The Decision Decoding ToolBOX (DDTBOX): a multivariate pattern analysis toolbox for event-related potentials

Daniel Bennett (daniel.bennett@princeton.edu)
The University of Melbourne
Parkville, Victoria 3010 Australia

Daniel Feuerriegel (dfeuerriegel@unimelb.edu.au)
The University of Melbourne
Parkville, Victoria 3010 Australia

Phillip M. Alday (phillip.alday@unisa.edu.au)
The University of South Australia and Max Planck Institute for Psycholinguistics
Adelaide, Australia and Nijmegen, The Netherlands

Stefan Bode (sbode@unimelb.edu.au)
The University of Melbourne
Parkville, Victoria 3010 Australia

Abstract

In recent years, multivariate pattern analysis (MVPA) has become an increasingly popular technique for analysis of neuroimaging data. Here we present the DDTBOX, an open-source MVPA toolbox for analysis of electroencephalography data using MATLAB and the LIBSVM library. The DDTBOX uses support vector machines trained on patterns of event-related potential (ERP) amplitude data for the classification or regression of experimental variables of interest. MVPA for ERPs complements conventional hypothesis-driven ERP analysis, and permits the detection of subtle decision-related information that might not be evident in conventional ERP analyses. MVPA for ERPs also allows researchers to perform an exploratory search for information in situations where no ERP component is known to be specifically linked to a cognitive process of interest. The DDTBOX is an easy-to-use and open-source software package that allows researchers to derive information time-courses for various cognitive processes. It can be applied to data from a variety of experimental paradigms, and may therefore prove a valuable tool for the neuroimaging community.

Keywords: EEG; multivariate pattern analysis; event-related potentials; machine learning; decoding; toolbox

Introduction

In recent years, neuroimaging research in cognitive neuroscience has increasingly used multivariate pattern analyses (MVPA) to investigate higher cognitive functions. These techniques are most commonly applied to functional magnetic resonance imaging (fMRI) data. Due to the poor temporal resolution of fMRI, however, it is often difficult to track the temporal dynamics of fast cognitive processes, and therefore to determine when predictive information becomes available. However, MVPA can also be applied to electroencephalography (EEG) data (Blankertz et al., 2011), which has a far better temporal resolution (in the range of milliseconds, as opposed to seconds for fMRI).

There are several reasons that one might wish to apply MVPA to ERP data. One reason is to ensure that analyses make use of all information contained in ERP data, rather than dismissing most of it as noise. The classical approach in data modelling and statistics aims to build a model that reflects the structure of reality, with interpretable model parameters, resulting in a focus on inference (Breiman, 2001). Algorithmic modelling, however, reverses this approach: the structure of the statistical model–and the interpretability of model parameters–becomes irrelevant, since models do not assume that the structure of reality is known. The focus of this approach is on prediction, and the accuracy of a model is tested by the accuracy of its out-of-sample predictions. Machine learning is one implementation of this approach that has recently gained popularity in cognitive neuroscience. In particular, a supervised-learning approach using support vector machines (SVM) is a powerful tool in neuroimaging analysis, both for fMRI and EEG data.

Here we present the DDTBOX, a novel open-source MVPA toolbox for ERPs that is tightly integrated with EEGLab for MATLAB (Delorme and Makeig, 2004). The DDTBOX can be used to predict latent cognitive variables directly from multivariate patterns of ERP data.

Methods

The DDTBOX uses support vector machines (SVMs) on patterns of EEG amplitude data for the classification or regression of experimental variables of interest (see Figure 1). Amplitude patterns can be extracted across space (i.e. from all channels; spatial decoding), time (i.e., all data points for each channel; temporal decoding), or both (spatio-temporal decoding). It allows for the use of linear or non-linear kernels, and adjustment of analysis time window width and of the step size with which this window is moved through the trial.

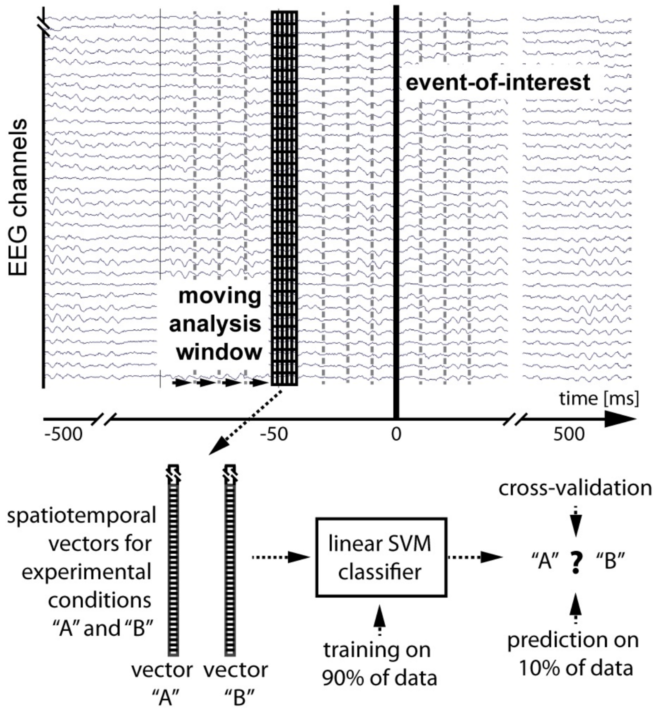

Figure 1: Schematic overview of analysis pipeline for spatio-temporal decoding of ERP data with 10-fold cross-validation.

It further comprises the extraction of feature weight maps (including corrections as in Haufe et al., 2014), shuffled-label permutation tests for group-level statistical testing, estimates of the prevalence of decodable information in the population (Allefeld et al., 2016), a variety of correction techniques for multiple comparisons, and it contains various plotting functions for individual and group-level results.

Results

Some of the recent results obtained with the DDTBOX illustrate its applicability: 1) Applied to perceptual decisions, we have shown that even subtle decision biases, present several hundred milliseconds before stimulus processing, were represented in neural activity patterns (Bode et al., 2012). 2) The same techniques have been used to demonstrate the evolution of fast cognitive correction processes for erroneous decisions that start 100 ms before response execution (Bode and Stahl, 2014). 3) Support vector regression could also be used to predict participants' ratings of abstract stimulus attributes such as arousal and time reference, even in the absence of any explicit cueing of these dimensions (Bode et al., 2014).

Discussion

Using MVPA for ERPs complements conventional hypothesis-driven ERP analysis, and therefore has several benefits: First, even subtle decision-related information can be detected that would otherwise be overlooked (Bode et al., 2012). Second, patterns of activity can be directly linked to parameters in decision models, or used to predict processing of decision-related aspects of stimuli (e.g., Bode et al., 2014). Finally, MVPA for ERPs allows for a more explorative search for information when no ERP component is known to be specifically linked to the cognitive process of interest.

The DDTBOX is an easy-to-use and open-source software package that allows for deriving information time-courses for various cognitive processes. It can be applied to data from a variety of experimental paradigms, is not restricted to decision making, and could therefore be a valuable tool for the neuroimaging community.

Toolbox code is freely available for download at `http://ddtbox.github.io/DDTBOX/`. Users can subscribe to the mailing list by emailing `ddtbox-request@freelists.org` with 'subscribe' in the subject line.

Acknowledgements

The DDTBOX was inspired by SB's work with Prof. John-Dylan Haynes on MVPA for fMRI, and some features of the code were modelled from code initially developed in the Haynes lab. We further acknowledge helpful input from Dr Carsten Bogler and Dr Chun Siong Soon, and improvements due to collaborative work with Prof. Jutta Stahl, Dr Simon Lilburn, Prof. Philip L. Smith, Dr Elaine Corbett, and Dr Carsten Murawski. This work was funded by an Australian Research Council DECRA award to SB (DE140100350).

References

Allefeld, C., Görgen, K., & Haynes, J.-D. (2016). Valid population inference for information-based imaging: From the second-level t-test to prevalence inference. *NeuroImage*, *141*, 378–392.

Blankertz, B., Lemm, S., Treder, M., Haufe, S., & Müller, K.-R. (2011). Single-trial analysis and classification of erp components: a tutorial. *NeuroImage*, *56*(2), 814–825.

Bode, S., Bennett, D., Stahl, J., & Murawski, C. (2014). Distributed patterns of event-related potentials predict subsequent ratings of abstract stimulus attributes. *PLoS One*, *9*(10), e109070.

Bode, S., Sewell, D. K., Lilburn, S., Forte, J. D., Smith, P. L., & Stahl, J. (2012). Predicting perceptual decision biases from early brain activity. *The Journal of Neuroscience*, *32*(36), 12488–12498.

Bode, S., & Stahl, J. (2014). Predicting errors from patterns of event-related potentials preceding an overt response. *Biological Psychology*, *103*, 357–369.

Breiman, L. (2001). Statistical modeling: The two cultures. *Statistical Science*, *16*(3), 199–231.

Delorme, A., & Makeig, S. (2004). Eeglab: an open source toolbox for analysis of single-trial eeg dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21.

Haufe, S., Meinecke, F., Görgen, K., Dähne, S., Haynes, J.-D., Blankertz, B., & Bießmann, F. (2014). On the interpretation of weight vectors of linear models in multivariate neuroimaging. *NeuroImage*, *87*, 96–110.