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Dissociating absolute and relative reward- and punishment-related electrocortical processing: An event-related potential study

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A B S T R A C T

The meaning of reward and punishment signals depends on context. Receiving a small reward where a larger reward could have been obtained can be considered a punishment, while a small loss in the context of avoiding a larger loss can be experienced as a reward. The aim of this study was to investigate the electrophysiological processes associated with absolute and relative reward and punishment signals. Twenty healthy right-handed volunteers performed a decision-making task and were instructed to judge which of two neutral objects was the most expensive. The received outcome was presented together with the non-received outcome for the alternative choice. The feedback-related potentials P200, FRN and P300 were recorded in response to absolute (i.e., received) outcome and relative (i.e., received in the context of the alternative) outcome. Absolute rewards yielded higher P200 amplitudes as compared to relative rewards, while the P200 amplitude was largest for relative as compared to absolute punishments. The P300 amplitude showed a main effect of valence with larger amplitudes for more positive relative and absolute outcomes. No effect of absolute or relative outcome was observed for the feedback-related negativity (FRN). Our findings suggest distinct processes associated with context-dependent and context-independent processing during feedback processing.

1. Introduction

During decision making external feedback determines the success of an action and whether that action is repeated in the future. Importantly, however, what is subjectively perceived as a reward or a punishment depends on the relative value within the context in which choices are made. A small loss, for instance, can be interpreted as a positive outcome if the alternative choice would have resulted in an even greater loss. This means that in absolute terms a small loss is a punishment, but in relative terms it can in fact be perceived as a reward. Similarly, a small absolute reward is a positive outcome, but in relative terms may be perceived as a punishment if the alternative choice would have yielded a larger reward.

Effects of context have first been described by the prospect theory of human decision making (Kahneman and Tversky, 1979). The theory states that feedback signals are used to form internal prediction models to predict the intrinsic value of reward and punishment. However, when reward and punishment feedback signals are not informative for the formation of an accurate prediction model, effects of context will bias decision making (Tversky and Kahneman, 1992). This behavioral phenomenon is demonstrated by the so-called framing effect. The framing effect postulates that two statements are interpreted differently depending on positive or negative phrasing, while the expected value is the same (Tversky and Kahneman, 1992). Analogously, subjective valuation of a reward is influenced by the presence of alternative reinforcers (Holroyd et al., 2004). For example, when 20 Euro is retained after one started with 50 Euro, one could frame this as a 20 Euro win or a 30 Euro loss. De Martino et al. (2006) showed that the latter scenario of this example was perceived as more negative by the subjects, and was followed by more risky decision making to compensate for the perceived punishment. Additionally, these contextual effects were associated with fronto-cortical network activation, consisting of the orbitofrontal, ventromedial prefrontal and anterior cingulate cortex (De Martino et al., 2006).

Studies investigating event-related potentials (ERP) in response to reward and punishment signals have identified several feedback-related brain potentials associated that have been linked to expectancy, valence and magnitude (Bellebaum et al., 2010a; Kreussel et al., 2012; Meadows et al., 2016; Weismüller and Bellebaum, 2016; Wu and Zhou, 2009). A fronto-central positivity, peaking around 200 ms after feedback onset (P200), has been associated with attention capture and allocation (Flores et al., 2015; Potts et al., 2006; San Martin et al., 2010). It has been proposed that this P200 component primarily reflects saliency rather than the mismatch between prediction and outcome (Potts

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et al., 2006). This is evidenced by findings showing larger P200 for better-than-expected outcomes compared to worse-than-expected outcomes, even in the absence of explicit attention cues. In both conditions the mismatch between predictions and outcomes was equal, suggesting that the difference in P200 amplitude is related to valence (Potts et al., 2006). Even though larger P200 amplitudes have been related to more positive outcomes (San Martin et al., 2010), others have observed larger P200 amplitudes for more negative outcomes (Carretié et al., 2001; Carretié et al., 2005; Schuermann et al., 2012). Together, these findings suggest that the P200 may be an arousal component reflecting a valence effect that is associated with the relevance of feedback.

Following the P200, a fronto-central negative deflection that peaks between 150 and 350 ms can be observed after feedback onset. This so-called feedback-related negativity (FRN) component is sensitive to unexpected outcomes (Hajcak et al., 2007; Weismüller and Bellebaum, 2016) and is thought to reflect reward-related prediction errors. This view finds support from results showing larger FRN amplitudes for unpredicted as compared to predicted outcomes (Hajcak et al., 2007). These findings suggest a link between the FRN and the evaluation of the accuracy of the internal prediction model (Alexander and Brown, 2011).

Finally, the P300, which is a positive wave between 350 and 500 ms after feedback onset, reaches its peak over posterior scalp locations. The P300 is related to attention allocation in response to unexpected events or outcomes during learning (Fischer and Ullsperger, 2013; Polich, 2007). Functional neuroimaging studies have shown that the P300 is related to the fronto-parietal attention network (Bengson et al., 2015; Pfabigan et al., 2014). The allocation of attention following the detection of a mismatch is proposed to reflect an active process of error minimization by updating the internal prediction model (Fischer and Ullsperger, 2013). Indeed, Kopp et al. (2016) showed increased P300 amplitudes during high compared to low certainty, suggesting that attention is directed towards the most valid information. Moreover, the P300 is shown to be correlated to higher learning rates, further supporting its involvement internal prediction models (Fischer and Ullsperger, 2013).

A large amount of studies on feedback ERP components has focused on the electrophysiological correlates of valence and magnitude in the processing of reward and punishment signals (for a review see Ullsperger et al., 2014). An additional factor that can play a role in feedback processing is context (Gehring and Willoughby, 2002; Gibbons et al., 2013; Goyer et al., 2008; Peterburs et al., 2013). Consistent with the prospect theory, rewards may be perceived as a punishment when an alternative larger non-received reward was present, while losses are perceived as a reward in cases where a larger loss was avoided (Tversky and Kahneman, 1992). Holroyd et al. (2004) showed that a punishment is associated with a small FRN amplitude when the alternatives would have yielded an even larger punishment (i.e., relative reward). Furthermore, a reward is associated with a large FRN amplitude when the alternative outcome would have resulted in a larger reward (i.e., relative punishment). This suggests that the presence of alternative outcomes influences the FRN (Holroyd et al., 2004). Furthermore, Peterburs et al. (2013) used a gambling task in which participants were able to place a bet prior to the decision. They found that the FRN amplitude was increased in a high risk context, that is when a bet was placed, as compared to a low risk context. The same distinction between risk conditions was observed for the P300 (Peterburs et al., 2013), suggesting that both early and late feedback ERPs can be affected by context. In contrast, Zeng et al. (2014) suggested that the P300 may be less sensitive to context as its amplitude is modulated by absolute, but not relative outcomes.

Although these studies suggest that context influences reward- and punishment-related feedback processes, a direct comparison between the effects of absolute and relative rewards and punishments on the P200 brain potentials has, to our knowledge, not been made. To this end, we investigated the effects of the presence of alternative outcomes on the P200, FRN and P300 amplitude by comparing feedback-related reward and punishment signals. Rooted in the idea that the FRN and P300 are involved in the formation of an internal prediction model we anticipate that the FRN and P300 display distinct processes in terms of absolute and relative outcomes. As feedback was provided pseudorandomly, making the formation of an accurate prediction model extremely unlikely, it was expected that these components would be particularly susceptible to contextual information. Specifically, we hypothesized larger FRN amplitudes for relative losses as compared to relative gains, leaving the FRN unaffected in response to absolute outcomes. Similarly, larger P300 amplitudes were expected for relative gains compared relative losses. In contrast, the early P200 component, which is thought to reflect implicit attentional processes, may be less influenced by contextual effects and is therefore primarily affected by absolute outcomes. Consequently, P200 amplitudes were hypothesized to be increased for absolute gains compared to absolute losses, but no effect of relative outcomes on the P200 amplitude was expected.

2. Materials and methods

2.1. Participants

Twenty healthy right-handed adult volunteers (14 females, mean age ± SD: 22.7 ± 3.8) participated in the present study. All participants were right handed (44.1 ± 3.65 of maximally 48) as determined by the Edinburgh inventory of handedness (Oldfield, 1971). Furthermore, participants had normal or corrected-to-normal vision, and no history of neurological or psychiatric disorders. Subjects received a monetary compensation of 10 Euro for participation. The study protocol was approved by the local ethical committee of the Donders Centre for Cognition in Nijmegen and carried out in accordance with the standards set by the Declaration of Helsinki (Fortaleza Amendments).

2.2. Decision making task

In this two alternatives forced choice decision making task, participants were presented with two vases and were instructed to indicate which of the vases is the most expensive one. After their choice, pseudorandom feedback was presented showing the amount of points associated with each vase. One outcome corresponded to the participant's choice, whereas the other outcome corresponded to a non-received outcome. The outcome corresponding to subject's choice was added to the total score. Importantly, outcome of the non-chosen vase was shown to inform subjects about the amount of point they would have received for choosing the alternative. Participants were instructed that choosing the correct vase always yields a relative rewards. Unknown to the participant rewards and punishments were presented in a pseudo-randomized and counterbalanced way, meaning that no learning effect could occur. In total there were twelve feedback combinations as depicted in Table 1. The combinations were categorized according to absolute and relative gains and losses. Importantly, contingencies were chosen in a way such that in one trial an absolute gain would correspond to a relative loss and a relative gain would correspond to an absolute loss (Table 1). In the relative condition a large positive outcome was 60 points better than the other outcome, whereas a large negative outcome was 60 points worse than the other outcome. A small positive outcome was 20 points better than the other outcome, whereas a small negative outcome was 20 points worse than the other outcome. Absolute values were categorized to be directly comparable to relative values, with categories of large positive (on average +60 points), small positive (on average +20 points), small negative (on average −20 points) and large negative (on average −60 points). The combination of 90/30 is not included in the absolute reward condition, as the inclusion of this condition would lead to an absolute gain of larger than +60 and confound the comparison to the other conditions. By grouping