NX-421: Neural signals and signal processing

MINI PROJECT

For this mini-project, we propose 3 project variants and you will only do the one assigned to your group. Each variant has a practical part that will require you to write code and provide results in the form of images and plots, and a theoretical part where you will need to elaborate on concepts based on your knowledge and report your reasoning. You will need to address both parts and include them in your report and video recording.
Make sure that you properly familiarize yourself with the instructions before you proceed.

The deliverables should include **a written report, a code repository**, **and a recording** which should last **between 4 and 5 minutes (sharp).**

Recordings Guidelines:

- Use Zoom recording option
- The presentation needs to be shared evenly across group members (i.e., each member should speak approximately the same amount of time, and this does not necessarily have to reflect the individual contributions to the project)
- Presenting flow:
    - Briefly present the dataset and the motivation of the mini project
    - Answer succinctly questions in the given order first starting from **part 1**'s practicals then theoreticals followed by **part 2** in a similar fashion
    - Add a final slide with the project contributions of each group member.

Written reports Guidelines:

- **5 pages max** (including images), single column, font-size 11px in Arial.
    - We suggest that you address each part separately; for each part, discuss and report the results of the practical, then provide answers to the theoretical questions.
    - Include a brief list of the contributions of each group member.
- **Submit the code** you used for solving the mini-project with the structure and naming described in the “Miniproject guideline” document that has been previously shared with you.
- Please, **do not** upload datasets, images beyond the ones in the report, or any additional content.

All deliverables should be submitted on Moodle.

Deliverables are due on **Thursday 6th November at 16:00**.
Note that this is a sharp deadline, no extensions are allowed.

*: Harder question, brings you additional points but not necessary to get full grade.

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Description

Part 1 (Suggested time allocation: 17th October - 29th October)
As a researcher you are interested in studying the brain neural activity related to motor tasks. Specifically, you want to understand which regions of the brain are activated when the subject is moving their hands in comparison to moving their feet during fMRI scanning.

The dataset that you will use is a subset taken from the Human Connectome Project, a publicly available neuroimaging dataset. It is accessible through this link, and is acquired during a motor task experiment.

```
.
├── T1w
│   └── T1w.nii.gz
├── dataset_description.md
├── fMRI
│   ├── tfMRI_MOTOR_LR
│   │   ├── events_LR.csv
│   │   └── tfMRI_MOTOR_LR.nii
│   └── tfMRI_MOTOR_RL
│       ├── events_RL.csv
│       └── tfMRI_MOTOR_RL.nii
└── task-motor_bold.json
```

In particular, this task was adapted from a previously developed one by Buckner and colleagues (Buckner et al. 2011 [1]) with the goal to investigate and map motor areas**.** Participants are shown visual cues asking them to either tap their left or right fingers, squeeze their left or right toes, or move their tongue. The experiment has a block design with 10 possible movement types. Each block consists of ~12 seconds of movement preceded by a ~3-second cue. The experiment is repeated for 2 runs, each including the following 13 blocks: 2 tongue movements, 4 hand movements (2 right and 2 left), and 4 foot movements (2 right and 2 left). In addition, there are 3 15-second fixation blocks per run. The timing of the events is provided in the *event_*.csv* files found in the dataset structure.

Practicals (part 1)

Using what you learnt in the tutorials

1) Apply the following structural preprocessing steps using the methods of your choice (e.g., *fMRIPrep, FSL*-based, python-based):
    a) **Skull-stripping**. Report the brain plots before and after to visually assess the effect of this step.
    b) **Segmentation**. Report on a brain plot the tissues segmented.
2) Apply the following functional preprocessing steps using the methods of your choice (e.g., *fMRIPrep, FSL*-based, python-based):
    a) **Concatenate all runs** of interest of subject 101410 together after rescaling the variance to 1 (using global variance of the brain voxels) for each session *before* concatenation!
    b) **Motion correction** (you can take care of the irregular volumes the way you want). Report the plot of the framewise displacement.

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c) ***(Bonus)**** **Co-registration**. Report a brain plot overlaying the source and the target volume (you can show any single volume of your choice). Comment on the alignment. (**Note**: the results of this step are *not* to be used in the rest of the project)

d) **Gaussian smoothing** with a reasonable FWHM. Report the FSLeyes brain plot before and after this step (you can show any single volume of your choice).

Briefly justify in your report the purpose of each of the structural and functional preprocessing steps.

3) Report the experimental design matrix to use for this subject, which you will be using in the following GLM analysis.
4) Run the GLM at the level you deem reasonable and report the statistical maps of each of the task-related regressors. Briefly comment on the statistical maps and, if you can, relate them to the corresponding task.
5) Using the results of the GLM analysis and a contrast vector of your choice, create the activation maps corresponding to the **hand motion against feet motion**. Please include in the report the contrast vector used and the contrast map you obtained.
6) To better interpret your results, overlay the contrast map with the **AAL atlas parcellation *(hint: take a look at NiLearn)***. Report in which brain regions you find maximal contrast. (**Note**: the functional data are already in MNI space, so there is no need to do coregistration and normalization!)

Theoreticals (part 1)

Answer the following questions, and justify your answers (you do not need to write nor provide any code for this, only report your reasoning):

1) Can you do a second level analysis on the specific dataset provided? Why?
2) Now consider you are provided a dataset of 10 subjects for the same task. Alongside the neuroimaging data, you also know the age of each participant. Could you perform second-level analysis on this dataset? Which types of scientific question(s) could you answer with the provided data? Which contrast vector would you need to perform appropriate statistical testing and draw your conclusions? Note that there are multiple possible questions that you could ask and hence multiple possible correct answers to this point, but we only require you to provide at least one.

Part 2 (Suggested time allocation: 29th October - 7th November)

Note that this part is split into 3 variants, you are assigned to one of the following variants according to your group letter.

Now you proceed to do a different analysis by employing multivariate pattern analysis methods. The goal is to find spatial maps in a data-driven manner (no GLM) and to investigate which spatial map would include the regions found in the GLM analysis.

You know that different methods exist to find these spatial patterns, and you will be required to use one of them based on the project variant your group is assigned to:

- Principal Component Analysis (**variant 1**)
- Independent Component Analysis (**variant 2**)

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- K-means clustering (**variant 3**)

Practicals (part 2)

Variant 1

1. Apply PCA on the subject fMRI runs, considering one volume as one sample.
2. Select a number of components of your choice to keep while providing a justification for your choice. Show each of the selected PCA components separately overlaid on the anatomy, in axial view only.
3. Compute the pairwise similarity (using a similarity measure of your choice) of the first 5 (independently on the choice you made on point 2) obtained components. Report the similarity matrix.

Variant 2

1. Apply ICA on the subject fMRI runs, considering one volume as one sample.
2. Select a number of components of your choice to keep while providing a justification for your choice. Show each of the selected ICA components separately overlaid on the anatomy, in axial view only.
3. Compute the pairwise similarity (using a similarity measure of your choice) of the first 5 (independently on the choice you made on point 2) obtained components. Report the similarity matrix.

Variant 3

1. Apply K-means clustering on the subject fMRI runs, considering one volume as one sample.
2. Select a number of clusters of your choice to keep while providing a justification for your choice. Show each of the centroids separately overlaid on the anatomy, in axial view only.
3. Compute the pairwise similarity (using a similarity measure of your choice) of the first 5 (independently on the choice you made on point 2) obtained centroids. Report the similarity matrix.

Theoreticals (part 2)

Answer the following questions, and justify your answers (you do not need to write nor provide any code for this, only report your reasoning):

1. Brain activity at rest can be separated into known functional networks [2]. Choose a component in which you can recognise one or more of these functional networks and comment as to why these networks would be active during the task.
2. Compare the regions obtained in practical part 1.3 from GLM procedure and the spatial patterns obtained in your multivariate pattern analysis method from practical part 2.3.
    a. Considering the original research question of using the task to map different motor areas, would you say that it is more effective to perform GLM or MVPA? Why?
    b. When would you apply one and when would you apply the other? Please, justify your answers.

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References

[1] Buckner, Randy L., Fenna M. Krienen, Angela Castellanos, Julio C. Diaz, and BT Thomas Yeo. "The organization of the human cerebellum estimated by intrinsic functional connectivity." Journal of neurophysiology 106, no. 5 (2011): 2322-2345.
[2] Yeo, BT Thomas, Fenna M. Krienen, Jorge Sepulcre, Mert R. Sabuncu, Danial Lashkari, Marisa Hollinshead, Joshua L. Roffman et al. "The organization of the human cerebral cortex estimated by intrinsic functional connectivity." *Journal of neurophysiology* (2011).

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