Biological Psychology 89 (2012) 416–425

Contents lists available at SciVerse ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Behavioral approach and reward processing: Results on feedback-related negativity and P3 component

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ARTICLE INFO

Article history:
Received 25 February 2011
Accepted 2 December 2011
Available online 15 December 2011

Keywords:
ERP
Feedback-related negativity
P3
Reinforcement
Reward sensitivity
Reward expectation mismatch
Behavioral approach system
Behavioral inhibition system

ABSTRACT

This study examined the FRN, the P3, and individual differences in trait-BAS and trait-BIS in the context of reward expectation mismatch. A more negative FRN was predicted for higher vs. lower trait-BAS individuals and for higher vs. lower trait-BIS individuals. In the extinction-learning task, participants ($N = 102$) chose between two response buttons to earn a maximum of points. In the acquisition phase, button 1 was continuously rewarded and button 2 was partially rewarded. In the extinction phase, one button was unexpectedly no longer rewarded. The FRN amplitude was more negative for higher vs. lower trait-BAS individuals and for lower vs. higher trait-BIS individuals within the extinction phase. The P3 was more positive in the extinction compared to the acquisition phase. Our results suggest that higher trait-BAS individuals have a more pronounced reward expectation mismatch.

1. Introduction

Individuals often require feedback from the environment to determine the success of their actions. In purpose of optimizing the probability and amount of rewards, individuals evaluate outcomes of their actions and use these evaluations to guide decision-making. A main question in psychophysiological research is how neurobiological processes are linked to feedback-related decision-making and personality (Balconi and Crivelli, 2010; DePascalis et al., 2010). In cognitive neuroscience, researchers identified a feedback-locked event-related potential (ERP) – the feedback-related negativity (FRN) – that is sensitive to the valence of feedback (gain vs. loss) and to the amount of reward (small vs. large; e.g., Cohen et al., 2007; Gehring and Willoughby, 2002; Potts et al., 2011). There is growing evidence that personality dimensions like impulsivity, reward sensitivity, and extraversion modulate the magnitude of the FRN in gambling and choice tasks (e.g., Balconi and Crivelli, 2010; DePascalis et al., 2010; Kamarajan et al., 2009; Onado et al., 2010; Smillie et al., 2010).

Another ERP that has been investigated in reward-related processes is the feedback-locked P3 (e.g., Bellebaum and Daum, 2008; Bellebaum et al., 2010; Hajcak et al., 2005, 2007; Holroyd et al., 2003; Sato et al., 2005; Yeung and Sanfey, 2004). Moreover, recent studies reported that the magnitude of the P3 in the context of reward processing is also affected by personality dimensions like reward sensitivity and punishment sensitivity (e.g., DePascalis et al., 2010; Balconi and Crivelli, 2010). Referring to the revised reinforcement sensitivity theory (rRST; Corr, 2001, 2002, 2008; Gray and McNaughton, 2000) that allows for predictions on trait-BAS, trait-BIS, and reward expectation mismatch, the present study aimed at investigating individual differences of reward expectation mismatch by means of behavioral and feedback-locked ERP data.

1.1. Feedback-locked ERPs and reward expectation

The FRN is a negative deflection occurring between 200 and 300 ms at frontocentral sites. This frontocentral appearance of the FRN has been related to the activity of the medial and frontal cortex (Gehring and Willoughby, 2002; Miltner et al., 1997). According to the reinforcement learning theory (Holroyd and Coles, 2002), the anterior cingulate cortex (ACC) represents a monitoring system that receives an error signal from the mesencephalic dopamine system via the basal ganglia (Schultz, 1999, 2001) when a reward prediction error occurs. The monitoring system uses this error signal to optimize the acquisition of new action-outcome relations (Bellebaum and Daum, 2008). It is involved in a fast and coarse evaluation of ongoing events leading to a simple distinction between

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doi:10.1016/j.biopsycho.2011.12.004

good vs. bad outcome or between better vs. worse than expected outcome (Hajcak et al., 2006; Holroyd et al., 2004, 2006; Sato et al., 2005; Yeung and Sanfey, 2004). In line with this prediction, more negative FRN amplitudes were observed in response to negative compared to positive outcome (Gehring and Willoughby, 2002; Holroyd et al., 2003, 2004; Miltner et al., 1997; Nieuwenhuis et al., 2004; van Meel and van Heijningen, 2010; Yasuda et al., 2004).

Moreover, the feedback-locked P3 has been investigated in reward-related processes showing a more positive amplitude following a larger magnitude of win or loss feedback (Johnston, 1979; Sato et al., 2005; Sutton et al., 1978; Yeung and Sanfey, 2004; Yeung et al., 2004, 2005). Hajcak et al. (2005, 2007) as well as Bellebaum and Daum (2008) reported larger P3 amplitudes exclusively following positive feedback, whereas Frank et al. (2005) found a larger P3 amplitude exclusively for negative feedback. Moreover, Holroyd et al. (2003, 2004) reported more pronounced P3 amplitudes when reward was unexpected or larger than expected. Conclusively, the expectation of win and loss feedback appears to modulate the P3 amplitude and therefore the P3 was of interest in addition to the FRN.

1.2. Individual differences of reward expectation

A biologically oriented personality theory that predicts individual differences of reward sensitivity is the rRST (Corr, 2002, 2008; Gray and McNaughton, 2000). The rRST comprises three neural systems that underlie motivated behavior: the Behavioral Approach System (BAS) that is linked to trait-impulsivity, the Behavioral Inhibition System (BIS) that is related to trait-anxiety, and the Fight/Flight/Freezing System (FFFS) that is related to fear (Corr, 2008; Gray and McNaughton, 2000).

The BAS is activated by signals of reward, non-punishment, and relief from punishment. Corr (2002) emphasized that the BAS system is also activated by frustrative non-reward. Mainly, higher trait-BAS (also named as reward sensitivity) individuals are thought to be more reactive to and more strongly motivated by positive incentive stimuli, such that they are disposed toward approaching situations likely to bring reward. The BIS has been defined as a conflict detection and resolution device and mediates behavior that is executed by the FFFS and the BAS (Corr, 2004; McNaughton, 2006). The BIS is activated when concurrent goal conflicts come up and when a mismatch between predicted and actual outcome occurs. In those cases, the motor program will be stopped and the BIS sends signals to enhance attention and arousal in order to receive more information. A high BIS activation is associated with enhanced attention, arousal, trait-anxiety (also named as trait-BIS), and negative affect (Corr, 2008). Beyond a larger number of studies that investigated predictions of rRST by means of behavioral parameters (see Leue and Beauducel, 2008), the predictions of rRST have also been successfully investigated in ERP studies in the last years (e.g., Amodio et al., 2008; Balconi and Crivelli, 2010; DePascalis et al., 2010; Leue et al., 2009).

As mentioned above, the BAS system is sensitive to reward and, hence, the BAS system influences expectations determined by the reward comparator (Corr, 2002). In this respect, Corr (2002, p. 1250) pointed out that: “the match/mismatch of expected and actual reward should determine the direction and strength of BAS-sensitivity (...) under rewarding conditions”. With regard to individual differences of the BAS mechanism, the BAS has been associated with trait-impulsivity (Corr, 2002; Gable et al., 2000; Gray and McNaughton, 2000) because Gray (1973) introduced trait-BAS as a form of impulsivity. Accordingly, in the past trait-impulsivity measures have been often used to investigate individual differences of trait-BAS (Corr, 2001; Leue and Beauducel, 2008). However, trait-BAS is distinct from other conceptualizations of trait-impulsivity in a critical aspect. Whereas some perspectives of impulsivity emphasize on failures to consider the outcomes of one’s actions (e.g., Patton et al., 1995), the rRST predicts that reward sensitive individuals direct their behavior toward certain outcomes, namely, rewarding or positive stimuli (Smillie and Jackson, 2006). Accordingly, in a reward expectation mismatch situation, higher trait-BAS individuals compared to lower trait-BAS individuals might be more sensitive to frustrative non-reward and therefore higher trait-BAS individuals might have a more pronounced reward expectation mismatch.

Hajcak et al. (2007) reported that the FRN amplitude varied depending on the magnitude of an individuals’ reward expectation. The FRN amplitude was more negative when the outcome was less rewarding than expected (see Bellebaum and Daum, 2008; Bellebaum et al., 2010). This result points to the relevance of individual differences in reward expectation for the modulation of the FRN amplitude as an indicator of reward outcome evaluation. In this line, Smillie et al. (2010) reported the most negative FRN following an unexpected non-reward in extraverts. Because extraversion and trait-BAS are positively correlated trait dimensions (e.g., Heym et al., 2008), the finding of Smillie et al. (2010) supports the prediction of an association of trait-BAS and FRN amplitude. Moreover, Onado et al. (2010) found a significant negative correlation between FRN amplitude and Barratt’s nonplanning impulsivity scale. According to the available evidence, we therefore predict more negative FRN amplitudes under a condition of unexpected non-reward for higher trait-BAS individuals when compared to lower trait-BAS individuals.

Presuming that reward expectation mismatch also serves to activate the comparator function of the BIS (McNaughton and Corr, 2004), higher compared to lower trait-BIS individuals should display a more negative FRN amplitude following loss signals or unexpected non-reward. In this line, DePascalis et al. (2010) reported that high relative to low trait-BIS individuals showed a more negative FRN to loss signals on nogo trials in a go/nogo task. In a study of Balconi and Crivelli (2010), high trait-BIS individuals showed also a more negative FRN in a decision task for the false unexpected feedback. Moreover, Gu et al. (2010) reported a more negative FRN in high anxious individuals for an ambiguous compared to a negative feedback in a gambling task. Accordingly, we predict for higher relative to lower trait-BIS individuals a more pronounced expectation mismatch when unexpected changes of reward occurred. In sum, there is evidence that the FRN amplitude is modulated by trait-BIS related personality dimensions but also by trait-BAS related personality dimensions (Table 1).

Regarding P3, the amplitudes should be sensitive to the magnitude of win or loss (Johnston, 1979; Sutton et al., 1978; Yeung et al., 2004, 2005). Moreover, Balconi and Crivelli (2010) reported higher P3 amplitudes to unexpected feedback in higher relative to lower trait-BAS individuals. The authors referred this result to a higher attention in higher trait-BAS individuals when the reward feedback does not match with an individuals’ reward expectation. Thus, a more pronounced P3 amplitude could be expected for higher trait-BAS individuals.

1.3. Aims and hypotheses

In order to investigate the relationship between reward expectation mismatch, FRN amplitudes, P3 amplitudes, and individual differences (trait-BAS, trait-BIS) we used a choice task that induces a reward expectation mismatch by means of varying amount of reward (Avila and Parcet, 2000). The mismatch of reward expectation was manipulated by means of two buttons: All responses to button 1 were immediately and continuously rewarded (2–11 points) in the acquisition phase (100% reward) and were unexpectedly not rewarded in the extinction phase. Responses to button 2 were rewarded in 50% of all responses between 8 and 21 points