Error related fields: localizing the magnetic equivalent of the ERN.

Julian Keil, Nathan Weisz, Isabella Paul, Christian Wienbruch
Department of Psychology, University of Konstanz, Germany

Introduction:

It has been found in EEG studies, that a typical brain potential arises following an erroneous response. This error related negativity (ERN) is thought to be related to error monitoring and feedback. This is crucial for the detection of errors and correction of actions in the framework of organizing complex behaviors and high-level goals. Only a single published study investigated the magnetoencephalographic equivalent to the ERN (mERN) by means of single dipole modeling. This study as well as previous EEG works suggests the major source of the ERN to be located in the anterior cingulate cortex (ACC). While other studies reported on evoked (phase-locked) oscillatory activity, we focused on induced oscillatory activity in this study. It has been found, that phase-locked theta is crucial to the generation of the ERN, while the role of induced theta band activity has gained only limited attention.

We implemented a computerized version of test of sustained attention, to measure the error related field in the MEG and to localize the generator of the ERN using a distributed source model. Also, we explored the relation of induced oscillatory brain activity to the ERN.

Methods:

Subjects:

- * 13 (5m/8f) healthy student subjects

Stimuli:

- * 660 trials containing the d2-test stimuli (test of sustained attention, e.g. d'' or p')
- * Response to indicate if stimulus was correctly/incorrectly identified
- * Feedback (green + for correct responses, red x for incorrect responses)

Data aquisition:

- * 148-channel whole-head MEG system (MAGNES™ 2500 WH, 4D Neuroimaging, San Diego, USA)
- * 678.17 Hz sample rate
- * 0.1-200 Hz online band pass filter

Data analysis:

- * extraction of - 2 / 2 second epochs around button press
- * trial number between correct and incorrect trials equalized by randomly choosing from the larger dataset
- * visual inspection and rejection of trials containing eye, muscle or other artifacts
- * cluster based dependent samples T-test with monte-carlo randomisation was used for statistical comparisons
- * **all comparisons correct vs. incorrect responses**
- * t-values plotted for all topographic and source projections
- * **ERF:** no filter, -100 ms - 0 ms pre-response base line (avoid readiness potential), LCMV source localisation
- * **TFR:** 2-70 Hz, 2 Hz frequency interval with $\pm 0.4 \cdot f$ Hz frequency smoothing, DICS source localisation
- * Pseudo-individual MRI images were used for source reconstruction

All analysis steps performed using fieldtrip

RMS Time course for the correct vs. incorrect trials

Topography (t-values) of the mERN between 80 and 160 ms post response

LCMV source projection (t-values) of the mERN in the ACC

Results:

In this study we successfully used an attention test to measure the mERN in the MEG. Differences between correct and incorrect responses were computed in all comparisons. Event-related fields around the motor response revealed a discriminative activity. Following incorrect button presses, the cortical response was significantly augmented. The LCMV source projection identified the ACC as the source of this activity.

Statistical result (t-values) of the time-frequency-analysis, grand average over all channels

Time course of the time-frequency-analysis, masked for significant relative differences between correct and incorrect trials.

- Theta band increase in the incorrect trials (top)
- Alpha band increase in the incorrect trials (middle)
- Beta band increase in the correct trials (bottom)

DICS source projection (t-values) of the relative theta increase in the incorrect trials

Time-frequency analysis of the induced oscillatory activity identified a significant increase in theta activity starting 200 ms before the incorrect motor response. The DICS source projection identified the medial frontal gyrus to be the source of this activity. Following the incorrect motor response, there was a significant relative increase in alpha-band power. Following the correct motor response, there was a significant relative increase in beta-band power.

Conclusions:

We successfully measured the magnetic equivalent of the ERN and explored the role of error-related changes in induced oscillatory brain activity. ERP and induced brain activity was localised in different cortical areas.

In accordance with earlier studies, we measured the mERN in a period from 80 ms to 160 ms following an incorrect response. The localisation of the mERN in the ACC corroborates the role of the ACC in error monitoring and cognitive control of motor behavior. This lends credence to theories of ACC functioning, and the role of the ERN. Also, the role of induced frontal theta oscillations in the generation of the mERN and the associated error detection mechanism was explored. Event-related theta activity has been linked to the ACC, the localisation of the induced theta activity in the medial frontal gyrus could point to an involvement of a larger network in error detection. Importantly, the induced theta activity starts earlier than the event-related theta activity. The increase in alpha band power following the commission of an error in the frontal sensor group might provide an explanation why the error was committed because an increase in alpha power could reflect a disengagement from the task. The increase of beta-band activity in the correct trials could reflect an increased motivational relevance of these trials, as beta-band activity has most prominently been linked to attention and awareness.

Acknowledgements:

The Study was supported by the DFG (Deutsche Forschungsgemeinschaft) | julian.keil@uni-konstanz.de | www.uni-konstanz.de/obob

Literature:

Fieldtrip Matlab-toolbox: <http://fieldtrip.fcdonders.nl/>

Miltner, W., Lemke, U., Weiss, T., Holroyd, C., Scheffers, M., & Coles, M. Implementation of error-processing in the human anterior cingulate cortex: a source analysis of the magnetic equivalent of the error-related negativity. *Biological Psychology*, 64(1), 157-166.

Rolf Brickenkamp and Eric Zillmer, D2 Test of Attention, Hogrefe&Huber, Göttingen, 1998.