A custom analysis pipeline for fMRI data using the Statistical Parametric Mapping software

A. Vorreuther, A. Kasparbauer, U. Ettinger

Abstract

The following short paper provides information about an analysis pipeline designed to analyze and display results pertaining to behavioral and hemodynamic data. Subjects performed two learning tasks, a procedural learning task, and an object location association task. Behavioral data is analyzed by means of scripted IBM SPSS syntax and Matlab. Brain data analyses include preprocessing, first- and second-level analysis, and investigation of percentage of signal change. The pipeline moreover allows for manual configuration of analysis parameters, e.g., chosen region of interest. Code is implemented using the Statistical Parametric Mapping (SPM) and MarsBaR toolboxes for Matlab. All scripts can be found at https://github.com/acv132/SPM_pipeline_learning_tasks.

Keywords: SPM, Matlab, MarsBaR, fMRI, procedural learning, object location association, spatial learning

Introduction

The given scripts are supposed to serve as an analysis pipeline for behavioral and hemodynamic functional magnetic resonance imaging (fMRI) data of a sample population performing two distinct learning tasks while being administered either of the two substances methylphenidate and nicotine, or a placebo. Using the provided code for analysis was meant to automate the process of obtaining results and make replication possible more easily. Subjects were healthy right-handed male non-smokers (N = 75). The first task consisted of a procedural learning (PL) task where subjects were asked to follow a moving asterisk on a screen in a blocked design with random and pattern trials (for details see Ettinger et al., 2013). The second task was an object location association (OLA) task with two phases. During the first phase, images of either artificial or natural objects were shown in one of four quadrants on a screen (encoding phase). The same images were presented together with a set of novel images during the second phase and subjects were asked to recall whether the image was generally familiar and in which quadrant it was presented ([spatial context] retrieval phase; for details see Kukolja et al., 2009).

Methods

Behavioral data

All analyses were written in Matlab (2021) and IBM SPSS (version 25, 2017). The available code is structured in two pipelines: behavioral data analysis and analysis of fMRI brain data. The first pipeline starts by creating a data frame holding relevant task variables. Descriptive statistics are collected for included subjects (N = 71). A chi-square criterion was calculated to exclude subjects from the OLA analysis that statistically only guessed the correct spatial context rather than retrieving it. This can optionally be used to exclude some of the subjects from the OLA analyses. Sedation ratings assessed by visual analogue rating scales (Bond & Lader, 1974) are processed and compared between three time points of measurement (pre-medication, pre-scanning, post-scanning).

Subsequently, PL and OLA behavioral data is analyzed. For the PL task, mean reaction times (RTs), standard deviations (SDs), and coefficients of variation (CVs) of random and pattern trials are investigated using repeated measures analysis of variance (ANOVA) with trial type and block as within-subject factors (for details see Ettinger et al., 2013). A possible association between the amount of PL and sedation ratings is examined with correlational analysis (Pearson's r).

For the OLA task, encoding and retrieval phase are analyzed separately. For the encoding session, three event types are defined, consisting of two effects of interest, correctly and falsely encoded spatial context, respectively, (CorSCE, FalSCE) and one effect of no interest (comprising items presented during encoding but which were classified as "new" during retrieval as well as missed responses in the encoding and retrieval sessions). Similarly, three event types are defined for the retrieval session: two effects of interest (CorSCR, FalSCR) and one effect of no interest (including items shown during encoding but which were falsely attributed to be "new", new items correctly or incorrectly responded to, and missed responses). A two-way repeated measures ANOVA is then performed on RTs for effect of substance, subsequent source judgments, or interaction between them. Additionally a signal detection analysis is applied to investigate substance-related differences in "old" versus "new" judgments. This analysis determined the sensitivity d' and the response bias c and β of classifying old items as "old" (for details see Kukolja et al., 2009).

FMRI data

Further, the available code offers the possibility to run a scripted analysis of fMRI brain data with the Statistical Parametric Mapping (SPM) toolbox (version 12; Ashburner et al., 2014).

Adjustments to analyses are made possible by configuration options implemented in functions pertaining to each analysis step. First, subjects' hemodynamic data is preprocessed in a standard procedure including slice-realignment, slice time correction, co-registration and segmentation of images, normalization, and smoothing. After completion of all preprocessing steps, a first-level analysis is performed for both tasks. A full-factorial model is then estimated, and an ANOVA is performed for the PL task, OLA encoding, and OLA retrieval phase, respectively (see Methods

Behavioral data for details). Six head movement parameters are included as confounds. Further, a pipeline is constructed to display and save results with options to overlay different masks based on contrasts defined during analyses or regions of interest (ROIs). Finally, using the MarsBaR toolbox (Brett et al., 2002), it is investigated what percentage of signal change occurred in specific ROIs during the individual tasks. The code allows for definition of a ROI from a given file and displays average results in form of bar graphs showing the signal change in each substance group.

Requirements

The pipeline was written on a Windows system. Known and successfully tested minimum requirements are IBM SPSS (version 25, 2017), Matlab (version 9.11.0 [2021b], 2021), SPM software package (version 7771 [SPM12], https://www.fil.ion.ucl.ac.uk/spm/), and related toolboxes MarsBaR (version 0.45, Brett et al., 2002), and WFU brain atlas (version 3.0.5, Maldjian et al., 2004; Maldjian et al., 2003; Tzourio-Mazoyer et al., 2002).

Developer Access, Licensing and Availability

The source code is provided under MIT License and can be found at https://github.com/acv132/SPM_pipeline_learning_tasks.

Conclusion

The provided code can be used as an analysis pipeline for the tasks at hand. Both behavioral and brain data was analyzed successfully. Analysis steps can be repeated easily and by systematically modifying provided configuration options in the script, steps can be altered without use of the SPM interface. It should be noted that, while this code is clearly *not* written to provide a general SPM analysis pipeline of fMRI data, individual functions and the overall structure might be useful in developing new pipelines and possibly a more universally applicable script.

References

Ashburner, J., Barnes, G., Chen, C.-C., Daunizeau, J., Flandin, G., Friston, K., Kiebel, S., Kilner, J., Litvak, V., & Moran, R. (2014). SPM12 manual. *Wellcome Trust Centre for Neuroimaging, London, UK, 2464*, 4.

Bond, A., & Lader, M. (1974). The use of analogue scales in rating subjective feelings. *British Journal of Medical Psychology*.

Brett, M., Anton, J.-L., Valabregue, R., & Poline, J.-B. (2002). Region of interest analysis using an SPM toolbox. 8th international conference on functional mapping of the human brain,

Ettinger, U., Corr, P. J., Mofidi, A., Williams, S. C., & Kumari, V. (2013). Dopaminergic basis of the psychosis-prone personality investigated with functional magnetic resonance imaging of procedural learning. *Frontiers in human neuroscience*, *7*, 130.

Kukolja, J., Thiel, C. M., Wilms, M., Mirzazade, S., & Fink, G. R. (2009). Ageing-related changes of neural activity associated with spatial contextual memory. *Neurobiology of aging*, *30*(4), 630-645.

Maldjian, J. A., Laurienti, P. J., & Burdette, J. H. (2004). Precentral gyrus discrepancy in electronic versions of the Talairach atlas. *Neuroimage*, *21*(1), 450-455.

Maldjian, J. A., Laurienti, P. J., Kraft, R. A., & Burdette, J. H. (2003). An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *Neuroimage*, *19*(3), 1233-1239.

MATLAB. (2021). *version 9.11.0 (R2021b)*. Natick, Massachusetts: The MathWorks Inc.

SPSS, I. (2017). IBM Corp. Released, Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp. In.

Tzourio-Mazoyer N, Landeau B, Papathanassiou D, Crivello F, Etard O, Delcroix N, Mazoyer B, Joliot M. Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. Neuroimage. 2002; 15(1):273-89.