Spatio-temporal methods for EEG analysis in cognitive neuroscience

Electroencephalography (EEG) records electrical activity from the brain by measuring the resulting potential differences across the scalp. It has a long tradition in both a clinical and neuroscientific setting, and recently it has also started being used for consumer-oriented applications. While EEG can be a useful tool, it can be difficult to decipher information from its raw signals. In this thesis I will present three projects with the common goal of analysing EEG in ways that both extract meaningful information and visualise it in intuitive ways. The first project describes how we took neuroscience out of the laboratory and into the classroom. We reproduced an attention-tracking paradigm in a classroom and simultaneously recorded the neural activity of up to nine people. We had a focus on using equipment that was wireless and portable as well being relatively low-cost and computational methods in a setup that is feasible to extend into everyday scenarios. The second project revolved around creating a toolbox for the research field of microstate analysis, with a focus on open access and transparency of the applied methods. The toolbox is followed by a methodological guide that reviews the most commonly applied algorithms in microstate analysis. In the final project I investigated the feasibility of using the complexity of EEG as a neural marker of conscious processing. This project spans two studies investigating the capability of EEG complexity in two different scenarios; while people are sleeping, and while navigating a helicopter simulator.

EEG in the classroom: Synchronised neural recordings during video presentation

We performed simultaneous recordings of electroencephalography (EEG) from multiple students in a classroom, and measured the inter-subject correlation (ISC) of activity evoked by a common video stimulus. The neural reliability, as quantified by ISC, has been linked to engagement and attentional modulation in earlier studies that used high-grade equipment in laboratory settings. Here we reproduce many of the results from these studies using portable low-cost equipment, focusing on the robustness of using ISC for subjects experiencing naturalistic stimuli. The present data shows that stimulus-evoked neural responses, known to be modulated by attention, can be tracked for groups of students with synchronized EEG acquisition. This is a step towards real-time inference of engagement in the classroom.
Neural Markers of Responsiveness to the Environment in Human Sleep

Sleep is characterized by a loss of behavioral responsiveness. However, recent research has shown that the sleeping brain is not completely disconnected from its environment. How neural activity constrains the ability to process sensory information while asleep is yet unclear. Here, we instructed human volunteers to classify words with lateralized hand responses while falling asleep. Using an electroencephalographic (EEG) marker of motor preparation, we show how responsiveness is modulated across sleep. These modulations are tracked using classic event-related potential analyses complemented by Lempel-Ziv complexity (LZc), a measure shown to track arousal in sleep and anesthesia. Neural activity related to the semantic content of stimuli was conserved in light non-rapid eye movement (NREM) sleep. However, these processes were suppressed in deep NREM sleep and, importantly, also in REM sleep, despite the recovery of wake-like neural activity in the latter. In NREM sleep, sensory activations were counterbalanced by evoked down states, which, when present, blocked further processing of external information. In addition, responsiveness markers correlated positively with baseline complexity, which could be related to modulation in sleep depth. In REM sleep, however, this relationship was reversed. We therefore propose that, in REM sleep, endogenously generated processes compete with the processing of external input. Sleep can thus be seen as a self-regulated process in which external information can be processed in
lighter stages but suppressed in deeper stages. Last, our results suggest drastically different gating mechanisms in NREM and REM sleep.

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Multiview Bayesian Correlated Component Analysis

Correlated component analysis as proposed by Dmochowski, Sajda, Dias, and Parra (2012) is a tool for investigating brain process similarity in the responses to multiple views of a given stimulus. Correlated components are identified under the assumption that the involved spatial networks are identical. Here we propose a hierarchical probabilistic model that can infer the level of universality in such multiview data, from completely unrelated representations, corresponding to canonical correlation analysis, to identical representations as in correlated component analysis. This new model, which we denote Bayesian correlated component analysis, evaluates favorably against three relevant algorithms in simulated data. A well-established benchmark EEG data set is used to further validate the new model and infer the variability of spatial representations across multiple subjects.
Bayesian Correlated Component Analysis for inference of joint EEG activation

We propose a probabilistic generative multi-view model to test the representational universality of human information processing. The model is tested in simulated data and in a well-established benchmark EEG dataset.

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