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Effects of task complexity on ERP components in Go/Nogo tasks

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ABSTRACT

In Go/Nogo tasks the ERP at frontocentral electrodes generally exhibit a negativity (Nogo-N2) and a subsequent positivity (Nogo-P3) after Nogo in contrast to Go stimuli. The N2 was related to central inhibition or response conflict, while the P3 is most probably related to inhibition of overt response. In an attempt to elucidate the underlying processes in more detail, the effects of task difficulty on Nogo-N2 and Nogo-P3 were investigated and compared with effects on components in the Go-ERPs and with behavior. RT and false alarms were enhanced and the Nogo-N2 and the Nogo-P3 delayed with rising task difficulty. However, the latency effects were smaller for the Nogo-N2 than for the Nogo-P3. The amplitude of the Nogo-P3 decreased with rising task difficulty but no effects on the Nogo-N2 amplitude were found.

In the Go trials an early frontocentral positivity (Go-P2) and a late parietal positivity (Go-P3) were seen. The Go-P2 and Go-P3 showed again similar latency effects as RT, while the amplitudes were not affected by task difficulty. The Go-P3 peaked earlier than the Nogo-P3.

The results show that Nogo-N2 and -P3 are differentially affected by the task manipulations. In particular, the Nogo-N2 reflects the inhibition of a premature response plan, which is delayed in more complex tasks, while the Nogo-P3 appears to be linked to inhibition of motor response. The Go-P2 probably reflects stimulus-response activation, which considerably influences the Nogo N2 when measured by the Nogo minus Go difference waves (N2d), whereas the Nogo-P3d solely consists of the Nogo-P3.

1. Introduction

In recent years the concept of inhibition has gained much interest in neuroscience and in cognitive psychology and various neuroscience methods have been used to study inhibitory processes, such as ERPs (e.g. Fassbender et al., 2006; Enriquez-Geppert et al., 2010) and fMRI (Aron et al., 2007). A standard task to induce inhibition is the Go/Nogo task, in which participants are asked to respond to certain stimuli only, while refraining from responding to the other stimuli. Event-related brain potentials (ERPs) measured in Go/Nogo tasks consistently reveal differences, which consist of a negative displacement (N2) and a subsequent positivity (P3) in Nogo- as compared to Go ERPs (e.g. Karlin et al., 1970; Falkenstein et al., 2002). Both potentials are pronounced over frontocentral scalp areas. The N2 is larger when time pressure (as imposed by a RT deadline) is enhanced (Jodo and Kayama, 1992). Also, the N2 is smaller and delayed in subjects with high error rate (false alarms) compared to participants with low error rate (Falkenstein et al., 1999). These results support the view that the N2 is related to an inhibitory process. This process is probably not restricted to overt responses, but also occurs after the inhibition of covert responses, such as counting (Bruin and Wijers, 2002) or imagined responses (Burle et al., 2004). In an influential review, Folstein and van Petten (2008) recently claimed the relation of the N2 to control in various conflict tasks, and inhibition is the type of control needed in Go/Nogo tasks.

The evidence that the N2 reflects inhibition was recently challenged in two ways: Bruin et al. (2001) suggested that the N2-effect is due to, or at least influenced by positive ERP activity in Go trials, which possibly reflect response activation. In addition, Nieuwenhuis et al. (2003) and Donkers and van Boxtel (2004) suggested that the N2 reflects response conflict rather than inhibition.

The Nogo-P3 has also been related to inhibition by most researchers (e.g. Fallgatter and Strik, 1999; Tekok-Kilic et al., 2001). Furthermore, the Nogo-P3 is larger for an overt than for a counting (Bruin and Wijers, 2002) or an imagined response (Burle et al., 2004). These results underline the dependence of the Nogo-P3 on overt (non-) responding. The Nogo-P3 is not likely to be a real-time correlate of inhibition, since it often occurs after the response in Go trials. Hence, it could simply reflect the closure of the inhibition process reflected in the Nogo-N2, or a separate response-monitoring process. Accordingly, the Nogo-P3 was associated with efficiency of inhibitory control or evaluation of the inhibition process (Liotti et al., 2005; Schmajuk et al., 2006). In summary the functional significance of N2 and P3 in Nogo trials is not quite clear up to now (see also the comprehensive review of Huster et al., 2013-this issue).

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In the present study we manipulated task difficulty in order to investigate possible effects on N2 and P3. By comparing those putative effects with behavioral and ERP effects in the Go trials we hoped to shed more light on the functional significance of these components. In addition, by manipulating RT deadlines we wanted to assess the occurrence and variation of a fronto-central positive component in Go trials, which could contribute to the Nogo–Go difference. If this positivity was related to response activation, it should vary with task difficulty in a similar way than RT.

Task difficulty is known to influence task-relevant ERP components. In particular, the parietal P3 is usually delayed and its amplitude sometimes reduced in difficult tasks compared to easy tasks (e.g. Kok, 2001; Polich, 1997). Surprisingly, there are, to our knowledge, only few studies that have directly or indirectly manipulated task difficulty in Go/Nogo tasks. In their seminal study, Pfefferbaum et al. (1985) used two stimulus-response mapping rules with different directness and hence task difficulty. In the easy task words were used ("push", "wait") that directly indicated the response; in the more difficult task symbols were used with no direct relation to the required response. The authors found an N2-effect (i.e. a Go vs. Nogo difference in the N2 latency range) for the symbol stimuli only, while an N2-effect appeared to be absent for the direct word stimuli. However, in a later study of Verleger et al. (1991) a Nogo-N2 was visible also for direct stimuli such as used in Pfefferbaum et al. (1985). Kiefer et al. (1998) used auditory stimuli and manipulated difficulty by discriminability. In the Nogo trials they found only a very small N2 (which is due to the auditory stimulation; cf. Falkenstein et al., 1999, 2002) and a clear P3. While the former was not changed, the latter was increased in the more difficult task. Fox et al. (2000) manipulated task difficulty by having their participants respond or withhold responding to stimuli on the basis of either elemental information (which was unique to the Go resp. Nogo stimuli) or configural information (which was defined by the compound of two stimulus elements). In comparison to Go stimuli, elemental Nogo stimuli elicited both, an enhanced fronto-central N2 and a P3. In contrast, configural Nogo stimuli showed only a minor N2 enhancement and a more parietally distributed P3 component. The elemental task involved Nogo stimuli that may have induced pop-out effects due to their deviance from the Go stimuli, which was not the case for the configural task. Hence, the authors attributed the Nogo-N2 to an automatic detection of deviant stimulus features, rather than to inhibition.

A more recent study of Maguire et al. (2009) manipulated task difficulty by an increasing level of semantic processing using an object categorization task. In the single task an image of a car was associated with Go trials and an image of a dog with Nogo trials. In the multiple condition Go and Nogo trails were associated with different images of cars and dogs. Finally, the semantic condition included a wide range of objects from different categories for Go trials and a wide range of animals for Nogo trials. Increased task difficulty decreased the Nogo-P3 amplitude and increased its latency, while the Nogo-N2 was not significantly affected by the difficulty manipulation.

In summary, the literature results on effects of task difficulty on N2 and P3 are contradictory. With regard to the N2, there are either no or rather clear effects and concerning the P3, its amplitude increases or rather decreases or effects of topography occur. These differences may be due to different paradigms. In particular, they possibly result from different stimuli used for manipulating difficulty in the prior studies (with the exception of the Kiefer et al. (1998) study, which, however, suffered from the small N2 due to the auditory stimuli).In the present study we aimed at manipulating task difficulty regarding the stimulus-response mapping only, while leaving the stimulus pattern virtually constant. Also, possible pop-out effects were avoided by using similar word stimuli for Go and Nogo stimuli and making Go and Nogo trials equiprobable. Visual stimuli were used in order to obtain a large N2 and P3 in the Nogo trials. We tried to enhance inhibition by two means: first we had our participants respond with one finger only, which should induce high response preparation and premature response tendencies on each trial; second, we administered time pressure by an RT deadline method. In the easiest task (task 1) the words directly indicated the response; this task resembled the "intact word" condition in experiment 1 of Pfefferbaum et al. (1985). This task was made more difficult by reversing the assignment of responses to stimuli, which creates an incompatible S-R-mapping (task 2). In task 3 the S-R mapping was made rather complex while using the same stimuli as in tasks 1 and 2. A further issue addressed in our study is the problem whether difference waves between Nogo- and Go-ERPs, or rather raw Nogo ERPs are more appropriate to study inhibition-related ERPs and their changes due to experimental manipulations such as task difficulty. It is well possible that changes in the difference waves are due to changes in the Go rather than Nogo ERPs. Hence, in our study we studied both, difference waves as well as raw ERPs.

In summary, in the present study effects of task complexity on ERP components in Go/Nogo tasks were analyzed. This was done by specifying the relative contributions of Nogo- and Go-related ERPs to the Nogo–Go difference in order to elucidate the functional significance of the ERPs in this task.

2. Materials and methods

2.1. Participants

Fifteen healthy right-handed young subjects (7 female; 19 to 29 years, mean 24.5 years) participated in the study. They were recruited from a student population, had on average 13 (school) plus 3 (university) years of education, were free of any disease, and did not take any medication. All subjects gave signed informed consent for participation in the study.

2.2. Task

Among other tasks the participants performed three different Go/Nogo tasks. In all three tasks word stimuli were presented for 100 ms in the center of a 17" monitor; each word consisted of five letters and was 6° wide. For all tasks the words DRÜCK (German word for press) and STOPP (stop) were presented either in uppercase ("DRÜCK", "STOPP") or in lowercase ("drück", "stopp"). The uppercase letters were 1.5° high, the lowercase letters were about 1° high. The different words were presented in a random order within each block. The stimuli were presented with a constant interstimulus interval of 1400 ms in tasks 1 and 2, and 1600 ms in task 3. This was aimed at compensating for the expected RT prolongation in task 3. In task 1 (easy, compatible) the targets (Go-stimuli) were "DRÜCK" and "drück", and the nontargets (Nogo-stimuli) were "STOPP" and "stopp", so the mapping was direct and the response compatible to the stimulus meaning. In task 2 (easy, incompatible) the targets (Go) were "STOPP" and "stopp", and the nontargets (Nogo) were "DRÜCK" and "drück", so the mapping was reversed and incompatible. In task 3 (complex) the targets were "drück" or "STOPP", and the nontargets were "DRÜCK" and "stopp", so the mapping was complex and required substantial use of working memory. In all conditions Go and Nogo stimuli were equiprobable, i.e. 50% each. The participants were asked to press a button with their right forefinger to each target, and refrain from responding after a nontarget. Time pressure was administered by setting a task-specific RT deadline (500, 600 and 800 ms, for tasks 1, 2 and 3, respectively). When participants failed to meet the deadline, a feedback tone (1000 Hz, 70 dB SPL) was presented at 1200 ms poststimulus. The participants were asked to avoid the feedback tone by trying to keep the deadline, even at the risk of committing occasional errors. Tasks 1 and 2 contained 132 stimuli each, task 3 contained 200 stimuli. The order of the three tasks was counterbalanced across the subjects. 50 practice trials were administered before each task.