Model-Based Prediction of Between-Trial Fluctuations in Response Caution From EEG Data

Udo Boehm (u.bohm.1@student.rug.nl)[1]
Leendert van Maanen (l.vanmaanen@uva.nl)[2]
Birte Forstmann (buforstmann@gmail.com)[2]
Hedderik van Rijn (hedderik@van-rijn.org)[1]

[1]Department of Experimental Psychology, University of Groningen, Grote Kruisstraat 2/1
Groningen, 9712 TS, the Netherlands
[2]Cognitive Science Center Amsterdam, University of Amsterdam, Nieuwe Achtergracht 129
Amsterdam, 1018 WS, the Netherlands

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The Role of the Pre-SMA in Decision Making

Recent models of decision making under time constraints assume that the pre-supplementary motor area (pre-SMA) modulates the excitability of an action selection mechanism implemented by the basal ganglia (e.g. Forstmann et al., 2008). The basal ganglia exert a tonic inhibition on the cortex. By decreasing this inhibition the pre-SMA can decrease response caution, thus facilitating speeded but possibly faulty responses. This claim is supported by a series of neuroimaging studies on random dot kinematograms where participants were instructed either to be as quick or as accurate as possible (Van Maanen et al., 2011; Forstmann et al., 2008). The data were analysed by fitting a linear ballistic accumulation model (LBA, Brown & Heathcote, 2008) to the decision time data and correlating the model's response caution parameter with hemodynamic response in the pre-SMA.

Forstmann et al. (2008) showed that differences in response caution between conditions with speed instructions and conditions with accuracy instructions estimated with the LBA model correlated with individual differences in BOLD response change between conditions. Van Maanen et al. (2011) applied the LBA model to single trial data. They found that trial-by-trial fluctuations in response caution under speed stress but not under accuracy instructions correlated with the single-trial BOLD response in the pre-SMA.

The Pre-SMA in EEG Data

A number of EEG studies have linked the contingent negative variation (CNV), an often-studied slow negative potential, to brain regions in close proximity to the pre-SMA and to measures that express the ease with which participants can trigger a response. Leuthold and Jentzsch (2001), applying dipole source localisation to a response precueing task, found that the CNV preceding a response originates from sources close to the SMA. Moreover, a number of studies have reported a negative correlation between CNV amplitude and reaction time (e.g. Hillyard, 1968). Elbert (1990) suggested that the CNV might reflect adjustments of cortical excitability. He supports this claim with data from a signal detection experiment in which high CNV amplitudes correlated with an increase in false alarms and low CNV amplitudes increased the number of misses.

These results suggest that the CNV might reflect the same processes involved in the adjustment of response caution as the activity of the pre-SMA in fMRI studies. If this is the case, lower response caution should be observed for higher CNV amplitudes under speed but not under accuracy instructions. To further investigate this possibility we ran an EEG experiment using a random dot kinematogram and correlated the CNV amplitude with single-trial estimates of response caution from an LBA model.

EEG Experiment and LBA Modelling

Experiment

A group of 14 undergraduate students (10 female) participated in the experiment for partial course credit. They performed 200 trials of a random dot kinematogram task. EEG data were recorded from 32 scalp sites. Trials with an amplitude exceeding ±250µV and trials with artefacts were excluded. Eye blink artefacts were corrected using independent component analysis. Data were low-pass filtered at 35 Hz and baseline-corrected to a baseline-window from 300ms to 100ms before the onset of the fixation cross (see below). All further analyses were based on the FCz electrode.

Participants were asked to decide whether a cloud of 120 pseudo-randomly moving dots was moving to the left or to the right. At the beginning of each trial they were instructed to either react as quickly (SP for speed) or as accurately (AC for accurate) as possible.

Each trial started with a blank screen, followed by the speed instruction and another blank screen. A fixation cross was presented for before the onset of the dot kinematogram. This was followed by a blank screen and feedback on either the response speed in the SP condition or the accuracy in the AC condition.

The CNV was measured during the presentation of the fixation cross before the onset of the dot kinematogram.

CNV amplitude was defined as the mean amplitude between 200ms and 100ms before the cloud of dots was presented.

LBA model

The LBA model describes decisions as an evidence accumulation process with two accumulators, one for correct and one for incorrect responses. Starting from an initial amount of evidence, evidence is accumulated until one of the accumulators reaches a threshold at which point a decision is made. The model includes 5 parameters. The drift rate d for the evidence accumulation is sampled from a normal distribution with mean v and standard deviation s. The initial amount of evidence, reflecting response caution, is sampled from a uniform distribution from 0 to A. The more evidence is initially available, the less evidence needs to be accumulated and the quicker a response can be made. The response threshold b describes the amount of evidence that is needed to make a decision. Finally, the non-decision time $t0$ reflects all processes not related to the decision process, such as the execution of a motor response.

The best fitting model was selected based on formal model comparisons using Bayesian Information Criterion. The selected model was one in which the mean drift rate, the standard deviation of the drift rate and the response threshold were free to vary between speed instructions. The model was fit to participants' reaction time distributions as described in Donkin, Brown, and Heathcote (2011). Subsequently maximum likelihood estimates of the single trial drift rate d and initial evidence a were obtained as in Van Maanen et al. (2011).

Results and Discussion

Linear mixed effects models were used to assess the relationship between CNV amplitude and single-trial response caution and drift rate. The first model included fixed effects for speed instruction (2 levels: AC and SP), single-trial response caution and the interaction of the two as well as a random intercept per subject. While response caution did not predict CNV amplitude in the AC condition ($\beta = -0.01$, $p = .25$), the significant interaction term showed it to be a significant predictor in the SP condition ($\beta = 0.04$, $p < .01$). To test whether drift rate explains additional variance in the CNV amplitude, we constructed a second model that included single-trial drift rate and its interaction with speed instruction as additional predictors. Comparing this model to our first model showed that drift rate did not improve prediction ($\chi^2(2) = 1.95$, $p = .38$).

These results imply that while participants decrease their response caution when prompted to react as quickly as possible, no such adjustment is made if accurate responding is stressed. It aligns well with the findings of Van Maanen et al. (2011) as well as suggestions that the CNV might reflect response preparation processes (Elbert, 1990). Moreover, the finding that drift rates are not related to CNV amplitude shows that the LBA model recovers the differential contribution of drift rates and initial evidence to the accumulation process.

These findings bear interesting implications for two fields of research. On the one hand, the CNV might offer a more direct measure of response caution. Instead of having to rely on parameter estimates from a model that was fit to noisy reaction time data, the CNV might provide an easy-to-obtain measure of the neuronal activity underlying response caution. On the other hand, these findings might also help resolve a long-standing debate about the role of the CNV in time estimation. Macar, Vidal, and Casini (1999) suggested that the CNV reflects the accumulation of pulses from an internal clock. However, Van Rijn, Kononowicz, Meck, Ng, and Penney (2011) argue that the CNV reflects the response preparation or decision processes. The current findings support the latter interpretation. While participants are waiting for a time interval to pass their pre-SMA might become active to prepare the selection and execution of a response, which is reflected by a higher CNV amplitude.

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