



## Extraversion, neuroticism, and the electrocortical response to monetary rewards in adolescent girls<sup>☆</sup>

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### ABSTRACT

Affective personality traits, such as extraversion and neuroticism, are associated with individual differences in reward system functioning. The reward positivity ( $\Delta$ RewP) is an event-related potential (ERP) component that indexes sensitivity to reward, and can be elicited by feedback indicating monetary gains relative to losses. In a sample of 508 adolescent girls, the current study examined the relationship between extraversion, neuroticism, and their respective facets and the  $\Delta$ RewP. Results indicated an Extraversion  $\times$  Neuroticism interaction, such that greater extraversion was associated with an increased  $\Delta$ RewP, but only in the context of low neuroticism. This association was primarily due to the extraversion facet positive emotionality—high levels of positive emotionality were associated with an increased  $\Delta$ RewP, but only in the context of low neuroticism. In addition, increased neuroticism diminished the age-related increase in the  $\Delta$ RewP. The current study suggests that both extraversion and neuroticism are associated with reward system function in adolescence.

### 1. Introduction

Adolescence is a transformative period, characterized by significant biological and psychosocial changes that are necessary for the transition into adulthood (Petersen, Crockett, Richards, & Boxer, 1988); it is also a period characterized by increased risk for psychopathology (Lewinsohn, Hops, Roberts, Seeley, & Andrews, 1993). In particular, increased affective and behavioral responsiveness to rewarding stimuli is a defining feature of adolescence (Galvan et al., 2006; Luking, Luby, & Barch, 2014; Silverman, Jedd, & Luciana, 2015; Spear, 2011). For example, neuroimaging research has demonstrated that striatal response to monetary rewards peaks between the ages of 12 and 15 (Van Leijenhorst et al., 2010). At the same time, risk for first-onset depression increases dramatically in mid-adolescence, particularly for females (Avenevoli, Swendsen, He, Burstein, & Merikangas, 2015). In light of these important and co-occurring developmental changes, a growing body of research has examined associations between depression, risk for depression, and neural response to rewards during this sensitive period. Cumulative evidence suggests that a blunted neural response to rewards is a promising biomarker of risk for depression (Bress, Foti, Kotov, Klein, & Hajcak, 2013; Luking, Pagliaccio, Luby, & Barch, 2016;

Morgan, Olino, McMakin, Ryan, & Forbes, 2013; Nelson, Perlman, Klein, Kotov, & Hajcak, 2016; Olino et al., 2014).

Event-related potentials (ERPs) are an effective tool to study individual differences in reward responsiveness because they are a direct measure of neural activity with excellent temporal resolution. The ERP response to rewards is often evaluated using guessing tasks (e.g. the doors task; for a review see Proudfit, 2015), where the participant is required to make a selection that can result in a monetary gain or loss. Distinct reward-related ERP components are maximal at frontocentral sites approximately 300 ms following feedback: the reward positivity (RewP) observed as a relative positivity following gain feedback and the feedback negativity (FN) observed as a relative negativity following loss feedback, with the difference between gains and losses referred to as the  $\Delta$ RewP (Bress & Hajcak, 2013; Carlson, Foti, Mujica-Parodi, Harmon-Jones, & Hajcak, 2011; Foti, Weinberg, Dien, & Hajcak, 2011; Holroyd, Pakzad-Vaezi, & Krigolson, 2008). Previous research has found that the  $\Delta$ RewP is associated with self-report (Bress & Hajcak, 2013), behavioral (Bress & Hajcak, 2013), and functional magnetic resonance imaging (fMRI; Becker, Nitsch, Miltner, & Straube, 2014; Carlson et al., 2011; Foti, Carlson, Sauder, & Proudfit, 2014) measures of reward responsiveness. The  $\Delta$ RewP is clearly evident in children,

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adolescents and adults, and psychometric evaluations demonstrate good internal consistency (Levinson, Speed, Infantolino, & Hajcak, 2017; Marco-Pallares, Cucurell, Münte, Strien, & Rodriguez-Fornells, 2011) and test-retest reliability (Bress, Meyer, & Proudfit, 2015; Levinson et al., 2017; Segalowitz, Santesso, Murphy, Homan, & Chantziantoniou, 2010), making it an ideal tool to study individual differences across development. In regards to age-related differences in the  $\Delta$ RewP across childhood and adolescence, Hämmerer, Li, Müller, and Lindenberger (2011) demonstrated that  $\Delta$ RewP magnitude follows an inverted U pattern across the lifespan, peaking during adolescence and declining through adulthood. Consistent with Hämmerer et al. (2011) and neuroimaging studies of reward sensitivity (Luking et al., 2014; Van Leijenhorst et al., 2010), recent evidence suggests that the  $\Delta$ RewP increases during adolescence (Sheffield et al., 2015), reflecting heightened reward processing during this period.

Consistent with fMRI findings of reduced amygdala activity to positive stimuli broadly (Canli et al., 2004; Mitterschiffthaler et al., 2003), and reduced activity in reward circuitry specifically (Pizzagalli, 2014), recent ERP studies have consistently shown that the  $\Delta$ RewP is blunted in depression, indicating reduced reward sensitivity (Bress, Meyer, & Hajcak, 2015; Bress, Meyer, & Proudfit, 2015; Bress, Smith, Foti, Klein, & Hajcak, 2012; Foti & Hajcak, 2009; Foti, Weinberg, Bernat, & Proudfit, 2015). Furthermore, blunted  $\Delta$ RewP amplitude has been associated with specific depression symptoms that are negatively associated with positive emotionality, including anhedonia (Liu, Wang, Shang, Shen, Li, Cheung, & Chan, 2014) and impaired mood reactivity to positive events (Foti et al., 2014). Cumulative prospective evidence suggests that a blunted  $\Delta$ RewP precedes and predicts depressive symptomatology (Bress et al., 2013; Bress, Meyer, & Proudfit, 2015; Kujawa, Proudfit, & Klein, 2014; Kujawa, Proudfit, Laptook, & Klein, 2015). Furthermore, a large study of adolescent girls with no lifetime history of depression found that a blunted  $\Delta$ RewP predicted first-onset depressive disorder and greater depressive symptoms at an 18 month follow-up independent of other established risk factors, including baseline depressive symptoms and adolescent and parental lifetime psychiatric history (Nelson, Perlman, Klein, Kotov, & Hajcak, 2016). To further evaluate the  $\Delta$ RewP as a stable biomarker of risk it is important to determine how the  $\Delta$ RewP may relate to other trait measures that are relatively stable across development and also associated with risk for depression.

Extraversion and neuroticism are two early-emerging, broad affective-personality traits linked to the onset and maintenance of depression (Davidson, 1992; Depue & Iacono, 1989; Gray, 1994; Lang, Bradley, & Cuthbert, 1990). Extraversion is broadly characterized by energetic engagement with the world, enhanced sociality, activity and positive emotionality (John, Naumann, & Soto, 2008; Watson, Clark, & Harkness, 1994). Prior research has suggested that key facets of extraversion include positive emotionality, sociability, ascendance, and venturesomeness (Naragon-Gainey, Watson, & Markon, 2009; Simms, 2009; Shiner & Caspi, 2003). Evidence suggests that individuals high in extraversion are more sensitive to rewards (Lucas, Diener, Grob, Suh, & Shao, 2000; Olinio, Klein, Durbin, Hayden, & Buckley, 2005). In contrast, neuroticism is conceptualized as the tendency to experience negative emotions, including emotional instability and heightened reactivity to stress and negative environmental stimuli (John et al., 2008; Watson et al., 1994). Past research supports the inclusion of three facets of neuroticism: trait hostility, anxiousness and melancholia (Naragon-Gainey et al., 2009; Simms, 2009). Given that depression is defined clinically as a dysfunction in mood that involves pronounced feeling of sadness and/or loss of pleasure in activities (American Psychiatric Association, 2013), depression involves the combination of high neuroticism and low extraversion, particularly positive emotionality, that remains stable even after remittance of depressive symptoms (De Fruyt, Van Leeuwen, Bagby, Rolland, & Rouillon, 2006; Ormel, Oldenhinkel, & Vollenberg, 2004). A large body of converging evidence supports this personality-based view of depression (Klein, Kotov, & Bufferd, 2011),

and suggests that low extraversion is unique to depression while high neuroticism is common across internalizing psychopathology (Shankman & Klein, 2003).

In addition to developmental changes in reward system functioning during adolescence, there is evidence for co-occurring changes in extraversion and neuroticism during this important developmental period. Meta-analytic evidence indicates that adolescents display increasing extraversion and decreasing neuroticism with age (Roberts, Walton, & Viechtbauer, 2006). Additionally, rank order stability of personality traits increases during adolescence (Akse, Hale, Engels, Raaijmakers, & Meeus, 2007; Klimstra, Hale, Raaijmakers, Branje, & Meeus, 2009; Pullmann, Raudsepp, & Allik, 2006; Roberts & DelVecchio, 2000), suggesting that these changes in extraversion and neuroticism at the mean-level reflect normative development. Consistent with theoretical models of depression, longitudinal studies of personality and psychopathology in children suggest that lower extraversion predicts later internalizing symptoms, and that elevated neuroticism predicts later internalizing and externalizing symptoms (Rothbart & Bates, 1998). Notably, these associations are modest and the processes through which personality puts children at risk for psychopathology remains unclear.

Few studies have examined associations between broad personality traits (and their facets) and neural correlates of reward sensitivity, though preliminary evidence suggests a positive association between extraversion and reward sensitivity. For example, fMRI studies of adolescents and adults have found that greater extraversion was associated with increased activation in the ventral striatum and medial orbital frontal cortex following the receipt of reward (Cohen, Young, Baek, Kessler, & Ranganath, 2005; Forbes et al., 2010; Kennis, Rademaker, & Geuze, 2013; Simon et al., 2010). Conversely, greater behavioral inhibition (i.e. high neuroticism) has been associated with reduced activation in the ventral striatum following the receipt of reward (Simon et al., 2010). Previous studies in adults have found that more extraverted individuals display heightened reward responsiveness indexed by the  $\Delta$ RewP (Cooper, Duke, Pickering, & Smillie, 2014; Smillie, Cooper, & Pickering, 2011). A longitudinal study by Kujawa, Proudfit, Kessel, et al. (2015) found that laboratory observations of positive emotionality, a facet of extraversion, at age 3 predicted an enhanced  $\Delta$ RewP at age 9, but did not find associations between neuroticism and the  $\Delta$ RewP. Thus, preliminary evidence from children and adults suggests that extraversion, particularly positive emotionality, is associated with neural measures of reward processing, including the  $\Delta$ RewP. However, more research is needed to clarify if neuroticism or its facets are related to reward system functioning. In addition, it remains unclear how neuroticism and extraversion may be associated with the  $\Delta$ RewP during adolescence, a time where important changes in personality and reward sensitivity are taking place. Examining associations between personality traits that confer risk for depression and reward system activation during this sensitive period may aid in the identification of mechanistic processes that are implicated in the development of depression.

The current study examined the relationship between extraversion, neuroticism—and their respective facets—and the  $\Delta$ RewP in a large sample of adolescent girls with no lifetime history of depression. The current study utilized a sample of never-depressed adolescent girls for several reasons. First, we were able to examine the association between personality and the  $\Delta$ RewP without the obscuring effect of depression, which could alter both personality and reward sensitivity (Foti & Hajcak, 2009; Klein et al., 2011). Second, adolescence is a period characterized by divergent changes in extraversion and neuroticism (Roberts et al., 2006), increasing responsiveness to rewarding stimuli (Galvan et al., 2006; Luking et al., 2014; Silverman et al., 2015; Spear, 2000; Van Leijenhorst et al., 2010), and increasing risk for depression, especially for females (Avenevoli et al., 2015; Hankin et al., 1998). Therefore, this developmental window may be valuable for investigating the relationship between neural activity indexing reward

sensitivity and personality traits linked to depression risk. Based on previous research which suggest opposing relationships between extraversion and neuroticism with reward responsiveness, we hypothesized that extraversion and neuroticism would interact to predict the  $\Delta$ RewP, specifically that high extraversion in the context of low neuroticism would be associated with a larger  $\Delta$ RewP during a monetary guessing task. Furthermore, consistent with prior research we hypothesized that the association between extraversion and the  $\Delta$ RewP would be specific to the positive emotionality facet. As a result of the limited research on neuroticism and the  $\Delta$ RewP, we consider neuroticism facet analyses exploratory.

Due to the developmentally normative increase in reward sensitivity that occurs during adolescence, we examined the association between age and the neural response to gains and losses. Consistent with previous research, we hypothesized that age would be positively associated with the  $\Delta$ RewP. In addition, although it is well-established that reward system activation peaks in adolescence (Galvan et al., 2006; Luking et al., 2014; Silverman et al., 2015; Spear, 2000; Van Leijenhorst et al., 2010), it is unclear whether this developmentally normative increase is impacted by personality. Therefore, we conducted exploratory analyses examining whether the association of age and the  $\Delta$ RewP were moderated by extraversion, neuroticism, and their related facets.

## 2. Method

### 2.1. Participants

The sample consisted of 550 adolescent girls between the ages of 13.5–15.5 ( $M = 14.39$ ,  $SD = 0.63$ ) and a biological parent (93.1% mothers) who participated as part of the Adolescent Development of Emotions and Personality Traits (ADEPT) project. ADEPT is a longitudinal study of emotional and personality development and risk for depression, which focuses on early/mid adolescent girls because they are the demographic group at highest risk for developing depression (Avenevoli et al., 2015; Hankin et al., 1998). For the present study, data were taken from the initial assessment. Participant racial/ethnic background was 80.5% non-Hispanic Caucasian and 57.8% of parents had a bachelor's degree or greater.

Participants were recruited from the community using a commercial mailing list of homes with a daughter age 13–15 years, word of mouth, local referral sources (e.g., school districts), online classifieds, and postings in the community. Families were financially compensated for their participation. Inclusion criteria were fluency in English, able to read and understand questionnaires, and a biological parent willing to participate in the study. Exclusion criteria were a present or lifetime history of major depressive disorder (MDD), dysthymia, or intellectual disabilities. Lifetime history of MDD or dysthymia was determined using the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children, Present and Lifetime Version (Kaufman et al., 1997), which was administered by trained diagnostic interviewers closely supervised by clinical psychologists (R.K. and D.K.).

### 2.2. Personality

#### 2.2.1. Big five inventory (BFI; John, Donahue, & Kentle, 1991; John et al., 2008)

The BFI is a 44-item, factor-analytically derived self-report measure of broad personality traits: neuroticism, extraversion, agreeableness, conscientiousness, and openness. Items are comprised of short descriptive statements that are rated on a five-point Likert scale ranging from 1 (*disagree strongly*) to 5 (*agree strongly*). Psychometric evaluations of the BFI indicate good internal consistency, test-retest reliability and convergent and discriminant validity (John et al., 2008; Rammstedt & John, 2007). The current study focused on the extraversion (6 items) and neuroticism (8 items) scales, which were completed by the adolescent. See Table 1 for estimates of internal consistency in the current

**Table 1**  
Descriptive Statistics and Correlation Coefficients for Extraversion, Neuroticism, and Related Facets.

	1	2	3	4	5	6	7	8	9
<b>Extraversion</b>									
1. BFI Ext	–	.48	.66	.68	.47	–.26	–.22	–.26	–.28
2. IPIP Che	–	–	.40	.56	.40	–.30	–.34	–.29	–.43
3. IPIP Ast.	–	–	–	.63	.36	–.22	–.19	–.23	–.25
4. IPIP Fri	–	–	–	–	.35	–.39	–.45	–.43	–.48
5. IPIP Exc	–	–	–	–	–	–.07	.00	–.16	.05
<b>Neuroticism</b>									
6. BFI Neu	–	–	–	–	–	–	.71	.80	.65
7. IPIP Hos	–	–	–	–	–	–	–	.76	.70
8. IPIP Anx	–	–	–	–	–	–	–	–	–
9. IPIP Sad	–	–	–	–	–	–	–	–	.63
<i>M</i>	3.76	4.18	3.56	3.99	3.57	2.74	2.56	2.68	1.92
<i>SD</i>	0.78	0.54	0.79	0.70	0.67	0.81	0.86	0.80	0.85
Cronbach's $\alpha$	.80	.76	.87	.86	.79	.84	.85	.83	.91

Note. All correlations greater than  $|\text{.15}|$  were significant at  $p < .01$ . Bold-faced type =  $r$  values  $\geq 0.45$ ; Anx = anxiousness; Ast = assertiveness; BFI = Big Five Inventory; Che = cheerfulness; Exc = excitement seeking; Ext = extraversion; Fri = friendliness; IPIP = International Personality Item Pool; *M* = mean; Neu = neuroticism; Sad = sadness; *SD* = standard deviation.

sample.

#### 2.2.2. International Personality Item Pool (IPIP; Ashton, Lee, & Goldberg, 2007; Goldberg et al., 2006)

The IPIP was developed to provide a public-domain item pool to facilitate the self-report assessment of various personality characteristics. Items consist of short descriptive phrases and are rated on a five-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Evaluations of IPIP scales have indicated good internal consistency, as well as discriminant and convergent validity (Lim & Ployhart, 2006; Goldberg, 1999). The current study included 4 facets of extraversion, including cheerfulness (positive emotionality), assertiveness (ascendance), friendliness (sociability), and excitement seeking (venturesomeness), and 3 facets of neuroticism, including hostility, sadness (melancholia) and anxiousness. Each facet scale was comprised of 10 items (70 items total), which were completed by the adolescent. See Table 1 for estimates of internal consistency in the current sample.

### 2.3. Reward sensitivity

#### 2.3.1. Doors task

The doors task was administered using Presentation software (Neurobehavioral Systems, Inc., Albany, CA, USA) on an Intel Core i5 class computer with a 21" monitor placed at eye level, at a distance of approximately 39", and was consistent with versions used in previous studies (Dunning & Hajcak, 2007; Foti & Hajcak, 2009, 2010, Proudfit, 2015). The task consisted of 3 blocks of 20 trials, separated by participant-timed breaks. Each trial began with the presentation of two identical doors, graphically displayed horizontally adjacent (the graphic occupied approximately 6° of the visual field vertically and 8° horizontally), centered in the screen. Participants were instructed to select the left or right door by clicking the left or right mouse button, respectively. Participants were told that they could either win \$0.50 or lose \$0.25 on each trial. These values were chosen in order to equalize the subjective value of the gains and losses (Tversky & Kahneman, 1992). The goal of the task was to guess which door hid the reward while attempting to earn as much money as possible. The image of the doors was presented until the participant made a selection. After stimulus offset, a fixation cross (+) was presented for 1000 ms, and feedback was then presented on the screen for 2000 ms. A gain was indicated by a green arrow pointing upward (↑) and a loss was indicated by a red arrow pointing downward (↓). The feedback stimulus was

followed by a fixation cross presented for 1500 ms, immediately followed by the message “Click for next round.” This prompt remained on the screen until the participant responded with a button press to initiate the next trial. All cues and feedback were presented in the center of the screen, on a black background and occupied approximately 3° of the visual field vertically and 1° horizontally. There were an equal number of gain and loss trials (30 each), such that participants had an equal likelihood of receiving gain and loss feedback throughout the task. Three practice trials were completed to ensure participants understood the instructions prior to beginning the task.

### 2.3.2. EEG recording and processing

Continuous EEG was recorded using an elastic cap with 34 electrode sites placed according to the 10/20 system. Electrooculogram (EOG) was recorded using four additional facial electrodes: two placed approximately 1 cm outside of the right and left eyes and two placed approximately 1 cm above and below the right eye. All electrodes were sintered Ag/AgCl electrodes. Data were recorded using the ActiveTwo system (BioSemi, Amsterdam, Netherlands). The EEG was digitized with a sampling rate of 1024 Hz using a low-pass fifth order sinc filter with a half-power cutoff of 204.8 Hz. A common mode sense active electrode producing a monopolar (non-differential) channel was used as recording reference.

EEG data were analyzed using BrainVision Analyzer (Brain Products, Gilching, Germany). Data were referenced offline to the average of left and right mastoids, band-pass filtered (0.1–30 Hz), and corrected for eye movement artifacts (Gratton, Coles, & Donchin, 1983). Feedback-locked epochs were extracted with a duration of 1000 ms, including a 200 ms pre-stimulus and 800 ms post-stimulus interval. The 200 ms pre-stimulus interval was used as the baseline. Epochs containing a voltage greater than 50  $\mu\text{V}$  between sample points, a voltage difference of 300  $\mu\text{V}$  within a segment, or a maximum voltage difference of less than 0.50  $\mu\text{V}$  within 100 ms intervals were automatically rejected. Additional artifacts were identified and removed based on visual inspection.

Feedback-locked ERPs were averaged separately for gains and losses, and the ERP response to gains (i.e., the RewP) and losses (i.e., the FN) were scored as the mean amplitude from 250 to 350 ms following feedback at FCz (Levinson et al., 2017; Luking, Nelson, Infantolino, Sauder, & Hajcak, 2017; Nelson et al., 2016), where the difference between gains and losses was maximal (see Fig. 1). The average number of gain ( $M = 29.92$ ,  $SD = 0.81$ ) and loss ( $M = 29.93$ ,  $SD = 0.79$ ) trials included in ERP averages were proportionate. The  $\Delta\text{RewP}$  was then quantified as the difference between gain and loss trials (i.e., gain-loss).

### 2.4. Procedure

At the beginning of the visit, the participating parent gave their written informed consent and the adolescent gave their written informed assent to participate. Next, the EEG cap was set-up and the doors task was administered in the context of a battery of other tasks, with task order counterbalanced across participants. A set of computerized questionnaires including the BFI and IPIP was administered at the end of the visit. Breaks were provided throughout the visit, and small prizes were awarded after the completion of the EEG and questionnaires, respectively. At the end of the visit participants were paid their winnings from the doors task (\$7.50) and parents were compensated for their participation.

### 2.5. Data analysis

A total of forty-two participants were excluded from analyses for either not completing the EEG recording ( $n = 31$ ), outlier  $\Delta\text{RewP}$  values ( $n = 2$ ; Hoaglin & Iglewicz, 1987; Tukey, 1977), or missing personality measures ( $n = 9$ ), leaving a final sample of 508 participants. Pearson's correlations were conducted to examine the association between the personality traits and facets. Given that an essential criterion for conducting studies of trait-like individual differences is reliability in the measures used, the current study evaluated the internal consistency of the RewP and the FN by computing split-half reliability between averages based on odd- and even-numbered trials using the Spearman-Brown Prophecy Formula (Nunnally, Bernstein, & Berge, 1967). A mixed-measures analysis of covariance (ANCOVA) was conducted with outcome (gain vs. loss) as the repeated-measures factor and age as a covariate to examine the difference between the ERP response to gains and losses (i.e., the  $\Delta\text{RewP}$ ) and their association with age. Simultaneous linear regression was employed to examine the association between adolescent personality (i.e., extraversion, neuroticism, and their interaction) in relation to the  $\Delta\text{RewP}$ . Interactions between extraversion and neuroticism were followed-up by testing simple slopes of extraversion at low ( $-1$  SD), average (mean), and high ( $+1$  SD) levels of neuroticism. All significant trait analyses were followed-up by conducting identical analyses testing simple slopes using the extraversion (positive emotionality, ascendancy, sociability, venturesomeness) and neuroticism (hostility, anxiousness and melancholia) facets. Benjamini and Hochberg (1995) correction for multiple comparisons was used to adjust  $p$  values for facet-level analyses. All analyses were conducted in IBM SPSS Statistics, Version 22.0 (Armonk, NY, USA).

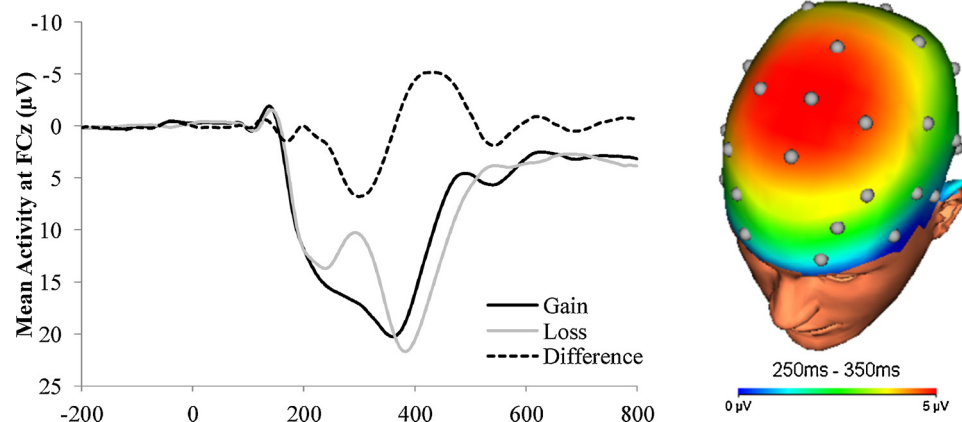


Fig. 1. ERP waveforms and 3D rendered scalp distribution of the mean activity of the  $\Delta\text{RewP}$  (i.e., gain-loss), scored as the average activity between 250 and 350 ms. ERP = event-related potential; ms = milliseconds; RewP = reward positivity.



### 3. Results

#### 3.1. Personality measures

Table 1 presents descriptive statistics and correlation coefficients for the self-report measures of extraversion, neuroticism, and their related facets. The extraversion and neuroticism facets were moderately to strongly associated with their respective broader personality dimension ( $r_s = 0.48$  to  $0.80$ ). Age was not associated with any personality dimension or facet ( $p_s > .10$ ).

#### 3.2. ERPs

The RewP ( $r = 0.91$ ), FN ( $r = 0.89$ ), and  $\Delta$ RewP ( $r = 0.49$ ) achieved moderate to excellent internal consistency as assessed using split-half reliability. Fig. 1 displays the waveforms and scalp distribution of the  $\Delta$ RewP during the doors task. As expected, the ERP response to gains and losses differed  $F(1, 506) = 407.09, p < .001, \eta_p^2 = 0.45$ , such that the electrocortical response to monetary gains (i.e. RewP;  $M = 17.34, SD = 9.43$ ) was more positive than the response to losses (i.e. FN;  $M = 12.28, SD = 8.57$ ). There was also a main effect of age,  $F(1, 506) = 5.86, p < .05, \eta_p^2 = 0.01$ , that was qualified by an Age  $\times$  Outcome interaction,  $F(1, 506) = 3.83, p = .05, \eta_p^2 = 0.01$ . Follow-up analyses indicated age was positively associated with the  $\Delta$ RewP,  $\beta = 0.09, t(507) = 1.96, p = .05$ . Furthermore, as shown in Fig. 2 the association between age and the  $\Delta$ RewP was primarily due to a positive association between age and the RewP ( $r = 0.12, p < .01$ ) but not the FN ( $r = 0.08, ns$ ).

For the personality and  $\Delta$ RewP analyses, age was included as a covariate to determine whether any associations were not better accounted for by the aforementioned relationship between age and the  $\Delta$ RewP. Extraversion and neuroticism were not independently associated with  $\Delta$ RewP magnitude ( $p_s > .35$ ). As shown in Fig. 3, there was an Extraversion  $\times$  Neuroticism interaction,  $\beta = -0.83, t(507) = -2.26, p < .05$ , such that greater extraversion was associated with an increased  $\Delta$ RewP at low levels of neuroticism,  $\beta = 0.98, t(507) = 2.14, p < .05$ , but not average,  $\beta = 0.31, t(507) = 0.92, ns$ , or high levels of neuroticism,  $\beta = -0.37, t(507) = -0.85, ns$ .<sup>1</sup> For the facet analyses, there was a Positive Emotionality  $\times$  Hostility interaction,  $\beta = -1.21, t(507) = -2.25, p < .05$ , Positive Emotionality  $\times$  Melancholia interaction,  $\beta = -1.20, t(507) = -2.38, p < .05$ , and Positive Emotionality  $\times$  Anxiousness interaction,  $\beta = -1.40, t(507) = -2.44, p < .05$ . To determine which, if any, of the neuroticism facets uniquely interacted with positive emotionality to predict the  $\Delta$ RewP we conducted a simultaneous regression with age, positive emotionality, hostility, melancholia, anxiousness, Positive Emotionality  $\times$  Hostility, Positive Emotionality  $\times$  Melancholia, and Positive Emotionality  $\times$  Anxiousness entered as independent variables. Results indicated that none of the neuroticism facets uniquely interacted with positive emotionality to predict the  $\Delta$ RewP ( $p_s > .25$ ), suggesting that the common variance of the higher order trait best accounted for these associations with positive emotionality. Indeed, there was a Positive Emotionality  $\times$  Neuroticism interaction,  $\beta = -1.31, t(507) = -2.30, p < .05$ , such that greater positive emotionality was associated with an increased  $\Delta$ RewP in the context of low,  $\beta = 2.02, t(507) = 2.81, p < .01$ , and average levels of neuroticism,  $\beta = 0.96, t$

<sup>1</sup> To examine whether the associations between extraversion and neuroticism were replicated using parental report of the participant's personality, we conducted a simultaneous linear regression to examine the association between informant reported adolescent personality (i.e., extraversion, neuroticism, and their interaction) in relation to the  $\Delta$ RewP, including participant age as a mean-centered continuous covariate. Extraversion or neuroticism, or their interaction were not associated with the  $\Delta$ RewP ( $p_s > .30$ ). Notably, correlations between self and informant report of extraversion, neuroticism and their facets was moderate ( $r_s$  range from  $0.37$ – $0.60$ ), suggesting that participants own report of their personality was more directly associated with the  $\Delta$ RewP.

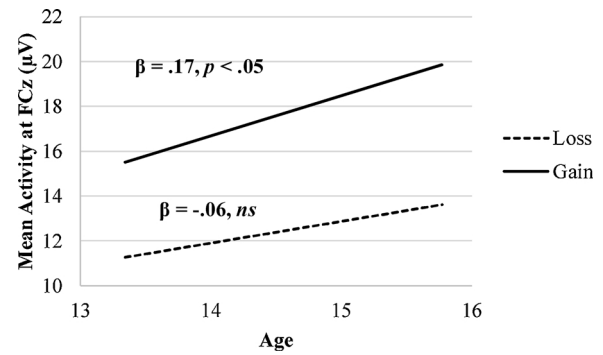


Fig. 2. Trend lines depicting the association between age the ERP response to monetary gains and losses.

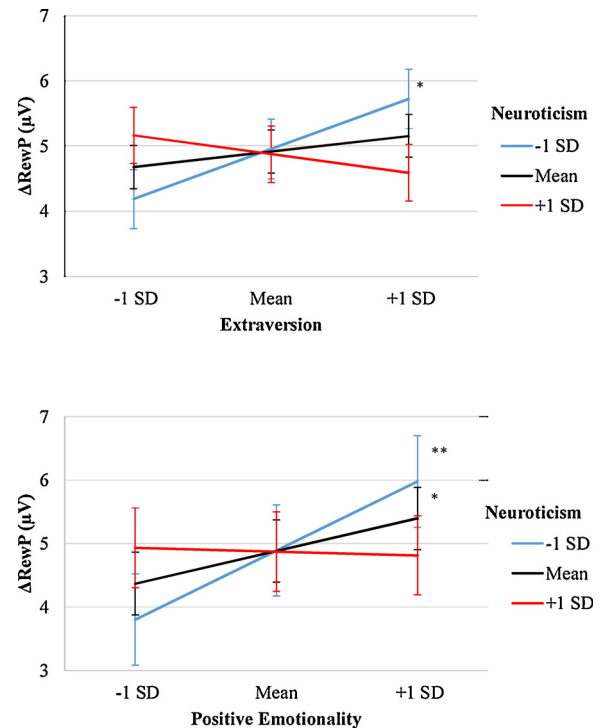


Fig. 3. Interaction between extraversion and neuroticism (top) and the facet positive emotionality and neuroticism (bottom) in relation to the  $\Delta$ RewP at FCz. Significant simple slopes are marked on the graph \*  $p < .05$ , \*\*  $p < .01$ . RewP = reward positivity; SD = standard deviation.

(507) = 1.95  $p = .05$ , but not high levels of neuroticism,  $\beta = -0.11, t(507) = -0.18, ns$  (see Fig. 3). Results also indicated a Sociability  $\times$  Anxiousness interaction,  $\beta = -1.02, t(507) = -2.43, p < .05$ , such that greater sociability was associated with an increased  $\Delta$ RewP at low levels of anxiousness,  $\beta = 1.34, t(507) = 2.40, p < .05$ , but not average,  $\beta = 0.53, t(507) = 1.32, ns$ , or high levels of anxiousness,  $\beta = -0.29, t(507) = -0.60, ns$ . When age, positive emotionality, sociability, anxiousness, Positive Emotionality  $\times$  Anxiousness, and Sociability  $\times$  Anxiousness were simultaneously entered into a regression, neither Positive Emotionality  $\times$  Anxiousness nor Sociability  $\times$  Anxiousness remained significantly associated with the  $\Delta$ RewP ( $p_s > .21$ ), suggesting that the common variance in sociability and positive emotionality interacted with anxiousness to predict the  $\Delta$ RewP.<sup>2</sup>

<sup>2</sup> To determine whether reward processing was related to the other broad personality traits in the big five inventory, partial correlations were examined between the  $\Delta$ RewP to openness, agreeableness, and conscientiousness, while controlling for age. There were no

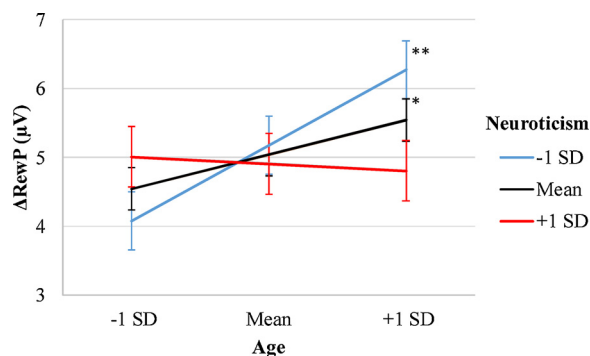


Fig. 4. Interaction between age and neuroticism in relation to the  $\Delta$ RewP at FCz. Significant simple slopes are marked on the graph \*  $p < .05$  and \*\*  $p < .01$ . RewP = reward positivity; SD = standard deviation.

Next, we examined whether the association between age and the  $\Delta$ RewP differed as a function of personality. To this end, we conducted a linear regression that examined the association between age and extraversion, neuroticism, and their interaction in relation to the  $\Delta$ RewP. Age did not interact with extraversion to predict the  $\Delta$ RewP,  $\beta = -0.34$ ,  $t(507) = -0.67$ , *ns*. As shown in Fig. 4, there was an Age  $\times$  Neuroticism interaction,  $\beta = -1.17$ ,  $t(507) = -2.44$ ,  $p < .05$ , such that older age was associated with an increased  $\Delta$ RewP at low,  $\beta = 1.74$ ,  $t(507) = 3.11$ ,  $p < .01$ , and average levels of neuroticism,  $\beta = 0.79$ ,  $t(507) = 1.99$ ,  $p < .05$ , but not high levels of neuroticism,  $\beta = -0.16$ ,  $t(507) = -0.29$ , *ns*. Follow-up analyses with neuroticism facets indicated that the interaction between age and neuroticism was not better accounted for by a specific facet ( $ps > .06$ ). In other words, greater neuroticism was associated with a disruption of the developmentally normative increase in the  $\Delta$ RewP.

#### 4. Discussion

In a large sample of adolescent girls the current study examined interactions between broad affective personality traits and the  $\Delta$ RewP, an ERP measure of reward sensitivity. Results indicated that greater extraversion was associated with an increased  $\Delta$ RewP, but only in the context of low neuroticism. The interaction between personality measures was replicated and strengthened using a specific facet-level measure of extraversion: high levels of positive emotionality was associated with an increased  $\Delta$ RewP, but only in the context of low and average levels of neuroticism. In addition, the shared variance in the positive emotionality and sociability facets of extraversion were positively associated with the  $\Delta$ RewP, but only in the context of low anxiousness. Finally, developmental analyses indicated a positive association between age and the  $\Delta$ RewP, and this relationship was modulated by neuroticism, such that increased neuroticism diminished the developmentally normative increase in the  $\Delta$ RewP.

The current study found that the largest  $\Delta$ RewP was observed in adolescent girls reporting both high extraversion and low neuroticism. The positive correlation between extraversion and the  $\Delta$ RewP, in the absence of neuroticism, is largely consistent with previous cross-sectional studies of the  $\Delta$ RewP and extraversion in adults, which suggest that extraversion is positively associated with  $\Delta$ RewP magnitude (Cooper et al., 2014; Smillie et al., 2011). Findings also overlap with a prospective study in children which found that a facet of extraversion – positive emotionality – at age 3 predicted an enhanced  $\Delta$ RewP at age 9 (Kujawa, Proudfit, Kessel et al., 2015), indicating that positive emotionality and the  $\Delta$ RewP are positively associated both cross-sectionally

(footnote continued)

significant associations between the  $\Delta$ RewP and the other big five personality traits ( $ps > .36$ ).

and prospectively. The current study adds to this literature by revealing that in adolescent girls, neuroticism moderates this association between extraversion and the  $\Delta$ RewP, suggesting that increased neuroticism attenuates the positive association between the  $\Delta$ RewP and extraversion.

Facet-level analyses revealed that associations between extraversion, neuroticism, and the  $\Delta$ RewP were driven by the positive emotionality facet of extraversion, but not by any specific facets of neuroticism. Neuroimaging studies have suggested that neuroticism is related to decreased processing of pleasant stimuli (Canli et al., 2001; Kehoe, Toomey, Balsters, & Bokde, 2012), but few studies have specifically examined associations between neural correlates of reward and neuroticism, and none have examined associations between neural correlates of reward to specific facets of this broad trait. The current study suggests that for adolescent girls, the anxiousness facet modulates the relationship between sociability and positive emotionality facets and the  $\Delta$ RewP, with lower levels of anxiousness resulting in potentiation of the  $\Delta$ RewP when sociability and positive emotionality are high.

While the current study only included never-depressed adolescent girls, the findings are consistent with personality-based models of depression, which posit that vulnerability for depression is characterized by low levels of extraversion and high levels of neuroticism (Clark, 2005; Clark, Watson, & Mineka, 1994; Watson et al., 1994). Indeed, the current study found that in adolescent girls extraversion and neuroticism interact to predict the  $\Delta$ RewP, a neural biomarker of risk for depression (Bress et al., 2013; Bress, Meyer, & Proudfit, 2015; Kujawa, Proudfit, & Klein, 2014; Kujawa, Proudfit, Laptook et al., 2015). It is possible that interactions between extraversion and neuroticism may contribute to the development of depression in adolescent girls through their association with reward system functioning, and future research should evaluate this possibility directly. These results may help to further understand the development of depression, such that low extraversion paired with high neuroticism (Kendler, Gatz, Gardner, & Pedersen, 2006), and a blunted  $\Delta$ RewP (Bress et al., 2013; Bress, Meyer, & Proudfit, 2015) are preexisting risk factors for depression, and may allow for combining measures to facilitate the identification of at-risk youth for intervention prior to depression onset (Patrick, Venables, Yancey, Hicks, Nelson, & Kramer, 2013). These findings suggest that risk for depression in adolescent girls may be broadly characterized by reduced approach motivation, indicated by low extraversion (specifically positive emotionality) and blunted  $\Delta$ RewP, and elevated neuroticism. Indeed, this conceptualization is largely consistent with motivational models of depression (Davidson, 1992; Depue & Iacono, 1989; Gray, 1994; Lang et al., 1990; Watson, Wiese, Vaidya, & Tellegen, 1999). It is also consistent with prior ERP research suggesting that low positive emotionality may be associated with reduced engagement with emotional stimuli (Speed et al., 2015), and high neuroticism may be associated with a blunted neural response to emotional stimuli (Bartussek, Becker, Diedrich, Naumann, & Maier, 1996). However past research and the current study utilized a cross-sectional design, and longitudinal investigations are required to elucidate the relationship between the  $\Delta$ RewP, extraversion, neuroticism and the subsequent development of depression across adolescence.

The current study also found age-related variability in the  $\Delta$ RewP. Specifically, age was positively correlated with the neural response to gains; associations between age and the neural response to loss did not reach statistical significance, resulting in a larger  $\Delta$ RewP in older participants. These findings are consistent with previous research demonstrating that sensitivity to reward increases during adolescence (Galvan et al., 2006; Silverman et al., 2015; Sheffield et al., 2015; Spear, 2000), peaking between 12 and 15 years of age (Van Leijenhorst et al., 2010). However, this developmental trajectory was moderated by individual differences in neuroticism. When neuroticism was elevated the positive correlation between the  $\Delta$ RewP and age was significantly reduced. Given that the reward system continues to develop across adolescence, these cross-sectional findings suggest that personality traits might

impact normative developmental processes. Indeed, there is evidence that neuroticism is positively associated with physiological stress, indexed by flattened cortisol rhythms across the waking day in adolescents (Hauner et al., 2008), and that stress in turn impacts reward system functioning (Bogdan & Pizzagalli, 2006; Zacharko, Bowers, Kokkinidis, & Anisman, 1983), suggesting one possibility for how neuroticism may impact the  $\Delta$ RewP during this sensitive period.

There are limitations to the current study that warrant discussion. The sample was limited to 13.5–15.5 year-old girls, and findings may not generalize to boys or a different age group. In addition, the current study utilized a cross-sectional design; longitudinal studies are needed to further clarify developmental changes in the  $\Delta$ RewP and associations with personality. Finally, as expected given the lack of shared method variance (Campbell & Fiske, 1959; Patrick et al., 2013), the significant effects reported in this study were relatively modest, and may not be observable in studies with smaller sample sizes. Notably, convergent evidence suggests that despite small effect sizes compared to psychosocial risk factors, neural measures such as the  $\Delta$ RewP capture unique variance in depression risk that may indicate mechanistic processes important to the development of the disorder (Proudfit, 2015; Proudfit, Bress, Foti, Kujawa, & Klein, 2015). For example, a recent study found that the  $\Delta$ RewP predicted first-onset depression in adolescent girls independent of other established risk factors, and provided incremental positive predictive value (Nelson et al., 2016), which may benefit in early identification and prevention efforts.

In sum, the current study found that high extraversion coupled with low neuroticism was associated with increased neural response to reward in a sample of adolescent girls. These findings highlight the importance of evaluating interactions between affective traits that may have opposing associations with motivational systems and depression risk. Relationships between these broad affective traits and the RewP were mostly likely driven by the more specific facets of positive emotionality, sociability and anxiousness. Furthermore, neural response to rewards increased with age, though this relationship was reduced with increased neuroticism. Future research should examine if the association between extraversion, neuroticism, and the  $\Delta$ RewP generalizes to other populations, and whether individual differences in these personality traits modulate or mediate the relationship between the  $\Delta$ RewP and depression.

## References

- Akse, J., Hale, W. W., III, Engels, R. C. M. E., Raaijmakers, Q. A. W., & Meeus, W. H. J. (2007). Stability and change in personality type membership and anxiety in adolescence. *Journal of Adolescence*, *30*, 813–834.
- American Psychiatric Association (2013). *DSM 5*. Arlington, VA: American Psychiatric Association.
- Ashton, M. C., Lee, K., & Goldberg, L. R. (2007). The IPIP–HEXACO scales: An alternative, public-domain measure of the personality constructs in the HEXACO model. *Personality and Individual Differences*, *42*(8), 1515–1526.
- Avenevoli, S., Swendsen, J., He, J. P., Burstein, M., & Merikangas, K. R. (2015). Major depression in the national comorbidity survey–adolescent supplement: Prevalence, correlates, and treatment. *Journal of the American Academy of Child & Adolescent Psychiatry*, *54*(1), 37–44.
- Bartussek, D., Becker, G., Diedrich, O., Naumann, E., & Maier, S. (1996). Extraversion, neuroticism, and event-related brain potentials in response to emotional stimuli. *Personality and Individual Differences*, *20*(3), 301–312.
- Becker, M. P., Nitsch, A. M., Miltner, W. H., & Straube, T. (2014). A single-trial estimation of the feedback-related negativity and its relation to BOLD responses in a time-estimation task. *Journal of Neuroscience*, *34*(8), 3005–3012.
- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)*, *57*, 289–300.
- Bogdan, R., & Pizzagalli, D. A. (2006). Acute stress reduces reward responsiveness: implications for depression. *Biological Psychiatry*, *60*(10), 1147–1154.
- Bress, J. N., & Hajcak, G. (2013). Self-report and behavioral measures of reward sensitivity predict the feedback negativity. *Psychophysiology*, *50*(7), 610–616.
- Bress, J. N., Smith, E., Foti, D., Klein, D. N., & Hajcak, G. (2012). Neural response to reward and depressive symptoms in late childhood to early adolescence. *Biological Psychology*, *89*(1), 156–162.
- Bress, J. N., Foti, D., Kotov, R., Klein, D. N., & Hajcak, G. (2013). Blunted neural response to rewards prospectively predicts depression in adolescent girls. *Psychophysiology*, *50*(1), 74–81.
- Bress, J. N., Meyer, A., & Hajcak, G. (2015). Differentiating anxiety and depression in children and adolescents: Evidence from event-related brain potentials. *Journal of Clinical Child & Adolescent Psychology*, *44*(2), 238–249.
- Bress, J. N., Meyer, A., & Proudfit, G. H. (2015). The stability of the feedback negativity and its relationship with depression during childhood and adolescence. *Development and Psychopathology*, *27*(4pt1), 1285–1294.
- Campbell, D. T., & Fiske, D. W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological Bulletin*, *56*(2), 81–105.
- Canli, T., Zhao, Z., Desmond, J. E., Kang, E., Gross, J., & Gabrieli, J. D. (2001). An fMRI study of personality influences on brain reactivity to emotional stimuli. *Behavioral Neuroscience*, *115*(1), 33–42.
- Canli, T., Sivers, H., Thomason, M. E., Whitfield-Gabrieli, S., Gabrieli, J. D., & Gotlib, I. H. (2004). Brain activation to emotional words in depressed vs healthy subjects. *Neuroreport*, *15*(17), 2585–2588.
- Carlson, J. M., Foti, D., Mujica-Parodi, L. R., Harmon-Jones, E., & Hajcak, G. (2011). Ventral striatal and medial prefrontal BOLD activation is correlated with reward-related electrocortical activity: A combined ERP and fMRI study. *Neuroimage*, *57*(4), 1608–1616.
- Clark, L. A., Watson, D., & Mineka, S. (1994). Temperament, personality, and the mood and anxiety disorders. *Journal of Abnormal Psychology*, *103*(1), 103–116.
- Clark, L. A. (2005). Temperament as a unifying basis for personality and psychopathology. *Journal of Abnormal Psychology*, *114*(4), 505.
- Cohen, M. X., Young, J., Baek, J. M., Kessler, C., & Ranganath, C. (2005). Individual differences in extraversion and dopamine genetics predict neural reward responses. *Cognitive Brain Research*, *25*(3), 851–861.
- Cooper, A. J., Duke, É., Pickering, A. D., & Smillie, L. D. (2014). Individual differences in reward prediction error: Contrasting relations between feedback-related negativity and trait measures of reward sensitivity, impulsivity and extraversion. *Frontiers in Human Neuroscience*, *8*, 1–11. <http://dx.doi.org/10.3389/fnhum.2014.00248>.
- Davidson, R. J. (1992). Anterior cerebral asymmetry and the nature of emotion. *Brain and Cognition*, *20*(1), 125–151.
- De Fruyt, F., Van Leeuwen, K., Bagby, R. M., Rolland, J. P., & Rouillon, F. (2006). Assessing and interpreting personality change and continuity in patients treated for major depression. *Psychological Assessment*, *18*(1), 71–80.
- Depue, R. A., & Iacono, W. G. (1989). Neurobehavioral aspects of affective disorders. *Annual Review of Psychology*, *40*(1), 457–492.
- Dunning, J. P., & Hajcak, G. (2007). Error-related negativities elicited by monetary loss and cues that predict loss. *Neuroreport*, *18*(17), 1875–1878.
- Forbes, E. E., Ryan, N. D., Phillips, M. L., Manuck, S. B., Worthman, C. M., Moyles, D. L., ... Dahl, R. E. (2010). Healthy adolescents' neural response to reward: Associations with puberty, positive affect, and depressive symptoms. *Journal of the American Academy of Child & Adolescent Psychiatry*, *49*(2), 162–172.
- Foti, D., & Hajcak, G. (2009). Depression and reduced sensitivity to non-rewards versus rewards: evidence from event-related potentials. *Biological Psychology*, *81*(1), 1–8.
- Foti, D., & Hajcak, G. (2010). State sadness reduces neural sensitivity to nonrewards versus rewards. *Neuroreport*, *21*(2), 143–147.
- Foti, D., Weinberg, A., Dien, J., & Hajcak, G. (2011). Event-related potential activity in the basal ganglia differentiates rewards from nonrewards: Temporospatial principal components analysis and source localization of the feedback negativity. *Human Brain Mapping*, *32*(12), 2207–2216.
- Foti, D., Carlson, J. M., Sauder, C. L., & Proudfit, G. H. (2014). Reward dysfunction in major depression: Multimodal neuroimaging evidence for refining the melancholic phenotype. *Neuroimage*, *101*, 50–58.
- Foti, D., Weinberg, A., Bernat, E. M., & Proudfit, G. H. (2015). Anterior cingulate activity to monetary loss and basal ganglia activity to monetary gain uniquely contribute to the feedback negativity. *Clinical Neurophysiology*, *126*(7), 1338–1347.
- Galvan, A., Hare, T. A., Parra, C. E., Penn, J., Voss, H., Glover, G., & Casey, B. J. (2006). Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. *Journal of Neuroscience*, *26*(25), 6885–6892.
- Goldberg, L. R., Johnson, J. A., Eber, H. W., Hogan, R., Ashton, M. C., Cloninger, C. R., & Gough, H. G. (2006). The international personality item pool and the future of public-domain personality measures. *Journal of Research in Personality*, *40*(1), 84–96.
- Goldberg, L. R. (1999). A broad-bandwidth, public domain, personality inventory measuring the lower-level facets of several five-factor models. *Personality Psychology in Europe*, *7*(1), 7–28.
- Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, *55*(4), 468–484.
- Gray, J. A. (1994). Framework for a taxonomy of psychiatric disorder. In S. H. M. van Goozen, N. E. Van de Poll, & J. A. Sergeant (Eds.), *Emotions: essays on emotion theory* (pp. 29–59). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Hämmerer, D., Li, S.-C., Müller, V., & Lindenberger, U. (2011). Life span differences in electrophysiological correlates of monitoring gains and losses during probabilistic reinforcement learning. *Journal of Cognitive Neuroscience*, *23*, 579–592. <http://dx.doi.org/10.1162/jocn.2010.21475>.
- Hankin, B. L., Abramson, L. Y., Moffitt, T. E., Silva, P. A., McGee, R., & Angell, K. E. (1998). Development of depression from preadolescence to young adulthood: emerging gender differences in a 10-year longitudinal study. *Journal of Abnormal Psychology*, *107*(1), 128–140.
- Hauner, K. K., Adam, E. K., Mineka, S., Doane, L. D., DeSantis, A. S., Zinbarg, R., ... Griffith, J. W. (2008). Neuroticism and introversion are associated with salivary cortisol patterns in adolescents. *Psychoneuroendocrinology*, *33*(10), 1344–1356.
- Hoaglin, D. C., & Iglewicz, B. (1987). Fine-tuning some resistant rules for outlier labeling. *Journal of the American Statistical Association*, *82*(400), 1147–1149.
- Holroyd, C. B., Pakzad-Vaezi, K. L., & Krigolson, O. E. (2008). The feedback correct-related positivity: Sensitivity of the event-related brain potential to unexpected positive feedback. *Psychophysiology*, *45*(5), 688–697.



- John, O. P., Donahue, E. M., & Kentle, R. L. (1991). *The big five inventory – Versions 4a and 54*. Berkeley, CA: University of California, Berkeley, Institute of Personality and Social Research.
- John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative big five trait taxonomy. In R. W. John (Ed.), *Handbook of personality: Theory and research* (pp. 114–158). (3rd ed.). New York, NY: Guilford Press.
- Kaufman, J., Birmaher, B., Brent, D., Rao, U. M. A., Flynn, C., Moreci, P., ... Ryan, N. (1997). Schedule for affective disorders and schizophrenia for school-age children-present and lifetime version (K-SADS-PL): Initial reliability and validity data. *Journal of the American Academy of Child & Adolescent Psychiatry*, 36(7), 980–988.
- Kehoe, E. G., Toomey, J. M., Balsters, J. H., & Bokde, A. L. (2012). Personality modulates the effects of emotional arousal and valence on brain activation. *Social Cognitive and Affective Neuroscience*, 7(7), 858–870.
- Kendler, K. S., Gatz, M., Gardner, C. O., & Pedersen, N. L. (2006). Personality and major depression: A Swedish longitudinal, population-based twin study. *Archives of General Psychiatry*, 63(10), 1113–1120.
- Kennis, M., Rademaker, A. R., & Geuze, E. (2013). Neural correlates of personality: An integrative review. *Neuroscience & Biobehavioral Reviews*, 37(1), 73–95.
- Klein, D. N., Kotov, R., & Bufferd, S. J. (2011). Personality and depression: Explanatory models and review of the evidence. *Annual Review of Clinical Psychology*, 7, 269–295.
- Klimstra, T. A., Hale, W. W., III, Raaijmakers, Q. A., Branje, S. J., & Meeus, W. H. (2009). Maturation of personality in adolescence. *Journal of Personality and Social Psychology*, 96(4), 898–912.
- Kujawa, A., Proudfit, G. H., & Klein, D. N. (2014). Neural reactivity to rewards and losses in offspring of mothers and fathers with histories of depressive and anxiety disorders. *Journal of Abnormal Psychology*, 123(2), 287.
- Kujawa, A., Proudfit, G. H., Kessel, E. M., Dyson, M., Olino, T., & Klein, D. N. (2015). Neural reactivity to monetary rewards and losses in childhood: Longitudinal and concurrent associations with observed and self-reported positive emotionality. *Biological Psychology*, 104, 41–47.
- Kujawa, A., Proudfit, G. H., Laptook, R., & Klein, D. N. (2015). Early parenting moderates the association between parental depression and neural reactivity to rewards and losses in offspring. *Clinical Psychological Science*, 3(4), 503–515.
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review*, 97(3), 377–395.
- Levinson, A. R., Speed, B. C., Infantolino, Z. P., & Hajcak, G. (2017). Reliability of the electrocortical response to gains and losses in the doors task. *Psychophysiology*, 54(4), 601–607. <http://dx.doi.org/10.1111/psyp.12813>.
- Lewinsohn, P. M., Hops, H., Roberts, R. E., Seeley, J. R., & Andrews, J. A. (1993). Adolescent psychopathology: I. Prevalence and incidence of depression and other DSM-III-R disorders in high school students: Correction. *Journal of Abnormal Psychology*, 102(4), 517. <http://dx.doi.org/10.1037/0021-843X.102.4.517>.
- Lim, B. C., & Ployhart, R. E. (2006). Assessing the convergent and discriminant validity of Goldberg's International Personality Item Pool: A multitrait-multimethod examination. *Organizational Research Methods*, 9, 29–54.
- Liu, W. H., Wang, L. Z., Shang, H. R., Shen, Y., Li, Z., Cheung, E. F., & Chan, R. C. (2014). The influence of anhedonia on feedback negativity in major depressive disorder. *Neuropsychologia*, 53, 213–220.
- Lucas, R. E., Diener, E., Grob, A., Suh, E. M., & Shao, L. (2000). Cross-cultural evidence for the fundamental features of extraversion. *Journal of Personality and Social Psychology*, 79(3), 452–468.
- Luking, K. R., Luby, J. L., & Barch, D. M. (2014). Kids, candy, brain and behavior: Age differences in responses to candy gains and losses. *Developmental Cognitive Neuroscience*, 9, 82–92.
- Luking, K. R., Pagliaccio, D., Luby, J. L., & Barch, D. M. (2016). Reward processing and risk for depression across development. *Trends in Cognitive Sciences*, 20(6), 456–468.
- Luking, K. R., Nelson, B. D., Infantolino, Z. P., Sauder, C. L., & Hajcak, G. (2017). Internal consistency of functional magnetic resonance imaging and electroencephalography measures of reward in late childhood and early adolescence. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, 2(3), 289–297.
- Marco-Pallares, J., Cucurell, D., Münte, T. F., Strien, N., & Rodriguez-Fornells, A. (2011). On the number of trials needed for a stable feedback-related negativity. *Psychophysiology*, 48(6), 852–860.
- Mitterschiffthaler, M. T., Kumari, V., Malhi, G. S., Brown, R. G., Giampietro, V. P., Brammer, M. J., ... Sharma, T. (2003). Neural response to pleasant stimuli in anhedonia: An fMRI study. *Neuroreport*, 14(2), 177–182.
- Morgan, J. K., Olino, T. M., McMakin, D. L., Ryan, N. D., & Forbes, E. E. (2013). Neural response to reward as a predictor of increases in depressive symptoms in adolescence. *Neurobiology of Disease*, 52, 66–74.
- Naragon-Gainey, K., Watson, D., & Markon, K. E. (2009). Differential relations of depression and social anxiety symptoms to the facets of extraversion/positive emotionality. *Journal of Abnormal Psychology*, 118(2), 299–310. <http://dx.doi.org/10.1037/a0015637>.
- Nelson, B. D., Perlman, G., Klein, D. N., Kotov, R., & Hajcak, G. (2016). Blunted neural response to rewards as a prospective predictor of the development of depression in adolescent girls. *American Journal of Psychiatry*, 173(12), 1223–1230.
- Nunnally, J. C., Bernstein, I. H., & Berge, J. M. T. (1967). *Psychometric theory*, Vol. 226. JSTOR.
- Olino, T. M., Klein, D. N., Durbin, C. E., Hayden, E. P., & Buckley, M. E. (2005). The structure of extraversion in preschool aged children. *Personality and Individual Differences*, 39(2), 481–492.
- Olino, T. M., McMakin, D. L., Morgan, J. K., Silk, J. S., Birmaher, B., Axelson, D. A., ... Forbes, E. E. (2014). Reduced reward anticipation in youth at high-risk for unipolar depression: A preliminary study. *Developmental Cognitive Neuroscience*, 8, 55–64.
- Ormel, J., Oldehinkel, A. J., & Vollebergh, W. (2004). Vulnerability before, during, and after a major depressive episode: A 3-wave population-based study. *Archives of General Psychiatry*, 61(10), 990–996.
- Patrick, C. J., Venables, N. C., Yancey, J. R., Hicks, B. M., Nelson, L. D., & Kramer, M. D. (2013). A construct-network approach to bridging diagnostic and physiological domains: Application to assessment of externalizing psychopathology. *Journal of Abnormal Psychology*, 122(3), 902–916.
- Petersen, A. C., Crockett, L., Richards, M., & Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of Youth and Adolescence*, 17, 117–133.
- Pizzagalli, D. A. (2014). Depression, stress, and anhedonia: Toward a synthesis and integrated model. *Annual Review of Clinical Psychology*, 10, 393–423.
- Proudfit, G. H., Bress, J. N., Foti, D., Kujawa, A., & Klein, D. N. (2015). Depression and event-related potentials: Emotional disengagement and reward insensitivity. *Current Opinion in Psychology*, 1(4), 110–113. <http://dx.doi.org/10.1016/j.copsyc.2014.12.018>.
- Proudfit, G. H. (2015). The reward positivity: From basic research on reward to a biomarker for depression. *Psychophysiology*, 52(4), 449–459.
- Pullmann, H., Raudsepp, L., & Allik, J. (2006). Stability and change in adolescents' personality: A longitudinal study. *European Journal of Personality*, 20, 447–459.
- Rammstedt, B., & John, O. P. (2007). Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German. *Journal of Research in Personality*, 41, 203–212.
- Roberts, B. W., & DelVecchio, W. F. (2000). The rank-order consistency of personality traits from childhood to old age: A quantitative review of longitudinal studies. *Psychological Bulletin*, 126(1), 3–25.
- Roberts, B. W., Walton, K. E., & Viechtbauer, W. (2006). Patterns of mean-level change in personality traits across the life course: A meta-analysis of longitudinal studies. *Psychological Bulletin*, 132(1), 1–25.
- Rothbart, M. K., & Bates, J. E. (1998). Temperament. In (5th ed.). W. Damon, & N. Eisenberg (Vol. Eds.), *Handbook of child psychology: Vol. 3. Social, emotional, and personality development: Vol. 3*, (pp. 105–176). New York: Wiley.
- Segalowitz, S. J., Santesso, D. L., Murphy, T. I., Homan, D., Chantziantoniou, D. K., & Khan, S. (2010). Retest reliability of medial frontal negativities during performance monitoring. *Psychophysiology*, 47(2), 260–270.
- Shankman, S. A., & Klein, D. N. (2003). The relation between depression and anxiety: An evaluation of the tripartite, approach-withdrawal and valence-arousal models. *Clinical Psychology Review*, 23(4), 605–637.
- Sheffield, J. G., Crowley, M. J., Bel-Bahar, T., Desatnik, A., Nolte, T., Fonagy, P., & Fearon, R. P. (2015). Reward-related neural activity and adolescent antisocial behavior in a community sample. *Developmental Neuropsychology*, 40(6), 363–378.
- Shiner, R., & Caspi, A. (2003). Personality differences in childhood and adolescence: measurement, development, and consequences. *Journal of Child Psychology and Psychiatry*, 44(1), 2–32.
- Silverman, M. H., Jedd, K., & Luciana, M. (2015). Neural networks involved in adolescent reward processing: An activation likelihood estimation meta-analysis of functional neuroimaging studies. *Neuroimage*, 122, 427–439.
- Simms, E. E. (2009). *Assessment of the facets of the five factor model: Further development and validation of a new personality measure*. The University of Iowa Retrieved from <http://gradworks.umi.com/33/83/3383172.html>.
- Simon, J. J., Walther, S., Fiebach, C. J., Friederich, H. C., Stippich, C., Weisbrod, M., & Kaiser, S. (2010). Neural reward processing is modulated by approach-and avoidance-related personality traits. *Neuroimage*, 49(2), 1868–1874.
- Smillie, L. D., Cooper, A. J., & Pickering, A. D. (2011). Individual differences in reward-prediction-error: Extraversion and feedback-related negativity. *Social Cognitive and Affective Neuroscience*, 6(5), 646–652.
- Spear, L. P. (2000). The adolescent brain and age-related behavioral manifestations. *Neuroscience and Biobehavioral Reviews*, 24, 417–463.
- Spear, L. P. (2011). Rewards, aversions and affect in adolescence: Emerging convergences across laboratory animal and human data. *Developmental Cognitive Neuroscience*, 1(4), 390–403.
- Speed, B. C., Nelson, B. D., Perlman, G., Klein, D. N., Kotov, R., & Hajcak, G. (2015). Personality and emotional processing: A relationship between extraversion and the late positive potential in adolescence. *Psychophysiology*, 52(8), 1039–1047.
- Tukey, J. W. (1977). *Exploratory data analysis*. Reading, MA: Addison-Wesley.
- Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, 5(4), 297–323.
- Van Leijenhorst, L., Zanolie, K., Van Meel, C. S., Westenberg, P. M., Rombouts, S. A., & Crone, E. A. (2010). What motivates the adolescent? Brain regions mediating reward sensitivity across adolescence. *Cerebral Cortex*, 20(1), 61–69.
- Watson, D., Clark, L. A., & Harkness, A. R. (1994). Structures of personality and their relevance to psychopathology. *Journal of Abnormal Psychology*, 103(1), 18–31.
- Watson, D., Wiese, D., Vaidya, J., & Tellegen, A. (1999). The two general activation systems of affect: Structural findings, evolutionary considerations, and psychobiological evidence. *Journal of Personality and Social Psychology*, 76(5), 820–838.
- Zacharko, R. M., Bowers, W. J., Kokkinidis, L., & Anisman, H. (1983). Region-specific reductions of intracranial self-stimulation after uncontrollable stress: Possible effects on reward processes. *Behavioural Brain Research*, 9(2), 129–141.