International Journal of Psychophysiology 128 (2018) 52–61

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Exploring the maximum duration of the contingent negative variation

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ARTICLE INFO

Keywords:
Contingent negative variation
Slow cortical potential
Event-related potential
Reaction time
Current source density

ABSTRACT

While the contingent negative variation (CNV) has been the subject of extensive research over the last fifty years, the maximum duration during which such cortical negativity can be maintained has, to the best of our knowledge, never been systematically explored. Participants were presented with the classic S1–S2 paradigm task, where a warning stimulus (S1) acts as a cue for the appearance of an imperative stimulus (S2). A fast motor response was required upon S2 arrival. Inter-stimulus intervals (ISIs) of 2.5, 5, 7.5 and 10 s duration were presented in blocked fashion. Data was analysed using both EEG referenced to linked mastoids and the current source density (CSD) technique, which maximizes the cortical origin of the measured voltage. Mean late CNV (lCNV) amplitude was found to be significantly higher for fast reaction time (RT) trials when CSD data was split according to the median into 'fast' and 'slow' RT halves. Post-hoc comparisons showed that this RT effect was particularly strong for the 10 s condition. This may be explained by the lack of an lCNV component and thus of cortical negativity prior to S2 in the 10 s condition. Our results suggest that intervals of a duration between 7.5 and 10 s represent the upper boundary during which the lCNV component can be elicited.

1. Introduction

The contingent negative variation (CNV) is an event-related potential component. It appears over frontocentral EEG sites when a contingency is established between pairs of stimuli. Excitatory postsynaptic potentials (EPSPs) at apical dendrites within the cerebral cortex are considered the most likely generating mechanism (Birbaumer et al., 1990). A biphasic CNV, consisting of distinct initial CNV (iCNV) and late CNV (lCNV) components, has been shown to appear when the inter-stimulus intervals (ISIs) during which such components are elicited are increased to a duration of 3 s or higher (Birbaumer et al., 1990). The CNV has been linked to such processes as cortical priming (Walter et al., 1964), timing and time perception (Macar et al., 1999; Praamstra et al., 2006), attention (Travis and Tecce, 1998; Heinrich et al., 2004) and preparation for the arrival of an upcoming event (for reviews see Birbaumer et al., 1990; van Rijn et al., 2011; and Mento, 2013). While the various components of the CNV and its role in timing processes and attention have been the subject of extensive research over the last fifty years, the maximum duration during which such cortical negativity can be maintained has, to the best of our knowledge, never been systematically explored. The question of how long the CNV signal can last touches upon the question of temporal integration of discrete time points, which may enable the experience of a certain temporal width. This is also termed the 'extended now' in consciousness (Northoff, 2014). The duration of the CNV could be an indicator for a temporal integration window of the experienced present moment (Fingelkurts and Fingelkurts, 2014; Wittmann, 2011).

CNV studies have traditionally employed an S1–S2 warning-cue paradigm. Participants are trained to react to a fixed temporal interval between the presentation of the cue (the conditional stimulus S1) and the presentation of an imperative stimulus (S2), with a fast motor response being required upon S2 onset. In most studies, comparatively short ISIs of up to 4 s are used. There is little precedent for the employment of longer intervals. We found a total of five studies employing comparatively longer ISI durations, with maximum intervals of 8 s (Connor and Lang, 1969; Weerts and Lang, 1973; and Loveless and Sanford, 1975), 10 s (Blowers et al., 1973) and 15 s (Loveless and Sanford, 1974), respectively. These provide evidence that the CNV can be reliably maintained during intervals of up to 8 s. When the ISI duration is stretched beyond this mark, however, results are less clear.

Blowers et al. (1973) presented participants with ISIs lasting 1, 3, 5, 7 and 10 s respectively in both blocked (identical ISI duration within blocks) and randomized order. They analysed mean CNV amplitude during the 150 ms directly preceding S2 (roughly equivalent to the

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https://doi.org/10.1016/j.ijpsycho.2018.03.020
Received 26 September 2017; Received in revised form 15 March 2018; Accepted 22 March 2018
Available online 28 March 2018
0167-8760/

lCNV component), which was around −1 μV during the 10 s condition for both forms of trial presentation. Interestingly, lCNV amplitude was very high during 1 s foreperiods, and then plateaued between 3 and 7 s ISIs between around −7 and −8 μV, before dropping steeply for the 10 s condition. This could indicate a 'shift' in processing mode at a duration between 7 and 10 s. The authors also calculated the 'peak' amplitude (as well as its latency) within the ISI. Their data offered no insight, however, into the time course of mean CNV amplitude throughout ISIs, nor about the various other CNV components. Each condition was presented a total of 16 times, which could be rather low for meaningful data. Meanwhile, Loveless and Sanford (1974) employed ISIs with a maximum duration of 15 s, during irregular and regular ISI (S1–S2) tasks. They found mean negative lCNV amplitude for all ISIs up to 15 s when regular foreperiods were employed. There is some indication that individual participants managed to maintain negativity throughout an entire 15 s foreperiod, with mean lCNV amplitude of around −3 and −8 μV appearing during 15 s blocked trials for older and younger participants respectively. However, grand average data was not shown relative to baseline, nor were the various CNV components analysed. Again, each foreperiod duration was presented just 16 times.

The maximum duration during which the CNV can be maintained thus remains unclear. The present study attempts to unravel this question, focusing on the nature of the CNV during intervals of increasing duration, along with its relation to behavioural data. With lCNV amplitude having been linked to preparation for motor response (see e.g. Rohrbaugh et al., 1976), reaction time (RT) is expected to decrease with increased amplitude. This relationship, which has been suggested to occur more strongly for within- than between-participant comparisons (see e.g. Smith et al., 2006), has been widely reported in the literature. In a study consisting of two choice-response S1–S2 paradigm tasks, for example, Wascher et al. (1996) reported lCNV amplitude to increase intraindividually with faster RTs. This effect occurred when S1 informed participants about the type of response required upon arrival of S2 in 100% (Experiment 1) and 50% (Experiment 2) of trials, respectively, albeit only at Cz in Experiment 2. Schevernels et al. (2014) presented participants with a warning cue-target cue paradigm, with the warning cue informing about target location, task difficulty and availability of a €0.04 reward. Here, the authors described greater differences in lCNV amplitude values in 'high-difficulty' than 'low-difficulty' tasks to be accompanied by faster RTs in the rewarded condition. Haagh and Brunia (1985) also reported such a relationship between higher lCNV amplitude and faster RTs in an experiment exploring muscle tension of agonist-antagonist pairs during an S1–S2 task. Meanwhile, a study of response anticipation and response conflict employing both fMRI and EEG recordings (Fan et al., 2007) provided further evidence of the association between the CNV and faster RTs (here, short ISI duration meant that dissociation between iCNV and lCNV did not occur), while Nikulin et al. (2008) reported that both scalp CNV and thalamic activity prior to the 'Go' stimulus correlate with faster RTs in a 'Go/NoGo' task with essential tremor patients, who were being treated by means of deep brain stimulation.

The relationship between greater lCNV amplitude and faster RT has thus been well documented. The RT-related CNV, with data split according to the median into 'fast' and 'slow' RT halves, will be the subject of specific attention in the present study. In order to elicit the CNV, the S1–S2 paradigm is employed, with ISIs ranging from 2.5–10 s. The number of trial repetitions, which was rather low in previous studies, is increased. The exact number of trials required to reliably elicit the CNV remains unclear. We chose to limit the task to 40 trials per condition, to prevent excessive tiring of participants. In contrast to the S1–S2 studies with longer ISIs mentioned above (Connor and Lang, 1969; Weerts and Lang, 1973; Loveless and Sanford, 1975), all other parameters, including stimulus intensity and location, are kept constant throughout trials. The ISI duration is thus the only variable that is altered between blocks, allowing us to focus specifically on the maximum duration of the CNV.

2. Material and methods

2.1. Participants

17 right-handed university students (6 female) with an age-range of 18–36 (mean age 24.6 years, SD = 4.0) were recruited to participate in the study. Three participants were excluded from the analysis due to EEG artefacts in > 50% of trials. Testing took place at the EEG lab of the University Medical Center Freiburg, Department of Psychosomatic Medicine. Compensation of €20, provided by the Department of Psychosomatic Medicine, was paid in return for participation. Written informed consent was given by all participants after a detailed explanation of the procedure had been provided. The study was approved by the local ethics committee of the Institute for Frontier Areas in Psychology and Mental Health.

2.2. Procedure

The experiment consisted of an S1–S2 paradigm task, which was presented on a computer screen inside an electromagnetically and acoustically attenuated chamber designed for EEG measurement. The task was created using *E*-Prime 2.0 software. Participants were requested to keep their right hand on the computer mouse and to maintain a constant upright sitting position at 60 cm distance from the computer screen. The screen measured 33.7 × 27 cm. At the beginning of each trial, participants were presented with an empty grey square with a black outline, with a visual angle of 3.15° (3.3 × 3.3 cm). The background of the screen was also grey. After a random inter-trial interval (ITI) with a range of 5–7 s, the warning stimulus (S1) appeared in the form of a change of colour of the square from grey to red. This was followed by a 'filled' ISI, meaning that the red colouring of the square was maintained throughout the interval. The ISI was terminated by the appearance of the imperative stimulus (S2), which was presented by means of a change of colour from red to green. Participants were instructed to perform a button click with their right index finger as soon as possible upon presentation of S2 (green square). The ITI began upon occurrence of the button press and thus termination of S2. The session began with a practice block, consisting of five trials, with fixed ISIs of 1.5 s and random ITIs within a range of 5–7 s. This was followed by four experimental blocks, each consisting of 40 trials. Each block had its own ISI duration of 2.5, 5, 7.5 or 10 s respectively, meaning that the ISIs of all trials within any given block were of the same duration. The order in which these blocks appeared was randomized. Similarly to the practice block, the duration of the ITI was randomized within a range of 5–7 s for all blocks.

2.3. EEG recording

A Brain Products actiCap with 64 active electrodes was employed for recording of EEG data, with a sampling rate of 500 Hz. The electrodes were in turn connected to a 72-channel BrainVision Standard EEG amplifier (QuickAmp, Brain Products). Electrodes were placed according to the 10–20 system, and a one-channel electrooculogram (EOG) was simultaneously recorded. The impedance level of each electrode was tested using ActiCap Control software, with 'good' level impedance set at 5 kΩ. Only when all electrodes showed impedance levels of 5 kΩ or below was E-Prime software started and the experiment allowed to begin. BrainVision Recorder software (Brain Products) was employed.

2.4. EEG data processing

EEG data collected in the lab was pre-processed using the EEGlab open source toolbox (Delorme and Makeig, 2004), with average and