



Blocked versus randomized presentation modes differentially modulate feedback-related negativity and P3b amplitudes



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HIGHLIGHTS

- ERP responses to feedback stimuli with explicit or assigned valence information were investigated with blocked or randomized trial presentation modes.
- Only P3b, but not feedback-related negativity amplitudes were affected by feedback type for both presentation modes.
- Results suggest using blocked design when using different types of feedback stimuli.

ABSTRACT

Objective: Electrophysiological studies on feedback processing typically use a wide range of feedback stimuli which might not always be comparable. The current study investigated whether two indicators of feedback processing – feedback-related negativity (FRN) and P3b – differ for feedback stimuli with explicit (facial expressions) or assigned valence information (symbols). In addition, we assessed whether presenting feedback in either a trial-by-trial or a block-wise fashion affected these ERPs.

Methods: EEG was recorded in three experiments while participants performed a time estimation task and received two different types of performance feedback.

Results: Only P3b amplitudes varied consistently in response to feedback type for both presentation types. Moreover, the blocked feedback type presentation yielded more distinct FRN peaks, higher effect sizes, and a significant relation between FRN amplitudes and behavioral task performance measures.

Conclusion: Both stimulus type and presentation mode may provoke systematic changes in feedback-related ERPs. The current findings point at important potential confounds that need to be controlled for when designing FRN or P3b studies.

Significance: Studies investigating P3b amplitudes using mixed types of stimuli have to be interpreted with caution. Furthermore, we suggest implementing a blocked presentation format when presenting different feedback types within the same experiment.

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1. Introduction

The monitoring of ongoing events – whether they concern internal states or external affairs – is crucial in daily life. Human neuroscience research has addressed internal and external performance monitoring extensively for over two decades now. Much of this research has relied on the use of event-related potentials (ERPs) which allow investigating the neuronal correlates of performance monitoring with a temporal resolution in the millisecond range. The feedback-related negativity (FRN; Miltner et al., 1997),

which is a negative-going component peaking around 200–300 ms after the presentation of external feedback, is an ERP component that has been repeatedly used to investigate performance monitoring based on external feedback. Enhanced FRN amplitudes have been reported after negative performance feedback (Miltner et al., 1997; Nieuwenhuis et al., 2004), after unexpected events (Hajcak et al., 2007; Pfabigan et al., 2011b), after monetary losses (Gehring and Willoughby, 2002), and after salient compared to insignificant outcomes (Gehring and Willoughby, 2002; Yeung et al., 2005). The P3b (Polich, 2007) is another ERP component repeatedly observed in situations requiring performance monitoring. It is a positive-going component peaking in the time window of 300–600 ms after external feedback presentation. P3b

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amplitude variation has been found to be sensitive to stimulus significance, the probability of occurrence of a stimulus (Duncan Johnson and Donchin, 1977), as well as to task and stimulus complexity (Isreal et al., 1980; Johnson, 1986) and effort spent on a task (Brocke et al., 1997).

More than one hundred studies on ERP correlates of feedback processing have been published so far, and there is considerable variation of the feedback stimuli used in these studies. Notably, feedback stimuli might differ with respect to a variety of factors, such as how much perceptual or cognitive processing they require (Zhang et al., 2012). For example, simple symbols like x, o, +, – have often been presented to indicate feedback valence via prior assignment (Hajcak et al., 2006, 2007; Holroyd et al., 2006; Miltner et al., 1997; Sato et al., 2005), while numbers (sometimes in different colors) as well as pictures of coins served as feedback stimuli to indicate the amount of monetary gain or loss more indirectly (Bellebaum and Daum, 2008; Bellebaum et al., 2010; Donamayor et al., 2012; Gehring and Willoughby, 2002; Pfabigan et al., 2011a; Sailer et al., 2010; Wu and Zhou, 2009; Yeung and Sanfey, 2004; Yu and Zhou, 2006). In addition, some studies have used social stimuli such as faces with either neutral (Warren and Holroyd, 2012; Zhang et al., 2012) or emotional facial expressions (such as anger, sadness or happiness; (Li et al., 2011; Pfabigan et al., 2011a; Schulreich et al., 2013) to explicitly indicate feedback valence. Feedback stimuli such as faces depicting basic facial emotion expressions contain valence information that can be recognized directly and universally (Ekman and Friesen, 1976). Furthermore, emotional facial expressions are considered to be important social cues comprising necessary information in social exchange situations (Rolls, 2000), conveying feedback valence without prior learning requirements (van der Veen et al., 2011). In contrast, the valence assignment for + and – symbols has to be learned before being used as valence indicator. Consequently, the question arises whether explicit or assigned valence information results in different feedback processing.

Notably, answering this question requires experimental designs that compare feedback-related neural signals within the same individuals – as individual variation across subjects might prevent the detection of potentially unique differences in feedback processing when relying on a between-subject design. As of yet, only one cognitive neuroscience study addressed the question whether different types of feedback stimuli influence neuronal activity during feedback processing within the same individuals. Using functional magnetic resonance imaging (fMRI), van der Veen et al. (2011) administered a time estimation task (Miltner et al., 1997) and used either emotional faces or verbal statements as feedback stimuli – with feedback type being randomly varied across the experiment. Their hypothesis was that facial feedback contained more direct emotional value and would lead to enhanced neuronal activation in brain areas associated with feedback processing, in comparison to verbal feedback. Although it was observed that facial feedback activated a generally larger neuronal network than verbal feedback with higher activation in occipital areas and the left inferior temporal gyrus, neuronal activation was comparable in brain areas associated with feedback processing when contrasting the two different feedback types. However, the poor temporal resolution of fMRI might not have permitted an adequate detection of the rapid neuronal changes known to be associated with feedback processing. Furthermore, electrophysiological indices of brain activity might provide access to aspects of neural processing that remain undetected by hemodynamic activation measures.

Thus, the current study is the first to apply a within-subject design to directly compare ERP indicators of feedback processing using feedback stimuli with explicit or assigned valence information. In principle, stimuli with assigned valence information (such as + and –) contain valence information comparable to stimuli

with explicit information (such as emotional facial expression). However, we were interested in whether emotional facial expressions added additional saliency to the feedback stimuli which might be reflected in enhanced ERP amplitudes. Our assumption of emotions impacting FRN amplitude variation is further supported by the observation that even slightly elevated levels of self-reported state and trait negative affect are associated with FRN enhancement after negative feedback (Santesso et al., 2012). Moreover, Santesso et al. (2012) suggested that FRN amplitude variation might be context-dependent, with negatively-valenced contexts eliciting larger FRN amplitudes. Thus, the question arises whether or not explicit negative feedback stimuli (i.e., angry facial expressions) have a comparable context effect on FRN amplitudes.

Concerning the P3b component, amplitude variation has been reported in response to negatively- as well as in response to positively-valenced stimuli. However, the picture is far from consistent. Larger P3b amplitudes after positive feedback have been reported several times (Bellebaum et al., 2010; Hajcak et al., 2007; Pfabigan et al., 2011b). Other studies reported no differences in P3b amplitude variation for positive and negative outcomes (Sato et al., 2005; Yeung and Sanfey, 2004). Schuermann et al. (2012) and Frank et al. (2005) found P3b amplitude enhancement after the presentation of negatively valenced stimuli. Research on emotional picture content suggested that P3b amplitude enhancement is elicited by the presentation of emotionally charged pictures in comparison to neutral pictures (Briggs and Martin, 2009; Keil et al., 2002). Based on this assumption, Yeung et al. (2005) suggested that P3b enhancement during feedback processing might reflect higher subjective task involvement. More precisely, P3b enhancement might also reflect the affective significance of the presented feedback stimuli (Yeung et al., 2005).

We conducted three separate experiments investigating the impact of different feedback stimuli – explicit versus assigned stimuli (i.e., emotional facial expressions versus symbols) – on neuronal correlates of feedback processing. We expected larger FRN amplitudes after negative than after positive feedback (Miltner et al., 1997), particularly for explicit stimuli (Santesso et al., 2012). The explicit stimuli were social stimuli which are thought to be crucial for behavioral adaptations (Rolls, 2000). On a longer time scale, recognizing emotional facial expressions has been proposed to be evolutionarily adaptive because it facilitates social interaction, helps to avoid threats and thereby enhances an individual's likelihood of survival (Vaish et al., 2008).

Concerning later stages of feedback processing, we expected larger P3b amplitudes after positive than after negative feedback stimuli (Bellebaum et al., 2010; Pfabigan et al., 2011b). In particular, we expected larger P3b amplitudes for explicit than for assigned feedback because of higher salience (Yeung and Sanfey, 2004) and higher stimulus complexity (Isreal et al., 1980; Johnson, 1986). Furthermore, we explored behavioral measures of time estimation and their relation to FRN and P3b amplitudes variation. Empirical evidence suggests that the larger FRN amplitudes, the larger the corresponding behavioral modifications (Holroyd and Krigolson, 2007; van der Helden et al., 2010). This is in line with the assumption that the anterior midcingulate cortex (aMCC), the most likely source of the FRN component (Gehring and Willoughby, 2002; Holroyd and Coles, 2002; Miltner et al., 1997), is implicated in behavioral adaptation (Holroyd and Coles, 2002).

In addition to investigating explicit versus assigned feedback stimuli, two further experiments were performed to corroborate the results from experiment 1 and to explore the effect of different presentation modes on FRN and P3b amplitudes. In the literature, mixed (i.e., randomized) and blocked presentation modes are typically assumed to be comparable and alternative designs. However, since mixed versus blocked presentation may potentially influence subjective stimulus predictability, which in turn has been found to

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