**Validation of the segregational capacity for Manifold Embedding Neuroimage Analysis (MENA) for continuous wave functional near infared spectroscopy (CW-fNIRS)**

**Supervisor**: Felipe Orihuela-Espina

**Collaborators**: Dr. Daniel Richard Leff (Imperial College London), Dr. Ilias Tachtsidis (University College London), Dr. Gustavo Rodríguez-Gómez (INAOE)

**Area**: Topology, data analysis and signal processing.

*Aim*: To validate MENA analysis for CW-fNIRS dataset.

*Background*: Manifold embedding neuroimage analysis (MENA) is a topology based approach for the analysis of both segregational and integrational neurological phenomena observed with continuous wave functional near infrared spectroscopy (CW-fNIRS). Despite its high expressivity, it lacks adoption because of its higher mathematical complexity (as compared to classical statistical approaches) as well as because in spite of its obvious empirical success, it has never been validated. In this project, we seek to validate the capacity of MENA to express segregational aspects of neurological processes for its use in CW-fNIRS data.

Scientific validation of new analytical models can be established by either, formal proof or empirically depending on the nature of the phenomenon being modelled as well as the type of validity being established. For physical phenomena, the validity of models relates to their capacity to explain and/or predict the phenomenon or the variance associated to it. Hence, the empirical approach being the dominant paradigm. Empirically establishing the validity of a model requires a number of stages of increasing elaboration; First, you will have to demonstrate that true known answers are recovered from synthetically generated data. Second, you add synthetic noise and establish the robustness of the approach under controlled noise conditions. Third, you add semi-synthetic noise for realistic noise condition but for which you still know the synthetic activation ground truth. Finally, you test on real experimental data for which you do not know the ground truth but you rely on gold standards for comparison.

Methods: This project requires you to:

1. Get a thorough understanding of manifold embedding neuroimage analysis (MENA) as well as the general linear model (GLM) as commonly used for fNIRS analysis.
   1. Learn to generate synthetic data using a forward model of brain haemodynamics, e.g. the double gamma approach convolved with the haemodynamic response function (HRF).
   2. Learn how to seed MENA for answering hypothesis driven research questions.
2. Validate on noiseless synthetic noise (face validity)
   1. Generate noiseless synthetic data
   2. Execute an experiment to establish whether, in the absence of noise, MENA can recover the ground truth about brain activation and whether its outcome matches that of the gold standard.
3. Validate on noisy synthetic noise (internal validity)
   1. Add noise to the synthetic data using forward models of noise for common artefacts, e.g. heart beat, optode movement, systemics, etc.
   2. Execute an experiment to establish whether, in the presence of synthetic noise, MENA can still recover the ground truth about brain activation and whether its outcome matches that of the gold standard.
4. Validate on semi-synthetic noise (content validity)
   1. Add experimental noise to the synthetic data using some existing resting state data (this will be provided to you).
   2. Execute an experiment to establish whether, in the presence of experimental noise, MENA can still recover the ground truth about brain activation and whether its outcome matches that of the gold standard.
5. Validate on experimental data (concurrent validity)
   1. You will be provided with a neuroimaging dataset collected using continuous-wave functional near infrared spectroscopy (CW-fNIRS) by our colleagues at Imperial College studying surgical neuroergonomics [2]. In this dataset, brain haemodynamics of the surgeons whilst executing a simulated surgical task was collected to understand surgical skill acquisition and performance in a cohort of surgeons of different expertise under some stress condition.
   2. To design and apply a reconstruction and processing pipeline to the provided fNIRS dataset to clean the raw data from major artefacts and prepare it for analysis. Existing software tools such as Homer 3, MNE-NIRS, ICNNA or NIRS Toolbox may be used for this task.
   3. Apply MENA and the gold standard analysis to the experimental dataset establish how on experimental data, MENA matches (or differs) from the outcome of the gold standard.
6. (Optional – Advance only) Formally proof that MENA generalises the standard GLM based model.

*Expected outcome*: Segregational statistics regarding the capacity of MENA to identify active brain regions under different experimental conditions and validation against ground truth or a gold standard statistical analysis.

*Related literature*:

[1] Orihuela-Espina, F et al, (2017)“Imperial College near infrared spectroscopy neuroimaging analysis framework,” Neurophoton. 5(1), 011011 , doi: 10.1117/1.NPh.5.1.011011.

[2] Goble, M et al (2023). Optical neuroimaging and neurostimulation in surgical training and assessment: A state-of-the-art review, Front. Neuroergon. 4:1142182. doi: 10.3389/fnrgo.2023.1142182