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Research Report

Learning context modulates the processing of expectancy violations

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ABSTRACT

The detection of unexpected or unfavorable events is crucial for successful behavioral adaptation. There is a family of ERP components, the so-called error negativities, that has been associated with these detection processes. In the current study, we explored the functional characteristics of one of these components, the N2b which reflects the detection of unexpected events in a stream of stimuli in our environment, in more detail. In a sequence learning task, we found that the same type of deviant event elicited an N2b only when it conveyed information about the to-be-learned sequence, but not when it was rendered learning-irrelevant by means of task instruction. This supports the view that deviant events generate an error negativity in a similar way as committed errors and negative feedback. It also demonstrates that error monitoring processes are very flexible and can be tailored to the specific demands of the task at hand, i.e., expectancy violations only activate the error system when the detected mismatch is classified as relevant for the specific goals in the current learning context. Additionally, a P3 to all deviant types was found reflecting a higher-order form of performance monitoring associated with evaluation of task-relevant events and updating of working memory contents.

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1. Introduction

To flexibly adapt our behavior to changing environmental demands and to acquire new behavior, we constantly have to evaluate our performance in the light of its potential consequences. For this purpose it is important that unexpected or unfavorable events can be detected. This has been demonstrated in numerous studies and several ERP components have been associated with the detection of unexpected events like perceived and committed errors or surprising feedback (for a review, see Gehring et al., 2012). These components share functional characteristics, rely on very similar neural mechanisms (cf. Folstein and Van Petten, 2008), and play an important role when the consequences of actions are processed.

In their reinforcement learning (RL) model, Holroyd and Coles (2002) suggested that if an event is worse than expected, e.g., an error is detected, the result is a dopaminergic reinforcement learning signal which can be measured in the event-related potential (ERP) in the form of an ERN (error-related negativity; Gehring et al., 1993) or Ne (error

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negativity; Falkenstein et al., 1990,1995; Gehring et al., 2012). This component can be observed over fronto-central brain regions at the time the error is made. Importantly, similar components cannot only be elicited by erroneous responses but also by stimuli signaling events that are worse than expected, e.g., by error observation (the oERN; De Bruijn and von Rhein, 2012; Bates et al., 2005; van Schie et al., 2004), and by negative or unexpected feedback (the feedback-related negativity (FRN); e.g., Ferdinand et al., 2012; Gehring and Willoughby, 2002; Holroyd and Coles, 2002; Miltner et al., 1997; Oliveira et al., 2007).

Only recently, the N2b[1] elicited by the detection of an unexpected event, has been argued to signal that our expectations might need revision (Ferdinand et al., 2008). In this latter ERP study, we investigated the build-up of expectancies and the detection of expectancy violations using a sequence learning paradigm and inserting deviant stimuli into an otherwise repeating sequence (Ferdinand et al., 2008). Interestingly, we observed an N2b to these deviant stimuli that developed with increasing sequence knowledge and that showed striking similarities to the learning-related changes in the response-locked ERN previously demonstrated by Holroyd and Coles (2002). We concluded that during learning deviant events acquire the status of an unexpected event, i.e., a perceived error (as opposed to a committed error), and can serve as a reinforcement learning signal. While performing the sequence learning task expectancies about upcoming events are generated, compared to the actual event, and evaluated on whether they deviate from the expectancies. The accuracy of this process improves with learning and this improvement is reflected in a gradual increase in N2b amplitude as a function of learning. Several other studies also reported enhanced N2b for stimuli that contradict participants' expectancies in learning situations. For instance, employing an incidental sequence learning task Eimer et al. (1996) found an N2b to stimuli that violated a learned spatial sequence (for similar results, see also Kopp and Wolff, 2000; Rüsseler et al., 2003; Verleger et al., 2015). Although not explicitly explored in these studies it is entirely conceivable that the N2b and the ERN reflect activity of a common neural generator (the ACC) initiated by input signaling that an event violates the participant's expectancy. Additionally, source-localization studies which show that the neural generators of the two components lie very close together in the medial frontal cortex, are consistent with a common neural source in the ACC (Holroyd, 2004; Nieuwenhuis et al., 2003; see also Folstein and Van Petten, 2008).

The most important commonality between these components regards the fact that they all are conceptualized to index that an event differs from expectation. What remains an open question, however, is what actually defines the dimension on which events are evaluated deviating from expectancies. Previous research on the FRN indicated that this evaluation can depend on the alternative outcomes (e.g., Goyer et al., 2008; Holroyd et al., 2004; Nieuwenhuis et al., 2004). For example, in a recent study it has been reported that feedback indicating that participants received no reward generated a FRN when the alternative outcomes were rewards. However, the same non rewarding feedback did not generate a FRN when the alternative outcomes were monetary losses (Holroyd et al., 2004). Similarly, using a gambling task it was shown that the FRN was larger if the outcome of the chosen gamble was worse than the simultaneously presented outcome of the unchosen gamble (Goyer, et al., 2008). Hence, one could infer that the event characteristics needed to elicit an FRN are context-dependent, i.e., in the above study the alternative feedback defines what is "better" and what is "worse" than expected. Crucially, Nieuwenhuis et al. (2004) demonstrated that this context-dependency is subject to an attentional bias. They conducted a gambling task in which participants had to choose one of two values (5 or 25). Feedback was given by adding a "−" or "+" sign to indicate whether the chosen value indicated a loss or a gain, so the feedback stimulus conveyed two types of information: 1) absolute valence information, i.e., whether the money was lost or won, and 2) relative valence information, i.e., whether the chosen gamble led to the better or worse outcome (5 cents lost is better than 25 cents lost). By using these compound stimuli, it was found that the FRN can be elicited likewise by absolute (gain or loss) or relative (better or worse than expected) information, depending on which aspect was emphasized by the instruction, respectively.

These studies demonstrate that the task context can influence which events are assessed as expectancy violations and that this is reflected in the size of the FRN amplitude. However, they do not clarify whether all aspects of an event (e.g., absolute AND relative information in the study by Nieuwenhuis et al. (2004)) are evaluated at the same time. Equally likely, this evaluation process may be flexible enough to differentially weigh several aspects of the same stimulus when the context of the evaluation changes. For instance, imagine a worker in a factory processing prawns. On one day, he works in the incoming inspection where he has to sort the prawns according to whether they should be further processed or whether they are spoiled and should be discarded (i.e., sorting according to smell or color). This same worker might be deployed to the final quality check on another day, where he has to assess whether the prawns are of sufficiently high quality to serve as gourmet food (i.e., sorting according to size). This means that he has to adapt his evaluation process to the current situation and the different properties of prawns should lead to an error signal depending on his function. This view assumes more economic evaluation processes in which only those aspects of an event are taken into account that are relevant in a specific learning situation. This differential importance of various features of one and the same stimulus to serve as a reinforcement learning signal depending on their behavioral relevance has not received much attention in the literature so far. Thus, the goal of the present study was to examine what determines the evaluation dimension on which actual events can deviate from expected ones. More specifically, we investigated what characteristics an expectancy violation must possess to elicit an N2b and whether all aspects of a stimulus or only those that

[1]"N2b" and the more general term "N200" are often used synonymously. Here we use the term "N2b" (except when citing other studies) to distinguish the component from the mismatch negativity (MMN), that is sometimes named "N2a".

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