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Research report

Higher, faster, stronger: The effect of dynamic stimuli on response preparation and CNV amplitude

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HIGHLIGHTS

- ► Two new response preparation tasks were designed to gain an optimal CNV.
- ► Dynamic stimuli were used in a regular and a Go/No-go version of the task.
- ► Response times increased as the probability of response requirement decreased.
- ► CNV amplitude was larger when probability of response requirement was higher.
- ► The dynamic task promotes response preparation.

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ABSTRACT

The contingent negative variation (CNV) is a slow negative shift in the electroencephalogram (EEG), observed during response preparation. To optimalize the CNV paradigm, this study developed a task using dynamic stimuli and next combined this task with a Go/No-go test. In the first experiment, 19 healthy volunteers were subjected to the classic Traffic light (TL) task and the new dynamic Lines task. In the Lines task, response time was faster and CNV amplitude was larger compared to the TL task. In the second experiment, 20 healthy participants were tested on a Go/No-go version of the Lines task. Response times increased as the probability of response requirement decreased. CNV amplitude was larger when probability of response requirement was higher. In conclusion, the dynamic task promotes response preparation. The new tasks may be especially valuable in groups with attention difficulties (i.e. elderly or ADHD patients).

1. Introduction

The contingent negative variation (CNV) is a slow negative shift in the electroencephalogram (EEG) which can be observed during response preparation to an anticipated stimulus [1–3]. Since its discovery by Walter in 1964 it has been studied extensively [4]. The amplitude of the CNV has been shown to increase with increased motivation and attention [2,5]. The diversity of tasks that are employed to evoke the CNV reflects the variety of applications of the CNV, ranging from fundamental research to studies in different clinical groups. The CNV may be affected in patients with attention deficit/hyperactivity disorder (ADHD), Alzheimer's disease (AD) and Parkinson's disease (PD) and can also be used to evaluate drug effects [6–11]. Hence, the CNV could potentially be used to screen for normalization of CNV amplitude in neuropsychiatric patients in response to treatment. The current paper describes the development of instruments that could eventually be applied as a screening tool, seeking to implement previously acquired knowledge about the CNV to optimize the CNV paradigm and reliably produce large CNVs. To this end, new response preparation tasks were designed to promote motivation and attention during task performance and induce larger CNVs and faster responses compared to conventional response preparation tasks.

Two components can be distinguished in the CNV, an early and a late component or wave, or the 'O-wave' and 'E-wave', referring to orientation and expectancy [12,13]. The early wave increases with stimulus intensity, is enhanced when auditory warning stimuli are used, and habituates over trials, all of which support that it reflects an orienting response [14–16]. It has been proposed that the late CNV is a composite of a readiness potential and stimulus preceding negativity [3,17], reflecting motor preparation and stimulus anticipation [18].

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The early CNV has its cortical origin in prefrontal supplementary sensorimotor areas; the late wave in prefrontal, supplementary sensorimotor, primary somatosensory, primary motor, temporal and occipital areas [19]. Hence, early CNV has been found to be least prominent at the Pz electrode location whereas the late wave was hardly visible at the Fz electrode [13,20].

The classic CNV task constitutes a warning stimulus (S1) followed by an imperative stimulus (S2) after a fixed and known interval. Stimulus manipulations differentially affect the early and late CNV waves [21]. For example, the amplitude of the early CNV wave increases with increased warning signal duration [13], whereas the amplitude of the late wave increases if the imperative stimulus contains information about the required response [3]. In a Go/No-go paradigm, in which the warning stimulus gives information about the required response, the warning stimulus may affect both early and late CNV [22–24].

In order for the response preparation task to be used as a screening tool, it needs to reliably evoke a CNV. Since CNV amplitude has been reported to be decreased in clinical groups such as PD and ADHD patients [7,25], a successful task should induce large CNV waves. To acquire an optimal CNV, a substantial number of trials have to be recorded in which the subjects have to produce speeded responses. Furthermore, the interval between S1 and S2 needs to be rather long (3–4 s) in order to observe both an early and a late wave [26]. This is potentially problematic, as especially the elderly, children, AD and ADHD patients may suffer from loss of focused attention and possibly fail to show an anticipatory response [8,27]. In this study, an attempt was made to overcome these problems by developing new tasks using stimuli that promote response anticipation.

In a conventional response preparation task, using static stimuli, there is a 4-s window in which nothing happens and attention is easily diverted away from the task. Therefore, it was decided a new task should employ moving stimuli. We designed a task in which participants view two lines moving toward each other that intersect after 4 s, to which the participant has to respond by a button press. In this 'Lines task' participants can continuously track the lines during the interval between S1 (the appearance of the lines) and S2 (the crossing of the lines). A major advantage of this task as opposed to static tasks or dynamic tasks in which the timing of S2 is varied [28] is that the movement of the lines allows very precise estimation of the occurrence of the imperative stimulus which was expected to enhance CNV amplitude and speed responses. An additional advantage of the Lines task could be that participants may feel more encouraged to provide a quick response and hence, maintain focused attention. In experiment 1, we tested the hypothesis that the 'Lines task' would lead to improved response preparation as indicated by an increase in late CNV amplitude and faster response times when compared to a standard CNV task using static stimuli.

Once efficacy of this task was established, the task was further adapted, creating a Go/No-go task. Within a Go/No-Go task, it is uncertain whether a response will be required. We were interested to see how this would affect the CNV. Moreover, in contrast with the S2 in the Lines task, the imperative stimulus in our Go/No-Go task carries information as to whether a response has to be given or not, an aspect that may affect not only the late, but also the early CNV wave. Both early and late CNV wave, as induced by the Go/No-go task were studied in experiment 2.

2. Experiment 1

2.1. Method

2.1.1. Participants

Nineteen healthy male volunteers (mean age = 23.4, SD = 5.4) were selected and paid to participate. They were all right handed. Participants were recruited by means of advertisement posters in university buildings and advertisements in the university newspaper. All subjects gave written informed consent. The study was part of a larger study which was approved by the ethical committee of Maastricht University and conducted in accordance with the Declaration of Helsinki 1975, revised Seoul, 2008.

Table 1
Mean amplitudes (SEM) of the CNV for 3 electrode positions of experiment 1.

Electrode	Stoplight	Lines
C3	−5.12 (0.60)	−9.29 (1.39)
Cz	−5.79 (0.81)	−11.07 (1.63)
C4	−4.62 (0.54)	−8.60 (1.41)

2.1.2. Procedure

Participants were invited into the lab at either 8:00 or 8:30 AM. EEG was measured using eleven electrodes placed on the scalp, according to the 10–20 system (Jasper, 1958) at the Fz, F3, F4, Cz, C3, C4, Pz, P3, P4, O1 and O2 electrode positions. Electrodes placed on the left and right mastoid served as reference channels. The ground electrode was placed at the AFz location on the forehead. An electrooculogram (EOG) was measured bipolarly above and below the right eye and horizontally next the left and right eye. Impedances were kept below 5 kΩ. Data were sampled at 1000 Hz and filtered online between 0.05 and 100 Hz. Participants received task instructions both orally and on the computer screen. They performed two different tasks: first a standard response preparation task, the 'TL task' (static task) immediately followed by the 'Lines task' (dynamic task).

2.1.2.1. CNV Traffic light task. In the CNV Traffic light (TL) task, participants watched the computer screen and were presented with a filled red circle (S1) on a black background. After 4 s, the red circle turned green (S2). Subjects were instructed to respond to the green circle by pressing a button with the index finger of the dominant (right) hand on a table mounted response box as fast as they could. The test consisted of 32 trials.

2.1.2.2. CNV Lines task. In the CNV Lines task, S1 was the appearance of two red line drawings. The Lines were oriented at a 90° angle of each other and after appearing both moved diagonally upwards to the center of the screen (forming and inverted V). The full movement of the lines spanned approximately 10 cm^2. Participants were instructed to fixate on the center of the screen between trials. This was indicated by a fixation cross, which disappeared at the start of the trial. After 4 s, the Lines crossed and turned green (S2). At this moment, participants pressed a response button with the index finger of the dominant (right) hand as fast as possible. The visual angle between the fixation cross and the location where the lines crossed was 0.026°. The test consisted of 25 trials.

2.1.3. Data analysis

EEG data were screened for artifacts offline, corrected for eye movements [29] and a low pass filter of 10 Hz was applied. Event-related potentials were extracted by stimulus locked averaging of epochs starting 100 ms before S1 and ending 1000 ms after S2. A baseline correction was applied on the whole epoch, using the 100 ms interval preceding S1 as reference. Late CNV amplitude was calculated by averaging the amplitude over the last 100 milliseconds before S2. Since the CNV amplitude was expected to be maximal at the central electrodes analyses was restricted to Cz, C3 and C4 electrodes.

Reaction time and EEG data were analyzed using repeated measures analysis of variance (ANOVA) with the within subjects factor *task* which had two levels, namely the TL task and the Lines task. For the amplitude data there was an additional within subjects factor *electrode* which had 3 levels (C3, Cz, C4). The behavioral dependent variable was *response time* (in ms) of correct responses (i.e. excluding responses before the lines changed color). The effects were evaluated using Greenhouse–Geisser correction and were considered significant at $p < 0.05$. Where necessary, the Bonferroni correction was applied. In the case of a significant main effect, post hoc pairwise comparisons were conducted. Interaction effects were analyzed post hoc by conducting additional repeated measures ANOVAs, including only those factors that were involved in the interaction. Only significant effects are reported.

2.2. Results

Average response time in the Lines task was faster than in the standard TL task (M_{TL} = 247 ms, M_{Lines} = 59 ms; $F_{1.0,0,18.00}$ = 932.752, $p < 0.001$).

Averaged CNV waves recorded at the Cz electrode during performance of the TL task and the Lines task are shown in Fig. 1. Mean CNV amplitudes at all electrodes are presented in Table 1. Amplitude of the CNV was significantly affected by both task ($F_{1.00,18.00}$ = 8.653, $p < 0.05$) and electrode position