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Research report

Time-frequency analysis of event-related potentials associated with the origin of the motor interference effect from dangerous objects

Peng Liu

School of Public Management, Northwest University, Xi'an, China

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ABSTRACT

Previous research has suggested that the motor interference effect of dangerous objects may originate from danger evaluations rather than direct response inhibition, as evidenced by a larger parietal P3 amplitude (which represents danger evaluations) under dangerous conditions than under safe conditions and an insignificant difference between dangerous and safe conditions in the frontal P3 component (which represents response inhibition). However, an alternative explanation exists for the null effect of the frontal P3 component. Specifically, this null effect may be attributed to cancellation between the theta and delta band oscillations, and only theta band oscillations represent response inhibition. To clarify this issue, the current study decomposed event-related potential data into different frequency bands using short-time Fourier transform. The results identified an insignificant difference of theta oscillations between dangerous and safe conditions in the mid-frontal area during a 200–500-ms time window. Instead, decreased alpha oscillations were identified in the dangerous compared with the safe condition in Go trials in the right parietal area during a 100–660-ms time window. Regression analyses further indicated that the alpha oscillations significantly contributed to the parietal P3 amplitude in the right parietal area. In summary, the results indicated that when an emergent dangerous object is encountered during the execution of prepared motor actions, an individual may tend to chiefly evaluate the potential dangerousness rather than directly suppress the prepared motor actions toward the dangerous object.

1. Introduction

With the development of manufacturing technology, more machines are used to improve production efficiency. However, the number of accidents that occur during the manipulation of machines increases with increasing contact opportunities between workers and machines. It has been suggested that human behavior is a contributory factor in approximately 80% of these accidents (Fleming and Lardner, 2002). For example, during the process of operating a machine, dangerous elements (e.g., rectangular or round saw blades) in the machine may cut off an individual's finger if the worker's prepared motor actions are not suppressed in time. To reduce the occurrence of these accidents, it is necessary to investigate how we process our prepared motor actions when an emergent dangerous object is encountered. Existing research has addressed this issue from both behavioral (Anelli et al., 2012) and event-related potential (ERP) perspectives (Liu et al., 2017); however, an explanation of the results from time-domain ERP components (e.g., frontal P3 components) remains controversial. The present study aims to successively investigate this issue and provide a deeper investigation of the ERP data via a time-frequency (TF) analysis.

Anelli et al. (2012) have suggested that dangerous objects may elicit a motor interference effect on the prepared response. They adopted a motor priming paradigm (a grasping right hand was used as a prime) and instructed the participants to respond to the categorization of the target objects (natural or artifact) by pressing one of two designated keys. Moreover, the dangerousness of the target was orthogonally manipulated. The study results indicated a motor interference effect from dangerous targets, as evidenced by longer reaction times (RTs) in the dangerous condition than in the safe condition, which suggests that the sense of danger induced by objects may conflict with an individual's prepared motor actions and thus slow his or her response.

To further clarify the origin of the motor interference effect of a dangerous object, research conducted by our laboratory adopted a motor priming paradigm mixed with a Go/NoGo task to imitate a motor situation in which the execution of a prepared motor reaction encounters an emergent dangerous object (Liu et al., 2017). Pictures of a left or right hand were used as primes, and green (Go signal) or red (NoGo signal) circles superimposed on dangerous

E-mail address: liupeng@nwu.edu.cn

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or safe objects were used as targets. Participants were instructed to prepare for the corresponding key press with the hand that was consistent with the handedness of the prime and not execute the key press until a Go signal appeared. Two candidate hypotheses were tested: 1) the motor interference effect may originate from response inhibition directly elicited by dangerous objects, and 2) the motor interference effect may originate from the evaluation of potential danger from a dangerous object. Once the encountered dangerousness is analyzed, subjects could further decide whether the prepared response should be executed. The former hypothesis predicted a more negative anterior N2 component (which reflects conflict detection) and a more positive frontal P3 component (which reflects response inhibition) in the dangerous than in the safe condition. However, the latter hypothesis predicted a more positive parietal P3 component in the dangerous condition than in the safe condition. The ERP analysis of the anterior N2 and frontal P3 components revealed no significant differences in the latencies and amplitudes between dangerous and safe conditions. However, the results showed larger P3 amplitudes at the parietal electrodes (P3, Pz and P4 electrodes) in the dangerous than in the safe condition in the Go trials. Therefore, Liu et al. (2017) concluded that the motor interference effect from dangerous objects might originate from danger evaluations.

Nevertheless, according to previous TF findings, there is an alternative explanation for the null effect between the dangerous and safe conditions in the frontal P3 component, which has been suggested to reflect response inhibition (Eimer, 1993; Falkenstein et al., 1999; Jodo and Kayama, 1992; Smith et al., 2013). There are many types of frequency dynamics in electroencephalogram (EEG) data that lack a representation in the time-domain ERP. A TF analysis could better decompose the frequency characteristics or time-scales of multiple processes that are overlapping in time (Ademoglu et al., 1998; Başar et al., 1999, 2001; Demiralp et al., 1999; Demiralp and Ademoglu, 2001; Samar et al., 1995). The output of this decomposition includes changes in the oscillations described in different frequency bands. These oscillations are known to represent the temporally overlapping activities of several neural networks that perform in different time-scales or frequencies during the performance of a task. It has been suggested that the time-domain frontal P3 component reflects a mixture of at least two sub-processes indexed by theta and delta event-related synchronization (ERS, ERS can be identified by the increase of power at a specific frequency band in association with various cognitive processes) (Barry, 2009; Harper et al., 2014). ERS in the theta band has been related to response inhibition (Barry, 2009; Kamarajan et al., 2004; Kirmizi-Alsan et al., 2006; Yamanaka and Yamamoto, 2010) and central executive and working memory processes (Klimesch, 1999; Sauseng et al., 2005; Tesche and Karhu, 2000). A larger theta ERS has been observed in high conflict compared with low conflict conditions, which indicated the presence of a larger conflict in the former condition. This result has been reported in a number of cognitive conflict tasks, such as the Stroop task (Hanslmayr et al., 2008; Kovacevic et al., 2012; Tang et al., 2013) and the Go/NoGo task (Barry, 2009; Cohen and Cavanagh, 2011; Harper et al., 2014; Kamarajan et al., 2004; Kirmizi-Alsan et al., 2006), among others. Furthermore, ERS in the delta frequency band has been related to stimulus evaluation and decision-making processes (Başar et al., 2001). A smaller delta ERS has been identified in the high conflict than in the low conflict condition in the Stroop task. These results indicated a relatively easier decision for processing an attenuated conflict in the low compared with the high conflict condition (Ergen et al., 2014).

Combined with the ERP results from Liu et al. (2017), which revealed an insignificant difference between the dangerous and safe conditions in the frontal P3 amplitudes in the time-domain, it may be argued that this null effect may be attributed to cancellation between the theta and delta oscillatory activities. Specifically, if the motor interference effect derives, at least in part, from the response inhibition elicited by the dangerous objects, a larger theta ERS (which suggests greater conflicts between response execution and inhibition) and a smaller delta ERS (which suggests more difficult decision to solve the response conflict) are predicted to occur in the dangerous than in the safe condition. As a result, the theta and delta oscillatory activities may be neutralized, which would result in an insignificant difference between the dangerous and safe conditions in the time domain frontal P3 component. Accordingly, the first aim of the current study is to clarify this argument by decomposing the ERP data from Liu et al. (2017) into different frequency bands using short-time Fourier transform (Zhang et al., 2012). If the motor interference effect from dangerous objects is derived, at least in part, from response inhibition, I expect to detect larger theta oscillatory activities during the dangerous than in the safe condition.

The second aim of the study is to present a deeper investigation of the parietal P3 component in the TF domain. Liu et al. (2017) identified larger parietal P3 amplitudes in the dangerous than in the safe condition in Go trials. The study explained the parietal P3 effect based on the notion that more attentional resources were recruited to evaluate danger for dangerous compared with safe stimuli in the Go trials. It has been acknowledged that increased attentiveness to engaging in a task leads to a decrease in alpha band oscillations (Jessen and Kotz, 2011; Klimesch, 2012; Niedermeyer and Lopes da Silva, 2004). Furthermore, alpha event-related desynchronization (ERD, ERD can be identified by the decrease in power at a specific frequency band in association with various cognitive processing) has been suggested to be associated with the parietal P3 component (Peng et al., 2012; Yordanova et al., 2001). Combined with these findings, it is reasonable to expect that at parietal electrodes, a decreased alpha ERD should be observed in the dangerous compared with the safe condition in the Go trials. Moreover, the power of the alpha band oscillations could contribute to the time-domain parietal P3 amplitude.

2. Results

The mean TF power changes were calculated in each time window (steps of 100 ms) relative to the baseline TF power. Fig. 1 shows the topographies of the TF power changes in the event-related delta (2–4 Hz), theta (5–7 Hz) and alpha (8–13 Hz) band activities. Relative to the pre-stimulus baseline, the delta band showed ERS during approximately 0–600 ms (Fig. 1a). In the Go/NoGo task, the delta oscillations showed different patterns between Go and NoGo conditions in two consecutive time windows (T1: 0–300 ms and T2: 300–600 ms) (Müller and Anokhin, 2012). A larger delta ERS was identified in the Go condition than in the NoGo condition in T1 in the centro-parietal area. In contrast, a larger delta ERS was identified in the NoGo condition compared with the Go condition in T2 in the frontal and central area. The different patterns between the T1 and T2 time windows suggested different cognitive processing in the two consecutive time windows. As a similar Go/NoGo task was used in the current study, the delta oscillations were analyzed according to Müller and Anokhin (2012). Two consecutive time windows (T1: 0–300 ms and T2: 300–600 ms) were defined as a within-subject factor. The analyzed time windows of the theta and alpha band oscillations were selected according to the maximum power depicted in the topographic plots (Fig. 1). The theta band yielded ERS relative to the pre-stimulus baseline with maximum power during an approximately 200–500-ms time window over the frontal areas (Fig. 1b). The alpha band showed ERD relative to the pre-stimulus baseline with maximum power during approximately 100–700 ms