Advanced cognitive neuroscience

Mads Jensen

Fall, 2021

E-mail: `mads [a] cas.au.dk`
Office: CFIN, Universitetsbyen 3, Build. 1710

Web: **Brightspace**
Lecture room: 1467-515
Class hours: Tuesday 8.00 - 10.00
Class room: 1481-264

Contents

1 Course description

For a description and regulations of the course and the program see **cognitive science program page** and the **the course page**

2 Materials and readings

- There are no text book for the course. Articles and book chapters that are not available through the library will be made available on Brightspace.
- Slides will be available on Brightspace on the page on the day of the lecture.
- Practical notes will also be available Brightspace page on the day of the practical.
- For the classes we will use Python with specific toolboxes, see next section.

Python packages

My recommendation is to use the Anaconda python package manager, either Anaconda or the command line only Miniconda

The packages we will use are:

- Python 3.6+
- MNE-python https://mne.tools/stable/index.html
- Scikit-learn https://scikit-learn.org/stable/

Following the MNE-python instructions (https://mne.tools/stable/install/mne_python.html), this will install most the of needed packages. After this activate the environment and to install Jupyter notebooks run:

```
conda install jupyter -y
```

Test that your installation works by running:

```
python -c "import mne; mne.sys_info()"
```

You should not get any errors.

3 Course structure

Lectures are on Mondays from 11.00 to 13.00 (remember the academic quarter) and corresponding classes (i.e. practical exercises) on Tuesdays 8.00-10.00 (again remember the academic quarter). Given the current regulations will we have one practical class with room for all. Please note that this is subject to changes if the regulations change and that this can happen swiftly.

4 Exam

EXAM DEADLINE: DECEMBER 20th

From the study regulation:
"The exam consists of a portfolio containing 3-7 assignments, which the student submits to the teacher during the course. Their form (individual and/or group-based, written, product and/or oral, set and/or on a topic of the student's choice), length and deadline for submission will be announced on Brightspace by the teacher at the start of the semester.

The complete portfolio must be handed in for assessment in the Digital Exam system by the date specified in the exam plan. The portfolio can be written individually or in groups of up to 3 students. It must be possible to carry out an individual assessment. So **if some parts of the portfolio have been produced by a group, it must be stated clearly which parts each student is responsible for, and which parts the group as a whole is responsible for**" (My bold).

Teacher's note. A good portfolio have an intrduction and discussion/conclusion that binds the individual assignments together.

Formalia for the portfolio papers

- A selection of two papers and a Jupyter notebook (converted to pdf) with an EEG analysis together with an introduction and discussion/conclusion is to be handed in as one joint submission.
- A paper can be maximum 7 normal pages, code goes in an appendix
- Introduction and discussion/conclusion is combined maximum of 7 normal pages.
- A normal page is 2400 characters *including* spaces and in-text references.
- The reference list does *not* count for the pages limits.
- Citation style is APA7

Writing assignment questions

Writing assignments should include the answer to a question and any code used to answer the question should be linked to or send as a file – *well commented*.

If you would rather answer a question(s) you have made yourself, please email the instructor to get an approval before submitting the assignment.

Topic	**Question**
The brain	• Describe a cognitive function? • Discuss the use of fMRI and EEG/MEG for action selection?
Electrophysiology	• What are the pros and cons of EEG vs MEG? • How are ERPs related to brain structures and functions of the mind?
Oscillations	• How can oscillations be used to investigate and cognition? • Link oscillations to a cognitive function. This can be in term of frequencies and/or cortical location(s) etc.
MVPA	• Why use MVPA for statistical assessment of EEG data? • Pros and cons of linear vs non-linear MVPA models for brain imaging data
Neural Networks	• Are neural networks better than MVPA for analysis of neuroimaging data? • Can Neural networks be used to model cognition?

5 Readings

Week 1: introduction

There are no assigned readings. But please make sure you have a working python environment with the packages mentioned in section 2.

Some resources for EEG refreshing:
(Some will cover both EEG & MEG, but for this the similarities outweigh the differences.)

- Fieldtrip introduction video, disclaimer I have not seen the video to the end.
- Cohen, M. X. (2014). *Analyzing neural time series data: Theory and practice*. The MIT Press. The first chapters are a fine induction to electrophysiology.
- Luck, S. J. (2014). *An introduction to the event-related potential technique*. MIT press. A classic text for ERP research, it does not cover oscillations, only ERPs.

Week 2: the brain and brain data.

- Lerch, J. P., van der Kouwe, A. J. W., Raznahan, A., Paus, T., Johansen-Berg, H., Miller, K. L., Smith, S. M., Fischl, B., & Sotiropoulos, S. N. (2017). Studying neuroanatomy using MRI. *Nature Neuroscience*, *20*(3), 314–326. https://doi.org/10.1038/nn.4501
- Logothetis, N. K. (2008). What we can do and what we cannot do with fMRI. *Nature*, *453*, 869–78. https://doi.org/10.1038/nature06976
- Hallett, M. (2000). Transcranial magnetic stimulation and the human brain. *Nature*, *406*, 147–50. https://doi.org/10.1038/35018000

Additional readings & resources

- Arthurs, O. J., & Boniface, S. (2002). How well do we understand the neural origins of the fMRI BOLD signal? *Trends in Neurosciences*, *25*(1), 27–31. https://doi.org/10.1016/S0166-2236(00)01995-0

Week 3: electrophysiology

- Baillet, S. (2017). Magnetoencephalography for brain electrophysiology and imaging. *Nature Neuroscience*, *20*(3), 327–339. https://doi.org/10.1038/nn.4504
- Maris, E. (2012). Statistical testing in electrophysiological studies: Statistical testing in electrophysiological studies. *Psychophysiology*, *49*(4), 549–565. https://doi.org/10.1111/j.1469-8986.2011.01320.x
- Sassenhagen, J., & Draschkow, D. (2019). Cluster-based permutation tests of MEG/EEG data do not establish significance of effect latency or location. *Psychophysiology*, e13335. https://doi.org/10.1111/psyp.13335

Additional readings & resources

- Gramfort, A., Luessi, M., Larson, E., Engemann, D. A., Strohmeier, D., Brodbeck, C., Goj, R., Jas, M., Brooks, T., Parkkonen, L., & Hämäläinen, M. (2013). MEG and EEG data analysis with MNE-Python. *Frontiers in neuroscience*, *7*, 267. https://doi.org/10.3389/fnins.2013.00267
- Video: EEG Analysis with the MNE Software by Alex Gramfort
- Video: MEG/EEG Toolkit Course 2018 Statistical testing of electrophysiological data
- http://www.fieldtriptoolbox.org/faq/how_not_to_interpret_results_from_a_cluster-based_permutation_test/

Week 4: oscillations

- Jensen, O., Spaak, E., & Zumer, J. M. (2014). Human brain oscillations: From physiological mechanisms to analysis and cognition. In S. Supek & C. J. Aine (Eds.), *Magnetoencephalography: From signals to dynamic cortical networks* (pp. 359–403). Springer Berlin Heidelberg
- Cohen, M. X. (2014). *Analyzing neural time series data: Theory and practice*. The MIT Press, chapters: 10-12

Additional readings and resources

- Video: MEG/EEG Toolkit Course 2018 Fundamentals of neuronal oscillations and synchrony
- Video from 3blue1brown on the Fourier transform

Week 5: record EEG data

- Record EEG data at CFIN, Aarhus University Hospital Skejby

More information will follow later.

Week 6: oscillations cont.

- Varela, F., Lachaux, J. P., Rodriguez, E., & Martinerie, J. (2001). The brainweb: Phase synchronization and large-scale integration. *Nat Rev Neurosci*, *2*(4), 229–39. https://doi.org/10.1038/35067550
- Fries, P. (2005). A mechanism for cognitive dynamics: Neuronal communication through neuronal coherence. *Trends in cognitive sciences*, *9*, 474–480. https://doi.org/10.1016/j.tics.2005.08.011

Additional readings and resources

- Fries, P. (2015). Rhythms for Cognition: Communication through Coherence. *Neuron*, *88*(1), 220–235. https://doi.org/10.1016/j.neuron.2015.09.034

Week 7: connectivity

- Bassett, D. S., & Sporns, O. (2017). Network neuroscience. *Nat Neurosci*, *20*, 353–364. https://doi.org/10.1038/nn.4502
- Bastos, A. M., & Schoffelen, J.-M. (2016). A Tutorial Review of Functional Connectivity Analysis Methods and Their Interpretational Pitfalls. *Frontiers in Systems Neuroscience*, *9*. https://doi.org/10.3389/fnsys.2015.00175

Additional readings and resources

- Fornito, A., Zalesky, A., & Bullmore, E. T. (2016). *Fundamentals of brain network analysis*. Elsevier. http://www.sciencedirect.com/science/book/9780124079083

Week 8: machine learning

- King, J. R., Gwilliams, L., Holdgraf, C., Sassenhagen, J., Barachant, A., Engemann, D., Larson, E., & Gramfort, A. (2018). Encoding and Decoding Neuronal Dynamics: Methodological Framework to Uncover the Algorithms of Cognition, 19. https://hal.archives-ouvertes.fr/hal-01848442
- Bzdok, D. (2017). Classical Statistics and Statistical Learning in Imaging Neuroscience. *Frontiers in Neuroscience*, *11*, 543. https://doi.org/10.3389/fnins.2017.00543

Additional readings and resources

- Hastie, T., Tibshirani, R., Friedman, J., Hastie, T., Friedman, J., & Tibshirani, R. (2009). *The elements of statistical learning* (Vol. 2). Springer. http://statweb.stanford.edu/~tibs/ElemStatLearn/. One of the statistical learning (machine learning) bibles, though extremely techinical!
- **james_2021**. An easier but very good introduction to statistical learning
- Bishop, C. M. (2006). *Pattern recognition and machine learning*. Springer. Also a very well known book om machine learning.
- Video introduction to scikit-learn, there are many of excellent quality on YouTube, this is just an example.

Week 9: machine learning cont.

- Molnar, C. (2020). *Interpretable machine learning*. Lulu.com. https://christophm.github.io/interpretable-ml-book/, chapters: 2 & 4
- 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. https://doi.org/10.1016/j.neuroimage.2013.10.067

Week 10: machine learning as signal processing

- Blankertz, B., Tomioka, R., Lemm, S., Kawanabe, M., & Muller, K.-R. (2008). Optimizing spatial filters for robust EEG single-trial analysis. *IEEE Signal processing magazine*, *25*(1), 41–56
- Kriegeskorte, N. (2008). Representational similarity analysis – connecting the branches of systems neuroscience. *Frontiers in Systems Neuroscience*. https://doi.org/10.3389/neuro.06.004.2008
- Cichy, R. M., Pantazis, D., & Oliva, A. (2014). Resolving human object recognition in space and time. *Nature Neuroscience*, *17*(3), 455–462. https://doi.org/10.1038/nn.3635

Week 11: neural networks

- LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature*, *521*, 436–444. https://doi.org/10.1038/nature14539
- Lawhern, V. J., Solon, A. J., Waytowich, N. R., Gordon, S. M., Hung, C. P., & Lance, B. J. (2016). EEGNet: A Compact Convolutional Network for EEG-based Brain-Computer Interfaces. *arXiv e-prints*. https://doi.org/10.1088/1741-2552/aace8c

Additional readings and resources

- Nielsen, M. A. (2015). *Neural networks and deep learning* (Vol. 2018). Determination press San Francisco, CA. http://neuralnetworksanddeeplearning.com/, chapters: 1-2
- Bengio, Y., LeCun, Y., & Hinton, G. (2021). Deep learning for AI. *Communications of the ACM*, *64*(7), 58–65. https://doi.org/10.1145/3448250

Week 12: summary and Q & A

- No readings.

6 Exercises and portfolio papers

For the practical classes there will be coding exercises for the topic we are having, where some will be covered in class and some are out-of-class activities with peer feedback. There will also be possibilities to write parts of the portfolio papers in the practical classes and get feedback on argument structures, materials selected, and similar questions.

The portfolio papers handed in doing the semester will be given peer feedback.

Remark. *The portfolio papers will **NOT** be given any official feedback doing the semester, as this would count as an exam attempt!*

Week	Exercise	Portfolio papers
1	Introduction to MNE-python	
2	To be decided	
3	MNE-python filtering and visualization cont.	
4	Writing paper 1	
5	Time-frequency analysis of EEG data	Paper 1
6	Class presentation	
7	MVPA	
8	Writing paper 2	
9	Class presentation	
10	PCA, SPoC, & CSP	Paper 2
11	Analysis Q&A	

Group presentations

Week 6 (Oct 26th)	**Week 9** (Nov 16th)
Group 2	Group 1
Group 4	Group 3
Group 5	Group 6