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A longitudinal examination of event-related potentials sensitive to monetary reward and loss feedback from late childhood to middle adolescence

Autumn Kujawa[a,*], Ashley Carroll[a], Emma Mumper[b], Dahlia Mukherjee[a], Ellen M. Kessel[b], Thomas Olino[c], Greg Hajcak[d], Daniel N. Klein[b]

[a] Penn State College of Medicine, 22 Northeast Drive, Hershey, PA 17033, USA
[b] Stony Brook University, Stony Brook, NY 11794-2500, USA
[c] Temple University, 1701 North 13th Street, Philadelphia, PA 19122, USA
[d] Florida State University, 1107 West Call Street, Tallahassee, FL 32306-4301, USA

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ABSTRACT

Brain regions involved in reward processing undergo developmental changes from childhood to adolescence, and alterations in reward-related brain function are thought to contribute to the development of psychopathology. Event-related potentials (ERPs), such as the reward positivity (RewP) component, are valid measures of reward responsiveness that are easily assessed across development and provide insight into temporal dynamics of reward processing. Little work has systematically examined developmental changes in ERPs sensitive to reward. In this longitudinal study of 75 youth assessed 3 times across 6 years, we used principal components analyses (PCA) to differentiate ERPs sensitive to monetary reward and loss feedback in late childhood, early adolescence, and middle adolescence. We then tested reliability of, and developmental changes in, ERPs. A greater number of ERP components differentiated reward and loss feedback in late childhood compared to adolescence, but components in childhood accounted for only a small proportion of variance. A component consistent with RewP was the only one to consistently emerge at each of the 3 assessments. RewP demonstrated acceptable reliability, particularly from early to middle adolescence, though reliability estimates varied depending on scoring approach and developmental period. The magnitude of the RewP component did not significantly change across time. Results provide insight into developmental changes in the structure of ERPs sensitive to reward, and indicate that RewP is a consistently observed and relatively stable measure of reward responsiveness, particularly across adolescence.

1. Introduction

Processing of reward and loss feedback is essential to learning and shaping behaviors, and alterations in reward responsiveness likely play a role in the development of both internalizing and externalizing disorders (Zisner and Beauchaine, 2016). As such, there has been growing interest in the measurement of individual differences in reward responsiveness across levels of analysis (National Institute of Mental Health, 2017), including behavioral (Pizzagalli et al., 2005), circuit (Liu et al., 2011), and neurophysiological measures, such as event-related potentials (ERPs; Proudfit, 2015).

Brain circuits underlying reward processing undergo considerable development from childhood into adolescence, with evidence of differential patterns of maturation of subcortical regions, such as the striatum, and regions of the prefrontal cortex (PFC) involved in cognitive control. That is, compared to both children and adults, adolescents show heightened activation of the striatum during receipt of reward (Casey et al., 2008; Galvan, 2010; Shulman et al., 2016). On the other hand, top-down cognitive control regions, such as lateral PFC, are thought to continue to mature into adulthood and increase in activation from adolescence to adulthood (Casey et al., 2008; Galvan, 2010; Shulman et al., 2016).

To complement circuit measures of reward responsiveness, neurophysiological measures, such as ERPs, are economically and easily assessed across development and provide insight into the temporal dynamics of reward processing (Nelson and McCleery, 2008). In particular, an ERP component known as the reward positivity (RewP) or feedback negativity, is a relative positivity following receipt of a reward or positive feedback approximately 300 ms after feedback over frontocentral sites in youth and adults (Foti et al., 2011; Gehring and Willoughby, 2002). RewP appears to be a valid measure of individual differences in reward responsiveness. It has been shown to correlate

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[*] Corresponding author at: Department of Psychiatry, Penn State College of Medicine, 22 Northeast Drive, Hershey, PA 17033, USA.
E-mail address: autumn.kujawa@gmail.com (A. Kujawa).

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with activation in subcortical and cortical brain regions involved in reward processing, including ventral striatum, anterior cingulate cortex, and medial PFC (Becker et al., 2014; Carlson et al., 2011), as well as self-report and behavioral measures of reward sensitivity and positive emotionality (Bress and Hajcak, 2013; Kujawa et al., 2015). Moreover, altered reward responsiveness, as measured by RewP, appears to play a role in the emergence of psychopathology, particularly depression, in children and adolescents (e.g., Belden et al., 2016; Bress et al., 2013; Kujawa and Burkhouse, 2017; Nelson et al., 2016). Yet, the extent to which developmental changes in circuits underlying reward processing are reflected in the development of RewP or other ERP components sensitive to reward and loss feedback remains relatively unexplored.

In addition to validity, reliable measures of reward responsiveness are essential for examining developmental changes, correspondence across levels of analysis, and assocations with the emergence of psychiatric symptoms. In general, ERP amplitudes tend to be stable across time (Cassidy et al., 2012), with evidence that ERPs measured in children show comparable reliability to ERPs in adults (Hämmerer et al., 2013). Moreover, there is growing evidence that RewP is a reliable measure of reward responsiveness that shows good internal consistency and test-retest reliability (Bress et al., 2015; Levinson et al., 2017; Luking et al., 2017; Segalowitz et al., 2010). Specifically, in young adults assessed across one week, strong test-retest reliability was observed for RewP to losses and gains separately ($rs = 0.45$ and 0.71), with lower reliability for difference score measures ($rs = 0.22$ and 0.27; Levinson et al., 2017). One longitudinal study of 8- to 13-year-olds also found strong reliability for RewP to monetary losses and gains assessed across two years ($rs = 0.64$ and 0.67), but lower reliability of RewP as a difference score ($rs = 0.18$ to 0.29; Bress et al., 2015). Given the broad age range of this sample, the authors were unable to evaluate test-retest reliability across specific developmental periods (e.g., childhood into early adolescence), which may be particulary important for evaluating the utility of ERPs for examining the emergence of psychopathology.

Although there is evidence to indicate ERP measures of reward responsiveness demonstrate strong psychometric properties and are useful for informing understanding of the role of altered reward processing in the development of psychopathology, a number of gaps in the literature remain. First, within-subject, longitudinal work has yet to systematically evaluate typical developmental changes in ERP measures of reward responsiveness, including the timing and scalp distributions of these components at discrete developmental periods and both rank-order and mean-level stability. Second, although there is some evidence that RewP is reliably measured across development, it is unclear how reliability may be affected by specific developmental stages or whether test-retest reliability of RewP is maintained for developmental periods longer than 2 years. To further inform understanding of ERP measures of reward responsiveness and optimal methods across development, we first used principal components analyses (PCA; Dien, 2012) to systematically differentiate timing and spatial distributions of neural activity in response to monetary reward and loss feedback in a longitudinal sample of youth assessed at 3 time points, spanning a period of 6 years (i.e., late childhood, early adolescence, and middle adolescence). This approach enabled us to identify the underlying components of reward-related ERPs at each assessment and examine qualitative developmental changes. Next, for reward-related components emerging across development, we evaluated rank-order and mean-level stability and tested typical developmental changes in the magnitude of ERP responses to rewards and losses.

2. Materials and methods

2.1. Participants

Participants were part of a larger community sample of children initially recruited when the children were 3 or 6 years old (see Kujawa et al., 2014; Olino et al., 2010). Participants were invited back to the laboratory for electroencephalogram (EEG) assessments approximately every 3 years following the initial assessment. The current study included data from a subset of 75 participants who completed the monetary reward task at 3 time points between late childhood and middle adolescence. Data were available for 90 participants who completed the most recent assessment in middle adolescence. Of these, 5 participants were missing data from one of the previous assessments and 10 participants were excluded for excessive noise in the EEG data at 1 or more assessments, yielding the total sample of 75. Mean age of the sample was 9.40 ($SD = 0.43$) at the late childhood assessment, 13.05 ($SD = 0.24$) at the early adolescence assessment, and 15.16 ($SD = 0.16$) at the middle adolescence assessment. The sample was 44.0% female, 8.0% Hispanic/Latino, 97.3% Caucasian, 1.3% African American, and 1.3% Asian American. This study was approved by the Stony Brook University Institutional Review Board. Parents of participants provided informed consent and children provided assent.

2.2. Measures

2.2.1. Reward task

The EEG reward task has been used in previous studies to elicit the RewP (Bress and Hajcak, 2013; Bress et al., 2015; Kujawa et al., 2014). Participants were told they could win up to $5 and completed practice trials before beginning the task. The task consisted of 60 trials, presented in three blocks of 20 trials. At the beginning of each trial, participants were presented with an image of two doors and instructed to choose one door by clicking the left or right mouse button. The doors remained on the screen until the participant responded. Next, a fixation mark (+) appeared for 1000 ms, and feedback was presented on the screen for 2000 ms. Participants were told that they could either win $0.50 or lose $0.25 on each trial. A gain was indicated by a green "↑," and a loss was indicated by a red "↓." Finally, a fixation mark appeared again and was followed by the message "Click for the next round", which remained on the screen until the participant responded and the next trial began. Across the task, 30 gain and 30 loss trials were presented in a random order. Participants received $5 following completion of the task.

2.2.2. EEG data collection and processing

Continuous EEG was recorded at each assessment using a 34-electrode cap (32 channels with the addition of FCz and Iz) and a BioSemi system (BioSemi, Amsterdam, Netherlands). The electrooculogram (EOG) generated from eye movements and blinks was recorded using facial electrodes placed approximately 1 cm above and below the eye and 1 cm from the outer corners of the eyes. Electrodes were also placed on the left and right mastoids. Per the design of the BioSemi system, the common mode sense active electrode and driven right leg passive electrode served as the reference and ground electrodes during data acquisition. Recordings were digitized with a sampling rate of 1024 Hz.

Offline processing was conducted using BrainVision Analyzer software (Brain Products, Munich, Germany). Data were referenced to an average of the recordings from left and right mastoids, band-pass filtered with cutoffs of 0.01 and 30 Hz, and segmented for each trial 500 ms before feedback, continuing for 1000 ms after feedback onset. In cases of faulty recordings from a specific electrode, data were interpolated from surrounding electrodes. Eye-blink correction (Gratton et al., 1983) and semi-automatic artifact rejection procedures were conducted. Criteria of a voltage step of 50 μV between sample points, a maximum voltage difference of 300 μV within a 200 ms interval, and minimum activity of 0.5 μV within 100 ms intervals were used to automatically detect artifacts, with additional artifacts removed by visual inspection. All participants had a minimum of 15 segments per condition at Cz after artifact rejection, and the mean number of included segments per condition was 28.08 ($SD = 2.61$). ERPs were averaged for reward and loss feedback, and baseline corrected to activity 500 ms