Development of processing and analysis methods for Biomedical data.

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1. Research Theme

- Development of MEG data processing and analysis methods for neural decoding
- Development of fNIRS data processing and analysis methods

The purpose of these studies is to develop robust and reliable methods that allow for a more accurate analysis of Biomedical data than those produced by the currently available techniques. This in turn will help us to better understand the mechanisms of speech production, language development, effects of brain disorders and more.

2. Major Research Outcomes

Development of MEG data processing and analysis methods for neural decoding.

In the preprocessing procedure of MEG data analysis, we have improved the classical denoising pipeline by incorporating Empirical Mode Decomposition (EMD) and Principal Component Analysis (PCA). Using EMD to remove high frequency noise improves the interpretability of the MEG data. The performance of Machine Learning (ML) methods is also improved. PCA does not improve interpretability but gives additional insight into the most informative time period. Also, PCA improves ML classification accuracy due to increased variance of the principal components. We thoroughly explain these aspects in our work titled: "*MEG Neural Decoding Pipeline: The issues residing within the data and methods to improve your decoding accuracy*", Patashov et.al. In this same study, we compare different approaches for classification of MEG data. We have shown that careful selection of the recorded channels, together with averaging of several epochs can drastically increase classification accuracy. In our data, object classification accuracy was increased from 42% to 91% and category classification accuracy increased from 68% to 96%. This was made possible using our proposed ML model design called Channel-Selection Combinations-Averaging Model (CSCAM).

In the analysis of cross-modality classification, we were able to produce classification accuracy maps with reasonable above-chance level accuracy [Figure 1]. It shows the time course of the conceptual representation of the items in our brains by learning the features of one modality and using them to classify another. An approach proposed by Dirani et.al. in "*The time course of cross-modal representations of conceptual categories*". Similarly to Dirani et.al. we have found off-diagonal classification patterns for cross-modality models. However, our patterns were slightly different from the ones observed by Dirani et.al. Also, we were able to produce higher above-chance-level accuracy, while using a larger number of target classes.

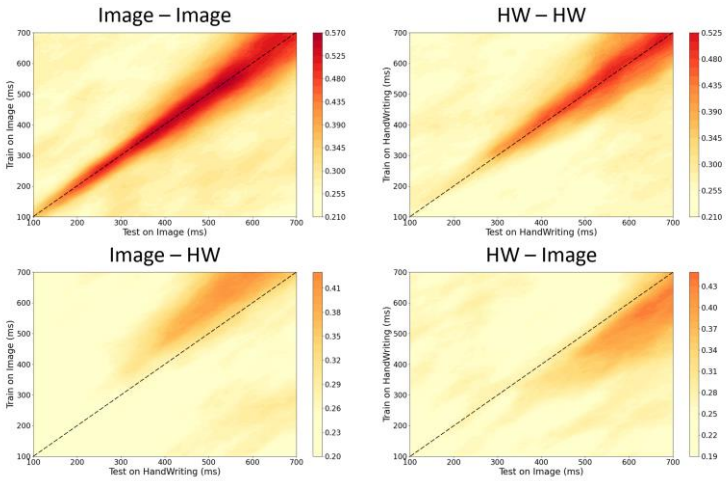

Figure 1: Y-axes of the figures represent the time periods used for training of the ML model. X-axes of the figures represent the time periods used for testing the trained model. Two top figures show in-modality classification accuracy, meaning that the training and testing were done within the same modality. Two bottom figures show cross-modality classification accuracy where the model was trained on one modality and tested on another.

These findings show us that similar representations of an object appear in our brains regardless of whether we observe an image depicting the object or read a word naming that same object. The off-diagonal affinity tells us that these representations, although similar, they occur at different times, depending on the modality used.

Development of fNIRS data processing and analysis methods

One of the core procedures for fNIRS data is Beer-Lambert calculation for differentiation of oxygenated and deoxygenated blood count. For many years no one has questioned the process of calculation for Beer-Lambert equation. For reference intensity, average or pre-recording intensity is used. We have assessed different referencing schemes for Beer-Lambert calculations and have discovered new emerging patterns and features which can be observed when changing the intensity reference definition. In “fNIRS: Non-stationary preprocessing methods” by Patashov et.al., we introduced a new method of filtration for fNIRS data, called Cumulative Curve Fitting Approximation (CCFA). Using this method, we have consistently received cleaner, more interpretable results. We have compared CCFA to other commonly used methods in fNIRS analysis when analyzing the data collected from infants and adults in two different studies. In the study on infants’ development, the resulting signals were easier to inspect and interpret visually. In the study involving adults with and without brain disorders, we were able to extract unique patterns capable of distinguishing between the individuals and between the tasks they performed with higher accuracy. We have also developed and are currently testing a filter for functional connectivity data. The idea of this filtering approach is to filter the entire multi-channel recording as a single entity, rather than doing so channel by channel. The strength of this approach is that it takes into consideration the entire recoded brain activity rather than just a single independent signal. This allows to retain and enhance global brain activity features which would be ignored otherwise.

3. Collaborating Researchers

Prof. Hiromu Sakai - Waseda Research Institute for Science and Engineering, Waseda University, Tokyo, Japan

Prof. Reiko Mazuka - Laboratory for Molecular Mechanism of Brain Development, RIKEN Center for Brain Science, Saitama, Japan

Dr. Dmitry Goldstein - Multimodal and complex Data Analysis Center, Holon Institute of Technology, Holon, Israel

Dr. Michal Balberg - Faculty of Engineering, Holon Institute of Technology, Holon, Israel

4. Research Achievements

Reviews and Books

I have reviewed Journal Article submissions for:

- IEEE Transactions on Human-Machine Systems
- Journal of NeuroEngineering and Rehabilitation
- Plos One

Academic and Social Activities

I am a core member of the organizing committee for the International Symposium on Brain Function and Cognition (ISBFC) that is scheduled to take place at Waseda University on September 2025. More information can be found at: isbfc.com

Conference presentations:

Spatiotemporal characteristics of semantic facilitation and interference: An MEG study using the cyclic picture-naming task - SNL 2024.

MEG Data Analysis for Cross-Modality Neural Decoding - Biomag 2024

The Time Course for Access to Object and Category Semantic Representations - Biomag 2024

5. Issues and Future Prospects of Research Activities

Development of MEG data processing and analysis methods for neural decoding.

Our current preprocessing pipeline is an improvement over the classical approach by attempting to compensate for the issues of stationarity assumption made by the classic tools. Going forward, we aim to completely replace all the tools that assume stationarity with more suitable solutions.

Development of fNIRS data processing and analysis methods

We are receiving very promising results using the novel approach for data processing and analysis. However, a more rigorous evaluation and comparison to other methods is required. We will concentrate on the evaluation of the novel techniques to find all of the important strengths and weaknesses they may have.