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The error-related negativity associated with different strength of stimulus–response interference

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HIGHLIGHTS

- The error-related negativity (ERN) elicited by both overt and partial errors became larger when the interference was stronger.
- Two different stimulus–response compatibility tasks, a spatial Stroop task and a Simon task, were compared, allowing us to systematically vary the strength of the interference effect.
- Focusing on the partial EMG that was followed by corrective EMG, it appears that the conflict-related N2 likely co-exists with the ERN in a stronger interference situation.

ABSTRACT

Objective: The present study was aimed at clarifying the effect of stimulus–response compatibility (SRC) interference on the ERN.
Methods: We compared ERNs in two tasks differing in the level of interference, an arrow (AR) task classified as a Simon task and a more complex arrow-orientation (AO) task classified as a spatial-Stroop task. We also compared ERNs between partial errors (with initial incorrect movement corrected by a proper full response) and overt (uncorrected) errors.
Results: Behavioral response time and error rate indicated that both interference and ERN amplitude were larger for the AO task than for the AR task. There was no significant difference in the ERN amplitude between the partial and overt errors.
Conclusions: The ERN becomes larger as a function of the SRC interference.
Significance: Our study presented evidence that the ERN may represent response-monitoring associated with the SRC interference.

1. Introduction

Numerous studies have confirmed that commission of an erroneous response elicits the error negativity (Ne) (Falkenstein et al., 1991) or error-related negativity (ERN)[1] (Gehring et al., 1993). The ERN peaks approximately 100–150 ms following the erroneous muscular activity. The ERN has a frontocentral distribution, reflecting neural activity thought to be generated in the anterior cingulate cortex (ACC) (e.g., Holroyd et al., 1998; Kiehl et al., 2000; Miltner et al., 1997; Stemmer et al., 2003).

Initially, the functional significance of the ERN was regarded as some form of error detection (Falkenstein et al., 1995; Gehring et al., 1993, 1995). However, Carter et al. (1998) disputed this interpretation because they found activation of the ACC even for correct trials in a response-competition task using fMRI. They asserted that the ERN might not represent error-detection but a competitive process between correct and incorrect response activations and this was supported by evidence from event-related potential (ERP) studies (e.g., van Veen and Carter, 2002).

In addition, advocators of the conflict-detection account have applied computational models to a number of phenomena concerning both the response-locked ERN and the stimulus-locked N2 (e.g., Yeung et al., 2004). Although the modeling does not attribute the response conflict to any ERP component, it is possible to assume that the strength of the pre-response conflict on correct trials can be estimated by the stimulus-locked N2, whereas the post-response conflict on incorrect trials can be estimated by the response-locked ERN. Furthermore, the response conflict on error trials should be stronger for compatible than for incompatible trials in stimulus–response compatibility (SRC) tasks, because the

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[1] The terms Ne and ERN denote the same component of response-locked ERPs to errors.

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erroneous activation should be corrected much faster on compatible than on incompatible trials, and therefore the overlap of response activation would be greater. Thus, the timing of the overlap is essential in this account (see Burle et al., 2008; Yeung et al., 2004). Although the functional significance of the ERN is still under debate, researchers agree that the ERN relates to response monitoring, the term including both error detection and response-conflict detection.

The ERN has been most often obtained using SRC tasks, because the incongruency induces more errors. Nevertheless, it is surprising that only a few studies have compared ERNs in different SRC tasks (e.g., Christ et al., 2000; Masaki and Segalowitz, 2004). Researchers have developed numerous SRC tasks that should induce the interference effect to varying degrees. The family of SRC tasks has been comprehensively classified by Kornblum's model (1992). Based on this model, as will be discussed below, we can manipulate the interference effect by adopting different SRC tasks that do not share the same locus of interference. Comparison of various SRC tasks may be another potential approach to clarify the characteristics of the ERN.

Christ et al. (2000) tested two different types of SRC tasks (a Simon task and a spatial Stroop task) but found no task difference in the ERN. On the other hand, Masaki and Segalowitz (2004) compared three different types of SRC tasks and found larger ERNs as a function of the interference effect. Because so few papers appear to compare different SRC tasks that induce different levels of interference and there has been a discrepancy among the previous findings, further research should investigate the robustness of the SRC effect. Although Masaki and Segalowitz (2004) clearly showed behavioral results (RT, error rate) across tasks indicative of various levels of interference, they did not show any psychophysiological evidence of their interference manipulation. Therefore, an electrocortical measure to estimate the level of interference would strengthen their argument.

It is well-known that the lateralized readiness potential (LRP) is a good chronometric marker of human information processing (e.g., Coles, 1989; Gratton et al., 1992). On the incompatible trials in the SRC task, the LRP usually shows an incorrect preparation in the early phase of the waveform, which becomes larger as a function of the stimulus–response interference.

In the present study, we compared two SRC tasks that should induce different amounts of interference effect and confirm the validity of our manipulation using results from the LRP. In addition, to monitor the strength of the response conflict we also compared the stimulus-locked N2 components between tasks, because this is said to represent an additional psychophysiological index of response conflict (Yeung et al., 2004). Because both tasks in this study should induce response conflict, incongruent stimuli in the stronger conflict task should elicit a larger N2 according to the response conflict notion (Yeung et al., 2004). Thus, information from not only behavioral results (i.e., RT and error rate) but also the psychophysiological evidence (i.e., LRP and N2) would confirm the validity of the SRC interference manipulation.

We used two SRC tasks, a version of the Simon task (Simon and Rudell, 1967) and a spatial version of Stroop task (Stroop, 1935), in order to manipulate the interference effect, according to the Kornblum's taxonomy (Kornblum, 1992). This taxonomy can distinguish SRC tasks in terms of overlap and dimensional relevance of the stimulus and response. The taxonomy includes eight types of ensembles, which are classified depending on whether the relevant and irrelevant stimulus dimensions or stimulus and response dimensions overlap in item properties.

In the case of the standard Stroop task, for example, the relevant stimulus (color), irrelevant stimulus (color word), and response (color naming) dimensions all overlap on the common properties of color. The taxonomy calls this kind of task a Type 8 ensemble. This classification is also applied to the spatial Stroop task adopted in the present study, in our paradigm called the arrow-orientation (AO) task (see Section 2). In the Simon task there is overlap between the irrelevant stimulus and relevant response dimensions, but there is no overlap in the relevant stimulus and relevant response dimensions and in the relevant and irrelevant stimulus dimensions. The taxonomy calls this kind of task Type 3 ensemble, and is represented by the arrow task (AR) in our paradigm (see Section 2). Thus, the taxonomy clearly ascribes the Stroop (AO) and the Simon (AR) tasks to distinct ensembles.

Kornblum's model also proposes a possible explanation of the locus of the interference effect observed in the Stroop and the Simon tasks in terms of dimensional overlap and dimensional relevance of the stimulus and response. The model presumes that Stroop interference is associated not only with the response identification process but also with the process of stimulus identification of the relevant stimulus, whereas Simon interference is associated only with the relevant response identification process that initially inhibits the automatically-activated irrelevant response and then retrieves the relevant response. Thus, the model also predicts that overall response time for both congruent and incongruent stimuli and time difference between incongruent and congruent stimuli (i.e., interference effect) should be longer for the Stroop than for the Simon task because of longer processing time of the relevant stimulus-property identification.

Previous ERP findings have suggested that the interference effect of these SRC tasks should be ascribed to the response-related stage (e.g., Duncan-Johnson and Kopell, 1981; Masaki et al., 2000; Valle-Inclán, 1996). Kornblum's model and ERP findings suggest that the interference effect is larger for a spatial version of the Stroop task than for the Simon task, because the Stroop task has a stronger connection between both relevant and irrelevant stimulus and response dimensions. The connection of stimulus and response dimensions underlying the interference effect can be shown in the incorrect preparation of the LRP (e.g., see Valle-Inclán, 1996). Thus, we would expect that the stronger the interference effect, the larger the incorrect preparation in the LRP.

To address discrepancies reported in previous studies (e.g., Christ et al., 2000; Masaki and Segalowitz, 2004) our main concern in this study was to investigate whether or not the degree of interference influences the ERN by comparing different types of SRC tasks. It should be noted that this study was not designed to test whether the error-detection account or the response-conflict account is more valid. Instead, we will interpret our results with consideration to both ERN hypotheses.

Previous studies have recorded electromyogram data (EMG) that would reflect the response unit activation to monitor response conflict (e.g., Gehring and Fencsik, 2001; Scheffers and Coles, 2000). Thus, one possible empirical approach to observe the response conflict might be to focus on EMG activities for partial errors (Burle et al., 2008; Masaki and Segalowitz, 2004; Vidal et al., 2000).

Even correct trials with incompatible stimulus–response mappings are more likely to engender simultaneous double responses, producing peripheral activity referred to as "the partial error" that occurs preceding the corrective peripheral activity. These partial errors can be observed in EMG activities recorded from the incorrect responding hand, and these types of responses indeed elicit an ERN regardless of behaviorally correct trials (Burle et al., 2008; Masaki and Segalowitz, 2004; Vidal et al., 2000). Therefore, it is intriguing to test whether or not the ERN elicited by partial errors can represent different magnitudes of the interference effect.

Furthermore, partial errors should have a greater N2 than pure correct responses on incompatible trials (i.e., without incorrect EMG activity), because on partial errors there is more competing activities from the two hands. However, the majority of studies