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# Distinguishing the influence of task difficulty on error-related ERPs using surface Laplacian transformation

Liesbet Van der Borght[a], Femke Houtman[a], Boris Burle[b], Wim Notebaert[a,*]

[a] *Department of Experimental Psychology, Ghent University, Belgium*
[b] *Laboratoire de Neurosciences Cognitives, UMR7291, Aix-Marseille Université, CNRS, Marseille, France*

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ABSTRACT

Electrophysiologically, errors are characterized by a negative deflection, the error related negativity (ERN), which is followed by the error positivity (Pe). However, it has been suggested that this latter component consists of two subcomponents, with an early frontocentral Pe reflecting a continuation of the ERN, and a centro-parietal Pe reflecting error awareness. Using Laplacian transformed averages, a correct-related negativity (CRN; similar to the ERN), can be found on correct trials. As this technique allows for the decomposition of the recorded scalp potentials resulting in a better dissociation of the underlying brain activities, Laplacian transformation was used in the present study to differentiate between both the ERN/CRN and both Pe components. Additionally, task difficulty was manipulated. Our results show a clearly distinguishable early and late Pe. Both the ERN/CRN and the early Pe varied with task difficulty, showing decreased ERN/early Pe in the difficult condition. However, the late Pe was not influenced by our difficulty manipulation. This suggests that the early and the late Pe reflect qualitatively different processes.

## 1. Introduction

In order to behave adaptively to the requirements of the environment, it is necessary to monitor signals that point out the need for adjustment. Although various signals are able to indicate suboptimal performance that requires cognitive adjustments, the detection of an error is probably the most important signal. Electrophysiological investigations have demonstrated a negative brain potential at frontocentral electrode sites, peaking between 0 and 100 ms, after error commission (error-related negativity, ERN, Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, & Coles, 1993). The origin of the ERN has been linked to the posterior medial frontal cortex (for an overview see Ullsperger, Danielmeier, & Jocham, 2014). Using Laplacian transformation, which allows spatial deblurring of EEG (Babiloni, Cincotti, Carducci, Rossini, & Babiloni, 2001), previous research has demonstrated that a similar negativity (albeit of a smaller amplitude which is often referred to as CRN), can be discerned on correct responses (Allain, Carbonnell, Falkenstein, Burle, & Vidal, 2004; Vidal, Hasbroucq, Grapperon, & Bonnet, 2000). This challenges the idea that the ERN is specific to errors but rather reflects a more general response evaluation (Bonini et al., 2014). In line with this idea, CRN amplitude increases with higher uncertainty (Pailing & Segalowitz, 2004). Although it has been argued that ERN and CRN might reflect different mechanisms (Coles, Scheffers, & Holroyd, 2001; Endrass, Klawohn, Gruetzmann, Ischebeck, & Kathmann, 2012), there is now strong evidence that they reflect the same modulated underlying processes (Bonini et al., 2014; Roger, Bénar, Vidal, Hasbroucq, & Burle, 2010).

Following the ERN, a slow positive wave with a maximum amplitude between 200 and 400 ms and a more diffuse scalp distribution is observed (error positivity, Pe, Falkenstein et al., 1991), which has been attributed to error recognition or error awareness (Endrass, Reuter, & Kathmann, 2007; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; O'Connell et al., 2007; Shalgi, Barkan, & Deouell, 2009; Wessel, Danielmeier, & Ullsperger, 2011). Interestingly, the Pe shares many characteristics with the P300, a positive stimulus-locked slow wave appearing between 200 and 400 ms after stimulus onset. The P300 has generally been associated with the processing of unexpected and motivationally significant events (for a review, see Nieuwenhuis, Aston-Jones, & Cohen, 2005) and has been divided into two subcomponents. The P3a occurs first with a frontocentral scalp distribution (Polich & Comerchero, 2003) and is mainly sensitive to the novelty of events. In contrast, the P3b is a later-occurring component with a parietal scalp distribution

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* Corresponding author at: Department of Experimental Psychology, Ghent University, Henri Dunantlaan 2, 9000 Ghent, Belgium.
*E-mail address:* wim.notebaert@ugent.be (W. Notebaert).

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and is sensitive to the amount of attentional resources allocated to a stimulus (Polich & Comerchero, 2003; Polich, 2007). Similarly, there is support that the Pe consists of two subcomponents, an early and a late one (Arbel & Donchin, 2009; Endrass, Klawohn, Preuss, & Kathmann, 2012; Endrass et al., 2007; Van Veen & Carter, 2002), where only the late Pe is seemingly related to error awareness (Endrass, Klawohn, Preuss et al., 2012). The early frontocentral Pe has been proposed to be generated by the same generators as the ERN (Debener et al., 2005; Van Veen & Carter, 2002) while the late posterior Pe is attributed to the parietal cortex and rostral ACC (Herrmann, Römmler, Ehlis, Heidrich, & Fallgatter, 2004; Van Veen & Carter, 2002; for an overview, see Ullsperger et al., 2014).

Consistent with the idea that the ERN reflects an outcome evaluation, a relationship between the ERN and task difficulty (indexed by increased perceptual difficulty) has been reported, which show a decreased ERN magnitude when task difficulty increases (Endrass, Klawohn, Gruetzmann et al., 2012; Hoffmann & Falkenstein, 2010; Pailing & Segalowitz, 2004). Comparisons across different cognitive tasks, such as the Stroop, flanker and go/no-go task also showed a smaller ERN-amplitude for the Stroop-task, which was associated with the highest error rate (Riesel, Weinberg, Endrass, Meyer, & Hajcak, 2013). However, when task difficulty in conflict tasks is manipulated by increasing the number of stimuli, as well as their associated responses, no influence on the ERN or CRN has been reported (Compton, Bissey, & Worby-Selim, 2014; Pailing & Segalowitz, 2004).

A small number of studies that have investigated the relationship between the early and late Pe and task difficulty suggest that the late Pe is sensitive to error saliency. Arbel and Donchin (2009) showed that only the posterior positive deflection was sensitive to the accuracy instruction, and was larger when accuracy was stressed compared to a neutral condition. Similarly, Endrass, Klawohn, Gruetzmann et al. (2012), using spatio-temporal Principal Component Analysis, showed that a centroparietal component in the time range of the Pe varied significantly with perceptual difficulty while a frontocentral component within the same time range did not. Both studies also observed that the ERN was affected by task instruction/difficulty, with more pronounced ERN for the easier condition. Such findings are in contrast to the hypothesis that the early Pe is a continuation of the ERN (Wessel, 2012).

In the present study, we manipulated task difficulty by means of the complexity of the mapping rule and investigated its effect on the ERN/CRN, early Pe and late Pe. As we manipulated task difficulty by increasing stimulus-response mappings, we did not expect to find a modulation of the ERN or the CRN (Compton et al., 2014; Pailing & Segalowitz, 2004). Based on previous findings and the idea that the early Pe is a continuation of the ERN, no modulation of this component was expected. Our difficulty modulation, however, should result in a difference in error saliency, which decreases with higher error rates and more difficult task requirements. We therefore expected to find a larger late Pe component in the easy condition. Based on the orienting account (Notebaert et al., 2009) this difference in error saliency should also be reflected in the amount of post-error slowing since infrequent or salient events trigger a larger orienting response that interferes with subsequent processing.

An overview of the literature revealed that while some studies reported an early and late Pe (Endrass et al., 2007; Van Veen & Carter, 2002), this differentiation was not always observed (Hajcak, McDonald, & Simons, 2003; Nieuwenhuis et al., 2001; Shalgi et al., 2009; Wessel et al., 2011), largely because the two components overlap in time and space, further amplified by volume conduction (Burle et al., 2015). Statistical procedures, such as independent component analysis (ICA—Debener et al., 2005) or principal component analysis (PCA—Arbel & Donchin, 2009; Endrass, Klawohn, Gruetzmann et al., 2012; Endrass, Klawohn, Preuss et al., 2012), have successfully differentiated both components. Such statistical approaches, however, are not based on any physical or physiological assumptions and can lead to nonphysiologically-plausible outcomes (e.g., Delorme, Palmer, Onton, Oostenveld, & Makeig, 2012). As an alternative decomposition approach, the estimation of Current Source Density through the computation of the Surface Laplacian (SL) of the scalp potential, provides data that are interpretable both physically and physiologically. From a physical point of view, the SL is proportional to the radial component of the current density flowing through the skull. It is able to reduce the current diffusion induced by the skull (Carvalhaes & de Barros, 2015), leading to a significant improvement of the spatial resolution of EEG signals (Tenke & Kayser, 2012). From a physiological point of view, the SL provides a fair approximation of the corticogram (Gevins, 1989), defined as the activity one would record if the electrodes were positioned over the dura. Importantly, SL computation requires no assumptions, except that the scalp is locally isotropic. Furthermore, it can be easily computed for each participants and does not require any selection of components (for comparisons between ICA and SL, see e.g., Foffani et al., 2004; Roger et al., 2010; Tenke & Kayser, 2012). Since SL proved to be a very powerful tool in revealing the presence of the CRN, we anticipate that it would also help dissociate the early and late Pe, which would allow us to assess the impact of task difficulty on all response-evaluation related activities (CRN, ERN, early and late Pe) using the same methodology.

## 2. Method

### 2.1. Participants

Sixteen participants participated in the experiment. Each participant gave written informed consent. The study was approved by the ethical committee of the Faculty of Psychology and Educational Sciences at Ghent University. All participants had normal or corrected to normal vision and were neurologically and psychiatrically healthy. Participants were paid 15€ per hour.

### 2.2. Material and procedure

A classic flanker task was modified in order to create two conditions that varied in difficulty. In the easy condition there were four possible stimuli: {,}, [and]. The curly brackets were mapped onto one response button and the blocked brackets onto the other response button. In each trial, one target stimulus flanked by four stimuli (two on each side) was presented. In the difficult condition, there were 8 possible stimuli, namely {,}, [,], (,), | and ¦. Two pairs of brackets were arbitrarily mapped onto the left or the right response button, resulting in a four to one mapping. Congruent trials always consisted of 5 identical brackets, while flanking stimuli on incongruent trials were always stimuli needing another response; i.e., response-incongruent. Congruent and incongruent trials were presented in a randomized order with equal frequency.

The participants were seated in a comfortable armchair in a lightdimmed and sound-attenuated room. They were tested on a Pentium IV personal computer with a 17-in. monitor running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Participants had to press two buttons on a Cedrus response box to give a manual response with the left and right index fingers. The stimulus was presented centrally on a blank screen until a response button was pressed with a maximum of 145 ms. For the remainder of the response deadline, 800 ms, a blank screen was presented. After the response was given or when the response deadline was reached there was an inter trial interval of 1100 ms. During the inter trial interval the screen was blank.