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Neural reactivity to monetary rewards and losses in childhood: Longitudinal and concurrent associations with observed and self-reported positive emotionality☆

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ABSTRACT

Reward reactivity and positive emotion are key components of a theoretical, early-emerging approach motivational system, yet few studies have examined associations between positive emotion and neural reactivity to reward across development. In this multi-method prospective study, we examined the association of laboratory observations of positive emotionality (PE) at age 3 and self-reported positive affect (PA) at age 9 with an event-related potential component sensitive to the relative response to winning vs. losing money, the feedback negativity (ΔFN), at age 9 (N = 381). Males had a larger ΔFN than females, and both greater observed PE at age 3 and self-reported PA at age 9 significantly, but modestly, predicted an enhanced ΔFN at age 9. Negative emotionality and behavioral inhibition did not predict ΔFN. Results contribute to understanding the neural correlates of PE and suggest that the FN and PE may be related to the same biobehavioral approach system.

1. Introduction

A number of theorists conceptualize personality and psychopathology in terms of independent biobehavioral motivational systems (Davidson, 1992; Depue & Iacono, 1989; Gray, 1994; Lang, Bradley, & Cuthbert, 1990). Each of these models include an approach system that is hypothesized to regulate reward processing (Dillon et al., 2013) and generate positive emotions, such as exuberance and joy, which are presumed to facilitate and reinforce appetitive behavior and engagement with rewarding stimuli (Depue & Collins, 1999; Polak-Toste & Gunnar, 2006; Smillie, 2013; Watson, Wiese, Vaidya, & Tellegen, 1999; Wilt & Revelle, 2009). Consistent with this, there is evidence that reward sensitivity and positive emotionality load on the same latent factor in children and adults (Lucas, Diener, Grob, Suh, & Shao, 2000; Olino, Klein, Durbin, Hayden, & Buckley, 2005). Most theorists assume that the approach system is fundamental to human functioning and survival, and emerges early in development. In addition, individual differences in the strength of this system are thought to contribute to stable variations in reward sensitivity and dispositional positive affect (PA; also referred to as positive emotionality, extraversion, and surgency; Putnam, 2012).

The approach system is typically contrasted with the withdrawal (Davidson, 1992) or behavioral inhibition (Gray, 1994) system. This system is characterized by sensitivity to signals of threat and punishment, and dispositional negative emotionality (NE) and behavioral inhibition (BI; Fox, Henderson, Marshall, Nichols, & Ghera, 2005; Kennis, Rademaker, & Geuze, 2013; Watson et al., 1999). While NE and BI are correlated temperament traits, NE refers to the tendency to experience a broad range of negative emotions (Clark & Watson, 1999), whereas BI refers specifically to the tendency to be fearful and hesitant in novel situations (Kagan, 1984).

Despite the rich theoretical literature on the approach system, empirical studies examining links between the neural processes

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associated with reward sensitivity and temperamental positive emotionality (PE) are surprisingly limited (Kennis et al., 2013; Wilt & Revelle, 2009). Much of the existing work has examined resting electroencephalogram (EEG) activity, with adult studies linking greater self-reported approach system sensitivity to greater left prefrontal activation (Sutton & Davidson, 1997; Tomarken, Davidson, Wheeler, & Doss, 1992). More recently, functional magnetic resonance imaging (fMRI) studies of adults and adolescents have suggested that self-reported approach system sensitivity and extraversion are associated with enhanced activation of the ventral striatum and medial orbitofrontal cortex in response to rewards (Cohen, Young, Baek, Kessler, & Ranganath, 2005; Forbes et al., 2010; Kennis et al., 2013; Simon et al., 2010). Given that individual differences in the approach system are presumed to emerge early in life, it is important to evaluate associations across development. However, the literature on reward reactivity and PE has typically focused on older adolescents and adults and used cross-sectional designs.

On the other hand, a number of studies have examined relationships between BI in early childhood and subsequent individual differences in neural reactivity to both threat and reward-related stimuli. For example, individuals classified as high BI in early childhood show greater right frontal EEG asymmetry, hypothesized to be a marker of withdrawal system reactivity (Fox et al., 2005), as well as enhanced electrocortical measures of error monitoring (McDermott et al., 2009). In addition, early BI has been related to greater striatal activation in response to cues indicating potential for reward and loss (Bar-Haim et al., 2009; Guyer et al., 2006) and in response to negative feedback (Helfinstein et al., 2011). These studies raise the question of whether the link between reward reactivity and temperamental emotionality is specific to approach system-related affective styles (e.g., PE).

The feedback negativity (FN) is an event-related potential (ERP) component characterized by a *relative* negativity in response to monetary losses compared to rewards that peaks approximately 250–300 ms over frontocentral recording sites that has been linked to activation in the ventral striatum and medial prefrontal cortex (Carlson, Foti, Mujica-Parodi, Harmon-Jones, & Hajcak, 2011; Foti, Weinberg, Dien, & Hajcak, 2011; Gehring & Willoughby, 2002; Hajcak, Moser, Holroyd, & Simons, 2006). Though the FN has previously been conceptualized as an enhanced negativity following losses, there is evidence to suggest that it may be better characterized as a relative positivity in response to rewards that is reduced or absent following losses (Foti, Weinberg et al., 2011; Holroyd, Pakzad-Vaezi, & Krigolson, 2008). The FN is often analyzed as the loss minus gain difference score (ΔFN) in order to isolate variation in the waveform attributed to processing of outcome valence (Dunning & Hajcak, 2007; Foti, Kotov, Klein, & Hajcak, 2011; Luck, 2005), and ΔFN has previously been related to neural reward circuitry using fMRI and to behavioral and self-report measures of reward sensitivity (Bress & Hajcak, 2013; Carlson et al., 2011).

The FN may be an economical and valid measure of reward system reactivity that can be applied across development. Cross-sectional research in adults has linked an enhanced FN to greater extraversion (Smillie, Cooper, & Pickering, 2011); however, it remains unclear whether approach-related temperament systems such as PE, measured in early childhood, relate to the FN later in development. Also, research is needed to evaluate the extent to which associations between the FN in monetary reward tasks are specific to PE, rather than temperament styles linked to the withdrawal system. Recently, several adult studies have examined associations between the FN and self-reported withdrawal/behavioral inhibition system temperament constructs in adults with mixed findings. Santesso and colleagues (2012) found that greater NE predicted an enhanced FN to negative performance feedback in a monetary incentive task. On the other hand, Lange, Leue, and Beauducel (2012) found that adults high in behavioral approach system sensitivity exhibited an enhanced FN when reward feedback changed to non-reward feedback, while people higher in behavioral inhibition system sensitivity showed a reduced FN.

The primary goal of the current study was to evaluate prospective associations between the FN and PE from early to late childhood. We used laboratory observations to assess temperament in a large sample of three-year-old children. Approximately six years later, children completed a monetary reward task while ERPs were recorded, and a self-report measure of temperament. We hypothesized that greater early PE would be associated with an enhanced FN. Demonstrating this effect across a six-year period spanning early to late childhood, a period of immense neural and socioemotional change (Giedd & Rapoport, 2010; Monk, 2008), provides a particularly stringent test of the relationship between PE and the FN. A secondary aim of the study was to evaluate whether self-reported PA concurrently related to the FN, and if so, whether the association between early PE and the FN remained significant when accounting for concurrent self-reported PA. Given the low correlations between laboratory and questionnaire measures of child temperament (Hayden, Klein, & Durbin, 2005; Mangelsdorf, Schoppe, & Buur, 2000), obtaining converging results across both measurement methods would provide greater support for a link between PE and the FN. Finally, a third aim was to explore the specificity of the PE-FN association by examining whether observed NE and BI at age 3 and self-reported NE at age 9 predicted the FN.

2. Method

2.1. Participants

Participants were part of a larger community sample ($N = 559$) recruited through a commercial mailing list for a prospective study of early temperamental emotionality and risk for internalizing disorders (Olino, Klein, Dyson, Rose, & Durbin, 2010). Three-year-old children with no significant medical conditions or developmental disabilities and living with at least one English-speaking biological parent were eligible to participate. A subset of 428 children participated in the second assessment approximately six years later. The children who completed the EEG did not significantly differ from the rest of the sample with regard to early PE, NE, or BI. Data from 1 participant was lost due to a technical error, and data from 43 participants were excluded due to poor EEG quality and from 3 participants due to temperament data points that were significant outliers according to Grubbs Test (Grubbs, 1969, $p < .05$). The final sample included 381 children (45.1% female). With regard to ethnicity, 7.6% of the sample was of Hispanic or Latino background. The sample was 94.8% Caucasian, 2.9% African American, and 2.4% Asian. The mean age was 3.55 years ($SD = .26$) at the first assessment and 9.20 years ($SD = .40$) at the second assessment.

2.2. Procedure

Both phases of the study were approved by the Stony Brook University Institutional Review Board. Parents provided written informed consent prior to the start of each assessment. When the children were approximately three years old, families visited the laboratory for the temperament assessment described below. Families were invited back to the lab as close as possible to the child's ninth birthday for a battery that included questionnaires and the reward task. During the second visit, EEG sensors were attached and children were told that they could win up to $5 in a guessing task. Children were instructed to press the left or right mouse button to select a door and completed five practice trials prior to beginning the reward task described below. Children also completed a questionnaire assessing trait positive and negative affect (described below).

2.3. Measures

2.3.1. Observational temperament assessment

At age three, each child and a parent visited the laboratory for an observational assessment of temperament. The assessment included a standardized set of 12 episodes: 11 episodes were from the Laboratory Temperament Assessment Battery (Lab-TAB; Goldsmith, Reilly, Lemery, Longley, & Prescott, 1995) and one was adapted from a Lab-TAB episode. A previous study found moderate stability of laboratory ratings of temperament from ages 3 to 7 and moderate concurrent and longitudinal associations between Lab-TAB ratings and home observations (Durbin, Hayden, Klein, & Olino, 2007). Tasks were videotaped and later coded. No episodes