing spectrum. *Journal of Abnormal Psychology*, *111*, 411–424.

Kuo, J. R., & Linehan, M. M. (2009). Disentangling emotion processes in borderline personality disorder: Physiological and self-reported assessment of biological vulnerability, baseline intesnsity, and reactivity to emotionally evocative stimuli. *Journal of Abnormal Psychology*, *118*, 531–544.

Laakso, A., Wallius, E., Kajander, J., Bergman, J., Eskola, O. Solin, O., et al. (2003). Personality traits and striatal dopamine synthesis capacity in healthy subjects. *American Journal of Psychiatry*, *160*, 904–910.

Laine, T. P. J., Ahonen, A., Räsänen, P., & Tiihonen, J. (2001). Dopamine transporter density and novelty seeking among alcoholics. *Journal of Addictive Disease*, *20*, 95–100.

Linehan, M. M. (1993). *Cognitive–behavioral treatment of borderline personality disorder*. New York: Guilford Press.

Linehan, M. M., & Comtois, K. A. (1996). *Lifetime parasuicide count*. Unpublished manuscript.

Linehan, M. M., Comtois, K. A., Brown, M. Z., Heard, H. L., & Wagner, A. W. (2006). Suicide attempt self-injury interview (SASII): Development, reliability, and validity of a scale to assess suicide attempts and intentional self-injury. *Psychological Assessment*, *18*, 303–312.

Lis, E., Greenfield, B., Henry, M., Guile, J. M., & Dougherty, G. (2007). Neuroimaging and genetics of borderline personality disorder: A review. *Review of Psychiatric Neuroscience*, *32*, 162–173.

Liu, X., Hairston, J., Schrier, M., & Fan, J. (2011). Common and distinct networks underlying reward valence and processing stages: A meta-analysis of functional neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *35*, 1219–1236.

Lloyd-Richardson, E., Perrine, N., Dierker, L., & Kelley, M. L. (2007). Characteristics and functions of non-suicidal self-injury in a community sample of adolescents. *Psychological Medicine*, *37*, 1183–1192.

Lobbestael, J., Leurgans, M., & Arntz, A. (2010). Inter-rater reliability of the Structured Clinical Interview for DSM-IV Axis I Disorders (SCID I) and Axis II Disorders (SCID II). *Clinical Psychology and Psychotherapy*, *18*, 75–79.

Lynam, D. R., Miller, J. D., Miller, D. J., Bornovalova, M. A., & Lejuez, C. W. (2011). Testing the relations between impulsivity-related traits, suicidality, and nonsuicidal self-injury: A test of the incremental validity of the UPPS model. *Personality Disorders: Theory, Research, and Treatment*, *2*, 151–160.

Maffei, C., Fossati, A., Agostoni, I., Barraco, A., Bagnato, M., Deborah, D., et al. (1997). Interrater reliability and internal consistency of the Structured Clinical Interview for *DSM-IV* axis II personality disorders (SCID-II), Version 2.0. *Journal of Personality Disorders*, *11*, 279–284.

Martin-Soelch, C., Leenders, K. L., Chevalley, A.-F., Missimer, J., Kunig, S., Magyar, A., et al. (2001). Reward mechanisms in the brain and their role in dependence: Evidence from neurophysiological and neuroimaging studies. *Brain Research Reviews*, *36*, 139–149.

Mazaika, P. K., Hoeft, F., Glover, G. H., & Reiss, A. L. (2009). Methods and software for fMRI analysis of clinical subjects. *NeuroImage*, *47*, S58.

McCabe, C., Mishor, Z., Cowen, P. J., & Harmer, C. J. (2010). Diminished neural processing of aversive and rewarding stimuli during selective serotonin reuptake inhibitor treatment. *Biological Psychiatry*, *67*, 439–445.

McClure, S. M., York, M. K., & Montague, P. R. (2004). The neural substrates of reward processing in humans: The modern role of FMRI. *Neuroscientist*, *10*, 260–268.

Minkoff, K., Bergman, E., Beck, A. T., & Beck, R. (1973). Hopelessness, depression, and attempted suicide. *American Journal of Psychiatry*, *130*, 455–459.

Minzenberg, M. J., Fan, J., New, A. S., Tang, C. Y., & Siever, L. J. (2008). Frontolimbic structural changes in borderline personality disorder. *Journal of Psychiatric Research*, *42*, 727–733.

Murray, E. A. (2007). The amygdala, reward and emotion. *Trends in Cognitive Sciences*, *11*, 489–497.

Nestler, E. J., & Carlezon, W. A., Jr. (2006). The mesolimbic dopamine reward circuit in depression. *Biological Psychiatry*, *59*, 1151–1159.

Neuhaus, E., & Beauchaine, T. P. (2013). Impulsivity and vulnerability to psychopathology. In T. P. Beauchaine & S. P. Hinshaw (Eds.), *Child and adolescent psychopathology* (2nd ed., pp. 197–226). Hoboken, NJ: Wiley.

New, A. S., Hazlett, E. A., Buchsbaum, M. S., Goodman, M., Mitelman, S. A., Newmark, R., et al. (2007). Amygdala–prefrontal disconnection in borderline personality disorder. *Neuropsychopharmacology*, *32*, 1629–1640.

Nock, M. K. (2008). Actions speak louder than words: An elaborated theoretical model of the social functions of self injury and other harmful behaviors. *Applied and Preventive Psychology*, *12*, 159–168.

Nock, M. K. (2009). Why do people hurt themselves? *Current Directions in Psychological Science*, *18*, 78–83.

Nock, M. K. (2010). Self-injury. *Annual Review of Clinical Psychology*, *6*, 339–363.

Nock, M. K., Joiner, T. E., Gordon, K. H., Lloyd-Richardson, E., & Prinstein, M. J. (2006). Non-suicidal self-injury among adolescents: Diagnostic correlates and relation to suicide attempts. *Psychiatry Research*, *144*, 65–72.

Oberlin, B. G., Dzemidzic, M., Bragulat, V., Lehigh, C. A., Talavage, T., O'Connor, S. J., et al. (2012). Limbic responses to reward cues correlate with antisocial trait density in heavy drinkers. *NeuroImage*, *60*, 644–652.

Oquendo, M. A., & Mann, J. J. (2000). The biology of impulsivity and suicidality. *Psychiatric Clinics of North America*, *23*, 11–25.

Pizzagalli, D. A., Holmes, A. J., Dillon, D. G., Goetz, E. L., Birk, J. L., Bogdan, R., et al. (2009). Reduced caudate and nucleus accumbens response to rewards in unmedicated subjects with major depressive disorder. *American Journal of Psychiatry*, *166*, 702–710.

Plener, P. L., Bubalo, N., Fladung, A. K., Ludolph, A. G., & Lulé, D. (2012). Prone to excitement: Adolescent females with non-suicidal self-injury (NSSI) show altered cortical pattern to emotional and NSS-related material. *Psychiatry Research Neuroimaging*, *203*, 146–152.

Plichta, M. M., & Scheres, A. (2014). Ventral–striatal responsiveness during reward anticipation in ADHD and its relation to trait impulsivity in the healthy population: A meta-analytic review of the fMRI literature. *Neuroscience & Biobehavioral Reviews*, *38*, 125–134.

Quay, H. C. (1993). The psychobiology of undersocialized aggressive conduct disorder: A theoretical perspective. *Development and Psychopathology*, *5*, 165–180.

Reynolds, W. M. (1987). *Suicidal Ideation Questionnaire—Junior*. Odessa, FL: Psychological Assessment Resources.

Reynolds, W. M. (1988). *Suicidal Ideation Questionnaire: Professional manual*. Odessa, FL: Psychological Assessment Resources.

Richards, J. M., Plate, R. C., & Ernst, M. (2013). A systematic review of fMRI reward paradigms in adolescents vs. adults: The impact of task design and implications for understanding neurodevelopment. *Neuroscience & Biobehavioral Reviews*. Advance online publication.

Rolls, E. T. (2000). The orbitofrontal cortex and reward. *Cerebral Cortex*, *10*, 284–294.

Rubia, K. (2011). "Cool" inferior frontostriatal dysfunction in attention-deficit/hyperactivity disorder versus "hot" ventromedial orbitofrontal-limbic dysfunction in conduct disorder: A review. *Biological Psychiatry*, *69*, e69–e87.

Rubia, K., Smith, A., Halari, R., Matukura, F., Mohammad, M., Taylor, E., et al. (2009). Disorder-specific dissociation of orbitofrontal dysfunction in boys with pure conduct disorder during reward and ventrolateral prefrontal dysfunction in boys with pure ADHD during sustained attention. *American Journal of Psychiatry*, *166*, 83–94.

Rudd, M. D., Joiner, T., & Rajad, M. H. (1996). Relationships among suicide ideators, attempters, and multiple attempters in a young-adult sample. *Journal of Abnormal Psychology*, *105*, 541–550.

Sagvolden, T., Johansen, E. B., Aase, H., & Russell, V. A. (2005). A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/ impulsive and combined subtypes. *Behavioral and Brain Sciences*, *28*, 397–418.

Sauder, C., Beauchaine, T. P., Gatzke-Kopp, L. M., Shannon, K. E., & Aylward, E. (2012). Neuroanatomical correlates of heterotypic comorbidity in externalizing male adolescents. *Journal of Clinical Child and Adolescent Psychology*, *41*, 346–352.

Schlaepfer, T. E., Cohen, M. X., Frick, C., Kosel, M., Brodesser, D., Axmacher, N., et al. (2007). Deep brain stimulation to reward circuitry alleviates anhedonia in refractory major depression. *Neuropsychopharmacology*, *33*, 368–377.

Schultz, W. (2000). Multiple reward signals in the brain. *Nature Reviews Neuroscience*, *1*, 199–207.

Seiffge-Krenke, I., & Kollmar, F. (1998). Discrepancies between mothers' and fathers' perceptions of sons' and daughters' problem behaviour: A longitudinal analysis of parent–adolescent agreement on internalising and externalising problem behaviour. *Journal of Child Psychology and Psychiatry*, *39*, 687–697.

Shaffer, D., Fisher, P., Lucas, C. P., Mina, K., & Schwab-Stone, M. E. (2000). NIMH Diagnostic Interview Schedule for Children Version IV (NIMH DISC-IV): Description, differences from previous versions, and reliability of some common diagnoses. *Journal of the American Academy of Child & Adolescent Psychiatry*, *39*, 28–38.

Shannon, K. E., Sauder, C., Beauchaine, T. P., & Gatzke-Kopp, L. (2009). Disrupted effective connectivity between the medial frontal cortex and the caudate in adolescent boys with externalizing behavior disorders. *Criminal Justice and Behavior*, *36*, 1141–1157.

Smoski, M. J., Felder, J., Bizzell, J., Green, S. R., Ernst, M., Lynch, T. R., et al. (2009). fMRI of alterations in reward selection, anticipation, and feedback in major depressive disorder. *Journal of Affective Disorders*, *118*, 69–78.

Soloff, P. H., Meltzer, C. C., Becker, C., Greer, P. J., Kelly, T. M., & Constantine, D. (2003). Impulsivity and prefrontal hypometabolism in borderline personality disorder. *Psychiatry Research: Neuroimaging*, *123*, 153–163.

Soloff, P. H., Pruitt, P., Sharma, M., Radwan, J., White, R., & Diwadkar, V. A. (2012). Structural brain abnormalities and suicidal behavior in borderline personality disorder. *Journal of Psychiatric Research*, *46*, 516–525.

Sourander, A., Helstela, L., & Helenius, H. (1999). Parent–adolescent agreement on emotional and behavioral problems. *Social Psychiatry and Psychiatric Epidemiology*, *34*, 657–663.

Stark, R., Bauer, E., Merz, C. J., Zimmermann, M., Reuter, M., Plichta, M. M., et al. (2011). ADHD related behaviors are associated with brain activation in the reward system. *Neuropsychologia*, *49*, 426–434.

Stoy, M., Schlagenhauf, F., Sterzer, P., Bermpohl, F., Hägele, C., Suchotzki, K., et al. (2012). Hyporeactivity of ventral striatum toward incentive stimuli in unmedicated depressed patients normalizes after treatment with escitalopram. *Journal of Psychopharmacology*, *26*, 677–688.

Strohle, A., Stoy, M., Wrase, J., Schwarzer, S., Schlagenhauf, F., Huss, M., et al. (2008). Reward anticipation and outcomes in adult males with ADHD. *NeuroImage*, *39*, 966–972.

Tripp, G., & Wickens, J. R. (2008). Research review: Dopamine transfer deficit: A neurobiological theory of altered reinforcement mechanisms in ADHD. *Journal of Child Psychology and Psychiatry*, *49*, 691–704.

Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., et al. (2002). Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. *NeuroImage*, *15*, 273–289.

US Public Health Service. (1999). *The surgeon general's call to action to prevent suicide*. Washington, DC: Author.

Volkow, N. D., Fowler, J. S., & Wang, G. J. (2004). The addicted human brain viewed in light of imaging studies: Brain circuits and treatment strategies. *Neuropharmacology*, *47*, 3–13.

Volkow, N. D., Wang, G.-J., Kollins, S. H., Wigal, T. L., Newcorn, J. H., Telang, F., et al. (2009). Evaluating dopamine reward pathway in ADHD: Clinical implications. *Journal of the American Medical Association*, *302*, 1084–1091.

Völlm, B., Richardson, P., McKie, S., Elliott, R., Dolan, M., & Deakin, B. (2007). Neuronal correlates of reward and loss in Cluster B personality disorders: A functional magnetic resonance imaging study. *Psychiatry Research: Neuroimaging*, *156*, 151–167.

Wilbertz, G., Tebartz van Elst, L., Delgado, M. R., Maier, S., Feige, B., Philipsen, A., et al. (2012). Orbitofrontal reward sensitivity and impulsivity in adult attention deficit hyperactivity disorder. *NeuroImage*, *60*, 353–361.

Winstanley, C. A., Theobald, D. E., Cardinal, R. N., & Robbins, T. W. (2004). Contrasting roles of basolateral amygdala and orbitofrontal cortex in impulsive choice. *Journal of Neuroscience*, *24*, 4718–4722.

Wolf, R. C., Thomann, P. A., Sambataro, F., Vasic, N., Schmid, M., & Wolf, N. D. (2012). Orbitofrontal cortex and impulsivity in borderline personality disorder: An MRI study of baseline brain perfusion. *European Archives of Psychiatry and Clinical Neuroscience*, *262*, 677–685.

Wrase, J., Schlagenhauf, F., Kienast, T., Wustenberg, T., Bermpohl, F., Kahnt, T., et al. (2007). Dysfunction of reward processing correlates with alcohol craving in detoxified alcoholics. *NeuroImage*, *35*, 787–794.