Biological Psychology 104 (2015) 184–192

Contents lists available at ScienceDirect

Biological Psychology

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

Context-sensitivity of the feedback-related negativity for zero-value feedback outcomes☆

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ARTICLE INFO

Article history:
Received 5 September 2014
Accepted 14 December 2014
Available online 22 December 2014

Keywords:
FRN
P300
sLORETA
Context dependency
Zero-value outcomes
Reward prediction error signals

ABSTRACT

The present study investigated whether the same visual stimulus indicating zero-value feedback (€0) elicits feedback-related negativity (FRN) variation, depending on whether the outcomes correspond with expectations or not.

Thirty-one volunteers performed a monetary incentive delay (MID) task while EEG was recorded. FRN amplitudes were comparable and more negative when zero-value outcome deviated from expectations than with expected gain or loss, supporting theories emphasising the impact of unexpectedness and salience on FRN amplitudes. Surprisingly, expected zero-value outcomes elicited the most negative FRNs. However, source localisation showed that such outcomes evoked less activation in cingulate areas than unexpected zero-value outcomes.

Our study illustrates the context dependency of identical zero-value feedback stimuli. Moreover, the results indicate that the incentive cues in the MID task evoke different reward prediction error signals. These prediction signals differ in FRN amplitude and neuronal sources, and have to be considered in the design and interpretation of future studies.

1. Introduction

Successful performance monitoring is more difficult to accomplish when the interpretation of observed behaviours or outcomes strongly depends on contextual factors. In a gambling situation, for example, the same outcome, for example, €0, can be better than expected, worse than expected, or entirely conform to expectations. Thus, the interpretation of identical outcomes also depends on the contextual framing of the situation in which they have been attained. Notably, the importance of social factors and context on performance monitoring correlates has also been emphasised and recommended in a recent review (Koban & Pourtois, 2014).

A neural correlate of performance monitoring is the so-called Feedback-Related-Negativity (FRN; Miltner, Braun, & Coles, 1997), an event-related potential (ERP) peaking frontally 200–350 ms after external feedback onset. Enhanced FRN amplitudes have been observed after negative performance feedback (Miltner et al., 1997; Nieuwenhuis, Holroyd, Mol, & Coles, 2004a), unexpected events (Hajcak, Moser, Holroyd, & Simons, 2007; Pfabigan, Alexopoulos, Bauer, & Sailer, 2011), monetary losses (Gehring & Willoughby, 2002), and after salient compared to insignificant outcomes (Gehring & Willoughby, 2002; Yeung, Holroyd, & Cohen, 2005). The FRN component is assumed to be generated within what has originally been labelled as anterior cingulate cortex (ACC; Gehring & Willoughby, 2002; Holroyd & Coles, 2002; Miltner et al., 1997). More recent neuroanatomical accounts refer to this region as anterior midcingulate cortex (aMCC; Vogt, 2005). FRN variation is assumed to classify outcomes in a good/bad dimension (Hajcak, Moser, Holroyd, & Simons, 2006; Yeung & Sanfey, 2004)

☆ Authors DMP, EMS, and CL designed the study. DMP, EMS, KP, and AG collected the data and DMP, KP, and AG analysed them. DMP, EMS, US, and CL wrote the first draft of the manuscript. All authors contributed to the discussion and interpretation of the results and approved the final manuscript.

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http://dx.doi.org/10.1016/j.biopsycho.2014.12.007
0301-0511/

– thereby indicating a negative reward prediction error signal, i.e., outcomes "worse than expected". This observation is incorporated in the reinforcement-learning theory (RL-theory; Holroyd & Coles, 2002), which states that a monitoring system within the basal ganglia evaluates on-going events and thereby evokes FRN variation. Recent theories, however, suggest that FRN modulation may reflect the unexpectedness (Alexander & Brown, 2011; Donkers, Nieuwenhuis, & van Boxtel, 2005) or the motivational salience of an outcome rather than solely outcomes "worse than expected" (Talmi, Atkinson, & El-Deredy, 2013). In terms of reward prediction errors (RPEs), these studies claim that FRN amplitude variation reflects absolute RPEs (aRPE; Alexander & Brown, 2011; Chase, Swainson, Durham, Benham, & Cools, 2011; Hauser et al., 2014; Talmi et al., 2013) rather than signed RPEs (sRPE) as suggested by Holroyd and Coles (2002). Absolute RPEs are assumed to represent unsigned deviance of an expected outcome – i.e., irrespectively of whether an outcome was better or worse than expected – which is often referred to as surprise (Hayden, Heilbronner, Pearson, & Platt, 2011). This assumption was recently corroborated by a study combining single-trial EEG analyses and functional imaging (Hauser et al., 2014).

Irrespective of this debate, FRN amplitudes are repeatedly reported to be context-dependent. FRN amplitude variation has been observed in relation to overall outcome probability (Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003), outcome sequence (Goyer, Woldorff, & Huettel, 2008; Osinsky, Mussel, & Hewig, 2012), and available information concerning possible decision outcomes (Holroyd, Larsen, & Cohen, 2004). Mostly, these studies used zero-value feedback as a control condition. However, the findings on zero-value feedback were highly inconsistent. Whereas Holroyd et al. (2004) found larger FRNs for zero-value feedback in an appetitive compared to an aversive context, Kujawa, Smith, Luhmann, and Hajcak (2013) failed to show FRN differences in zero-value feedback depending on the context. Holroyd, Hajcak, and Larsen (2006) found that negative and zero-value feedback elicited comparable FRN amplitudes, which were both more pronounced than FRNs to positive feedback. Several studies even observed enhanced FRN amplitudes after zero-value feedback compared to monetary loss or gain feedback (Gentsch, Grandjean, & Scherer, 2013; Osinsky, Walter, & Hewig, 2014). These diverging results may be due to the fact that all these studies embedded their feedback stimuli in different contexts–from overall reward probabilities (Holroyd et al., 2003) to trial-wise changes in context information (Osinsky et al., 2014). Osinsky et al. (2014) proposed to classify contextual factors as global (i.e., fixed reward probabilities during an experiment), local (i.e., trial-wise changes of reward probabilities), or intermediate factors (i.e., a mixture of the two former) and concurrently suggested that FRN amplitude variation seems to be impacted rather by global than local context factors. Moreover, the comparability of the mentioned studies is problematic because they compared the zero-value feedback stimuli – often framed as breaking-even outcomes – to other feedback stimuli with varying visual characteristics.

Consequently, the current study investigated whether the same visual stimulus indicating a payoff of €0 (i.e., a zero-value outcome), elicits FRN variation for different contextual settings – in this case different expectation levels. Our main objective was to clarify potential context-sensitivity of these identical visual feedback stimuli during trial-wise changes of global reward probabilities.

A monetary incentive delay (MID) task (Knutson, Westdorp, Kaiser, & Hommer, 2000) was administered to specifically investigate zero-value outcomes applying a trial-by-trial expectancy manipulation, introducing gain, loss, and neutral cues as global context settings. Referring to Osinsky et al. (2014), the current paradigm can be considered to contain intermediate contextual information as global reward probabilities were changed trial-wise, depending on the presented cue. FRN amplitudes are known to vary either due to the performance aspect of feedback (e.g., "Did I respond fast enough for a correct response?") or due the utilitarian aspect of feedback (e.g., "Did I choose the correct button to be rewarded?"), depending on which aspect is currently more salient (Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004b). Although one might consider the MID task as a classical utilitarian gambling task, its current version emphasises the performance rather than the utilitarian aspect of the feedback because participants' task was to react as fast as possible to the target stimulus. In contrast, previous studies investigating context sensitivity of the FRN component so far only used utilitarian feedback paradigms.

We assume that the contextual frame is essential for how otherwise identical zero-value feedback outcomes are processed. However, current theories allow different predictions concerning these feedback outcomes. According to the RL-theory emphasising feedback valence, zero-value outcomes worse than expected (i.e., gain-omission) should elicit more pronounced FRN amplitudes than zero-value outcomes better than expected (i.e., loss-avoidance). Expected-zero outcomes should elicit FRN amplitudes comparable to gain-omission outcomes when all outcomes are classified in a good/bad dimension (Holroyd & Coles, 2002). In contrast, according to theories emphasising feedback salience and surprise, gain-omission and loss-avoidance should elicit comparable FRN amplitudes, both more pronounced than expected-zero outcomes (Alexander & Brown, 2011; Hauser et al., 2014; Talmi et al., 2013).

In addition to the FRN, we also aimed to investigate whether the parietal P300 component, a positive-going ERP deflection around 300–600 ms after feedback onset, differed according to the contextual frame of zero-value outcomes. This is because, among other factors, P300 amplitude is sensitive to stimulus significance (Duncan Johnson & Donchin, 1977), attentional demands (Polich, 2007), and also motivational significance (Nieuwenhuis, Aston-Jones, & Cohen, 2005). We hypothesised smaller P300 amplitudes for expected-zero than for all the other outcomes because expected-zero outcomes should evoke less motivational significance and attentional demands compared to the other outcomes.

Besides analyses of these ERPs on the scalp surface, we explored differences in neuronal generators for zero-value feedback by means of standardised low resolution brain electromagnetic tomography (sLORETA; Pascual-Marqui, 2002). The aim of this approach was to gain additional information to differentiate zero-value feedback outcomes. We expected enhanced activation in the aMCC region for gain-omission outcomes compared to expected zero-value ones, based on previous source localisation evidence (Gehring & Willoughby, 2002; Miltner et al., 1997).

2. Methods

2.1. Participants

Thirty-four volunteers participated, of which three had to be excluded due to limited compliance with or comprehension of task instructions (for instance, consistent failure to respond by button press to presentation of the target following a neutral cue). The remaining 31 participants (14 women) were on average 24.06 (SD = 4.68) years old. All participants were right-handed (Oldfield, 1971), had normal or corrected-to-normal vision and reported no prior or current psychiatric disorder. They were screened with the Structural Clinical Interview for DSM-IV (SCID-I; APA, 1994) to exclude participants with psychiatric disorders. Written informed consent was obtained prior to the experiment. The study was approved by the ethics committee of the Medical University of Vienna.

2.2. Experimental task

In the MID task (Knutson et al., 2000) participants can maximise rewards and minimise losses by responding as quickly as possible to a visual target. Prior to target presentation, incentive cues indicated the context of the current trial, that is, whether money could be won (gain context) or lost (loss context), or whether no money was at stake (neutral context) – see Fig. 1. Each trial started with the central presentation of the incentive cue (1000 ms). Potential gain was indicated by a