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Electrophysiological correlates of attention, inhibition, sensitivity and bias in a continuous performance task

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Abstract

Objective: The aim was to verify the occurrence of proposed electrophysiological correlates of attention, inhibition, sensitivity and bias in a continuous performance task and to support their functional interpretation by using a manipulation intended to enhance subjects' response bias.

Methods: Electroencephalographic activity was recorded during administration of a transformed version of the AX continuous performance task in which cues signaled response alternatives.

Results: The previously reported parietal P3, NoGo–N2, NoGo–P3 and contingent negative variation were replicated. Besides, the frontal selection positivity and the lateralized readiness potential were demonstrated. With increasing Go-probability, the parietal P3 to the cue increased without changes in other cue-related correlates. In addition, reaction times decreased, non-parametric measures of sensitivity and bias decreased, the NoGo–N2 increased, and the parietal Go–P3 decreased.

Conclusions: The proposed electrophysiological correlates were identified. Sub-threshold LRPs suggested a central inhibition mechanism. Cue-related correlates revealed that anticipation of a high-probability Go-stimulus involves attention rather than bias. This implies that the increased NoGo–N2 reflected an increase in conflict rather than an increase in inhibition.

Significance: Electrophysiological measures can greatly enhance our understanding of normal and abnormal information processing during continuous performance and related tasks.

Keywords: Event-related potentials; P3; NoGo–N2; Frontal selection potential; Lateralized readiness potential; Contingent negative variation

1. Introduction

In the AX continuous performance task (CPT-AX) (Rosvold et al., 1956), which has been widely applied both inside and outside the context of behavioral disturbances, various letters are alternately presented on a computer screen. Subjects are instructed to press a button when the letter X (Go or Target) succeeds the letter A (Cue), but to refrain from responding when a letter other than X (NoGo) succeeds the letter A. Decrements in information processing have been inferred on the basis of specific error patterns (Corkum and Siegel, 1993; Halperin et al., 1988; Losier et al., 1996; Riccio et al., 2002). Omission errors are interpreted to reflect deficits in attention (the ability to focus on the processing of Go-stimuli over others), whereas commission errors are interpreted to reflect deficits in inhibition (the inability to withhold a response). The application of signal-detection theory provides measures of sensitivity (the perceptual ability to discriminate between Targets and Non-Targets) and bias (the decision criterion for responding). Behavioral measures, however, merely reflect the overt outcome of more covert information processing. Event-related potentials (ERPs) can be used to provide more insight into the actual brain processes employed during task performance. This holds especially for processes occurring in the absence of overt behavior, like preparatory and inhibitory processes.

In previous ERP studies using visual Go/NoGo tasks, a larger positivity has been found in response to Go-stimuli than in response to NoGo-stimuli around 300 ms at posterior electrodes sites (Bruin et al., 2001; Tekok-Kilic et al., 2001). This parietal P3 has been convincingly claimed to reflect

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attention (Picton, 1992). At frontocentral electrode sites, a negative deflection (around 150–400 ms) and a positive deflection (around 300–500 ms) have been found to be larger for NoGo-stimuli than for Go-stimuli (Eimer, 1993; Kok, 1986). Although their functional interpretation has been disputed (Falkenstein et al., 1999), both the NoGo–N2 and the NoGo–P3 have been claimed to reflect inhibition (Bruin and Wijers, 2002; Jodo and Kayama, 1992; Kopp et al., 1996; Pfefferbaum et al., 1985; Roberts et al., 1994). The use of cued-Go/NoGo tasks, such as the CPT-AX, offers the possibility of studying processes occurring in the Cue-Target interval. Gratton et al. (1990) reported that the amplitude of the parietal P3 elicited by the Cue is proportional to the amount of information it provides regarding the upcoming imperative stimulus. Another electrophysiological manifestation of preparatory activity is the Contingent Negative Variation (CNV) (Dias et al., 2003; Jonkman et al., 2003; Roberts et al., 1994), which has been subdivided into a relatively early wave associated with orientation towards the Cue (O-wave) and a relatively late wave associated with the expectation or preparation of responding (E-wave) (Brunia, 1988; MacCallum, 1988; Rohrbaugh et al., 1976, 1986).

The present work aims at identifying electrophysiological correlates of attention, inhibition, sensitivity and bias in the CPT-AX. Based on previous results, the parietal P3s elicited by the Cue and the Go-stimulus are proposed as correlates of attention, whereas the NoGo–N2 and the NoGo–P3 are proposed as correlates of inhibition. The frontal selection potential (FSP), a positive deflection starting around 150–200 ms reflecting the point in time at which task-relevant stimuli have been discriminated from other stimuli (Kenemans et al., 2002; Smid et al., 1996), is proposed as a correlate of sensitivity. It was studied by comparing the Cue to the NoCue (stimuli not signaling the subsequent presentation of a Go-stimulus), and the Go-stimulus to the X-only (Non-Target X not preceded by a Cue). The late CNV and the LRP, which reflects activity selectively related to the hand for which a response is prepared (Kutas and Donchin, 1980), are proposed as correlates of bias. Since a pre-requisite for measuring the LRP is that the Cue signals response alternatives (De Jong et al., 1990; Rohrbaugh et al., 1976), the CPT-AX was transformed into a two-choice Go/NoGo task by defining a second Go-stimulus ‘BX’. The LRP might additionally provide information on the properties of inhibitory control: inhibition is assumed to be centrally mediated in the case of sub-threshold LRPs, and predominantly peripherally mediated in the case of supra-threshold LRPs (De Jong et al., 1990, 1995).

To support the functional interpretation of the proposed electrophysiological correlates, we increased the probability of the Go-stimulus in a second study. This increase was expected to enhance subjects’ expectation of a Go-stimulus, which should be reflected in a larger parietal P3 or a larger CNV to the Cue, and to heighten subjects’ tendency to respond, which should be apparent from an increase in the number of pre-mature responses to the Cue, a decrease in reaction times, a decrease in bias (reflecting a more liberal response criterion) and an increase in the amplitude of the CNV and LRP. As a result, the demands made on the inhibitory system increase, which should be apparent from an increase in the number of commission errors or an increase in the amplitude of the NoGo–N2 (Bruin and Wijers, 2002; Eimer, 1993; Nieuwenhuis et al., 2003). Inducing impulsive behavior in healthy subjects by manipulating Go-probability might provide more insight into abnormal information processing in clinical populations suffering from a deficient inhibitory system (Barkley, 1997; Moeller et al., 2001; Quay, 1997).

2. Methods

2.1. Study 1

2.1.1. Subjects

Thirteen right-handed subjects, 9 students and 4 employees of Utrecht University, participated in this study (mean age = 23.38, age range 19–30, 4 males). Subjects were requested not to use drugs within 2 weeks and to restrict the use of nicotine and caffeine within 12 h prior to participation. Although inclusion eventuated in comparable results, two subjects that reported the use of psychopharmacological medication were excluded from data analysis ($n = 11$, mean age = 23.09, age range 19–30, 9 students, 3 males). All subjects claimed to have normal or corrected-to-normal vision. Students received € 6.80 per hour, whereas employees were not paid for participation. The Ethics Committee of the University Medical Center Utrecht approved this study.

2.1.2. Procedure and tasks

After subjects signed an informed consent and the EEG and EOG electrodes were attached, a computer screen was positioned in front of the subject at a distance of 100 cm in an acoustically and electrically shielded room. Three tasks were presented in balanced order. In the CPT-ABX, discussed here, the uppercase letters A, B, C, D, E, F, G, H, J, L and X were presented against a gray background between two continuously present vertical bars in the middle of the computer screen. The distance between the vertical black bars (width 0.05°, height 0.95°) was 1.9°. Each black letter (width 1.43°, height 0.95°) appeared for 150 ms. Inter-stimulus intervals varied between 1400 and 1600 ms. Subjects were instructed to press a right button with the right index finger when the letter X followed the letter A, and to press a left button with the left index finger when the letter X followed the letter B. This instruction reversed in half of the blocks. Both speed and accuracy were stressed.

To control for frequency differences, the letter H always appeared with a frequency of 20%, just like the letter X.