Clinical Neurophysiology 119 (2008) 704–714

www.elsevier.com/locate/clinph

Movement-related potentials in the Go/NoGo task: The P3 reflects both cognitive and motor inhibition

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Accepted 22 November 2007

Abstract

Objective: The contribution of movement-related potentials (MRPs) to the Go/NoGo N2 and P3 'inhibitory' effects is controversial. This study examined these components in overt and covert response inhibition tasks.
Methods: Twenty adult participants counted or button-pressed in response to frequent (60%) and rare (20%) Go stimuli in a Go/NoGo task with equiprobable rare (20%) NoGo stimuli.
Results: The N2 NoGo effect did not differ between Count and Press responses, but the P3 NoGo effect was amplified during the Press task. Additionally, subtraction of the ERP waveform for Count NoGo from Press NoGo trials revealed a positivity between 200 and 400 ms, occurring maximally over the central region, contralateral to the responding hand. This difference wave became significant at 210–260 ms, close to the estimated time taken to stop an overt response.
Conclusions: The N2 NoGo effect may reflect a non-motoric stage of inhibition, or recognition of the need for inhibition, while the NoGo P3 may overlap with a positive MRP occurring specifically on trials where overt motor responses must be inhibited.
Significance: The study confirms that the N2 and P3 NoGo effects are not solely due to movement-related potentials, and posits the NoGo P3 as a marker of motor inhibition.

Keywords: Inhibition; Movement-related potentials; N2; P3; NoGo

1. Introduction

In the Go/NoGo task, it is common to observe a larger frontal N2 and frontocentral P3 on trials where inhibition is needed (e.g., Kok, 1986; Jodo and Inoue, 1990; Jodo and Kayama, 1992; Bokura et al., 2001; van Boxtel et al., 2001; Bekker et al., 2004; Smith et al., 2006). Results from the stop-signal task are more complex: the N2 is larger, and the P3 smaller when inhibition fails (De Jong et al., 1990; Dimoska et al., 2003; Kok et al., 2004; Ramautar et al., 2004; Dimoska et al., 2006; but see Schmajuk et al., 2006, for a larger N2 for successful stops). The functional significance of these effects is under debate: apart from the possibility of attentional differences, the N2 may represent motor inhibition (e.g., Kok, 1986; van Boxtel et al., 2001) or detection of response conflict (Nieuwenhuis et al., 2003; Donkers and Van Boxtel, 2004), while recently, other researchers have argued that the P3 represents the inhibitory process (Kok et al., 2004; Ramautar et al., 2004; Bekker et al., 2005; Dimoska et al., 2006; Smith et al., 2006, 2007).

In most of the Go/NoGo literature, the contribution of movement-related potentials to the NoGo N2 and

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1388-2457/$32.00
doi:10.1016/j.clinph.2007.11.042

P3 effects has been controversial. For example, it is possible that, rather than increased positivity in the P3 range reflecting increased inhibitory activity on NoGo and successful inhibition trials, the effects result from movement-related negativity occurring on Go and failed inhibition trials. The literature seems to have readily adopted the position that variations in N2 and P3 represent at least some real inhibitory activation differences, yet the majority of researchers cite only two studies (Pfefferbaum et al., 1985; Bruin and Wijers, 2002) which have examined overt/motor forms of inhibition (e.g., "button press to Go but not NoGo stimuli") along with covert/non-motor inhibition (e.g., "count the Go but not NoGo stimuli"), seemingly ignoring recent evidence which suggests that motor potential overlap may contribute to some of these effects. Because of the importance of these findings for theories of inhibitory control, it is essential to determine whether the N2 and P3 'inhibitory' components differ when overt vs. covert responses are inhibited.

Pfefferbaum et al. (1985) examined the effects on N2 and P3 in an equiprobable visual Go/NoGo task. In separate blocks, participants either counted or button-pressed to Go stimuli. The NoGo N2 effect was present during both tasks, but larger in the press condition. For the P3, a frontocentral increase for NoGo stimuli was observed in both the count and press blocks, with no significant main effect of task. The authors concluded that the NoGo effects were not dependent on the execution or inhibition of an overt motor response.

Bruin and Wijers (2002) had participants perform a visual Go/NoGo task with varying levels of Go stimulus probability (25%, 50% and 75%), with counting or button pressing in response to the Go stimuli. The usual N2 NoGo effect, and frontocentral increase in P3 to NoGo stimuli, were reported for the press condition. In the count condition, a similar N2 effect was found, although the P3 effects differed from the press version: the NoGo P3 in the count condition was never larger in amplitude than the Go P3, even at frontocentral sites. This last result is not mentioned in the majority of the current literature, and Bruin and Wijers did not discuss it.

For support on its position on inhibitory vs. movement-related potential explanations of the N2 and P3 NoGo effects, the literature usually cites only the above two studies, yet recent evidence both supports and contradicts those results. In other studies, the N2 NoGo effect has been established as identical (or at least not significantly different) for overt and covert responses (Bruin and Wijers, 2002; Wang et al., 2002; Burle et al., 2004), in contrast to Pfefferbaum et al.'s (1985) original result, and Van't Ent and Apkarian (1999) have found similar N2 and P3 NoGo effects when the participants responded with a button press and with a saccadic eye movement. The effect of response mode on P3 is more controversial still: similar to Pfefferbaum et al. (1985), Starr et al. (1995) found no main effect of task, while Polich (1987) and Barrett et al. (1987) report larger P3 amplitudes with covert than overt responses, and Burle et al. (2004) reported larger P3 amplitudes for an actual rather than imagined response. Hatta et al. (1997) have further reported that P3 amplitude to non-targets was not affected by task, while topography to targets was. In addition, the Go/NoGo effects on P3 are also under debate: Burle et al. (2004) supported Pfefferbaum et al. (1985) by describing similar NoGo P3 effects in overt and covert tasks, yet Nakata et al. (2004) found similar results to Bruin and Wijers (2002), of no frontocentral increase for NoGo relative to Go in their Count condition. Thus, the issue of true inhibitory vs. movement-related Go/NoGo differences is far from resolved.

The most convincing evidence for the influence of movement potentials, in relation to the P3 in particular, comes from Salisbury's group. Salisbury et al. (2001) had participants perform three tasks: an oddball task in which subjects counted rare (15%) auditory targets; an identical task in which subjects pressed to these targets; and a task in which subjects pressed to the same auditory targets on 100% of trials. The target-locked waveforms in this third task were assumed to be a good model of movement-related activity, but without any overlap with the P3 since participants responded on every trial. Salisbury et al. subtracted ERPs from the simple RT task from ERPs in the oddball task requiring a motor response, after matching RTs from both tasks. The corrected and uncorrected press oddball P3 were then compared to P3 from the count oddball task. Before correction, P3 amplitude to press-targets was smaller in the midline, and showed a parietally maximal topography, as compared to the centroparietal maximum in the count task. The removal of movement-related potentials via the correction procedure increased midline P3 amplitude to the press-targets, mostly in the frontocentral region, but did not change the amplitude or topography of the P3 relative to count-targets in normalised data. Laterally, the uncorrected P3 showed a left < right effect in frontal and central regions, while the corrected P3 was symmetrical. The authors stated that the typical frontocentral Go/NoGo effect may be produced by a general reduction in Go P3 due to movement-related potentials at these sites, rather than an amplitude increase on NoGo trials.

Salisbury et al. (2004) presented participants with a series of tones, with three tasks associated with these stimuli. In one task, participants were required to silently count the number of rare (15%) stimuli embedded in the series of frequent stimuli ('silent-count task'). In another task, participants were required to respond to the rare stimuli with a button press ('Go task'), and in the third task, participants were required to respond to the frequent but not the rare stimuli ('NoGo