ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

XXXV Cycle

# Transition from Visually Evoked to Purely Imagined Steady-State Potentials in Brain-Computer Interfaces


Davide Consoli

Supervisor: Francesco P. Andriulli

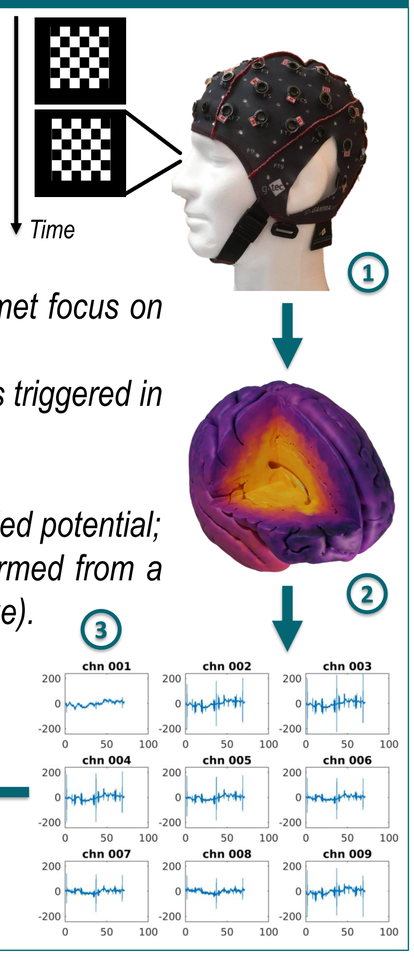

erc

## Research context and motivation

- Steady-State Visually Evoked Potential (SSVEP) based Brain Computer Interfaces (BCI) are simple and high performing in terms of bit-rate;
- Unfortunately, they requires external devices to provide the stimuli, limiting the scenarios in which they can be applied.

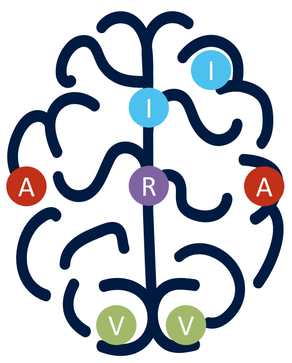
*Standard SSVEP-BCI pipeline:*

1. *A subject wearing an ElectroEncephaloGraphy (EEG) helmet focus on a pattern flickering at a certain frequency;*
2. *A brain electric activity that follow the flickering frequency is triggered in the occipital area;*
3. *This activity is recorded from the EEG;*
4. *Machine learning algorithms are used to classify the recorded potential;*
5. *Depending on the predicted class an action can be performed from a computer or from an actuator (e.g. move a cursor on a maze).*

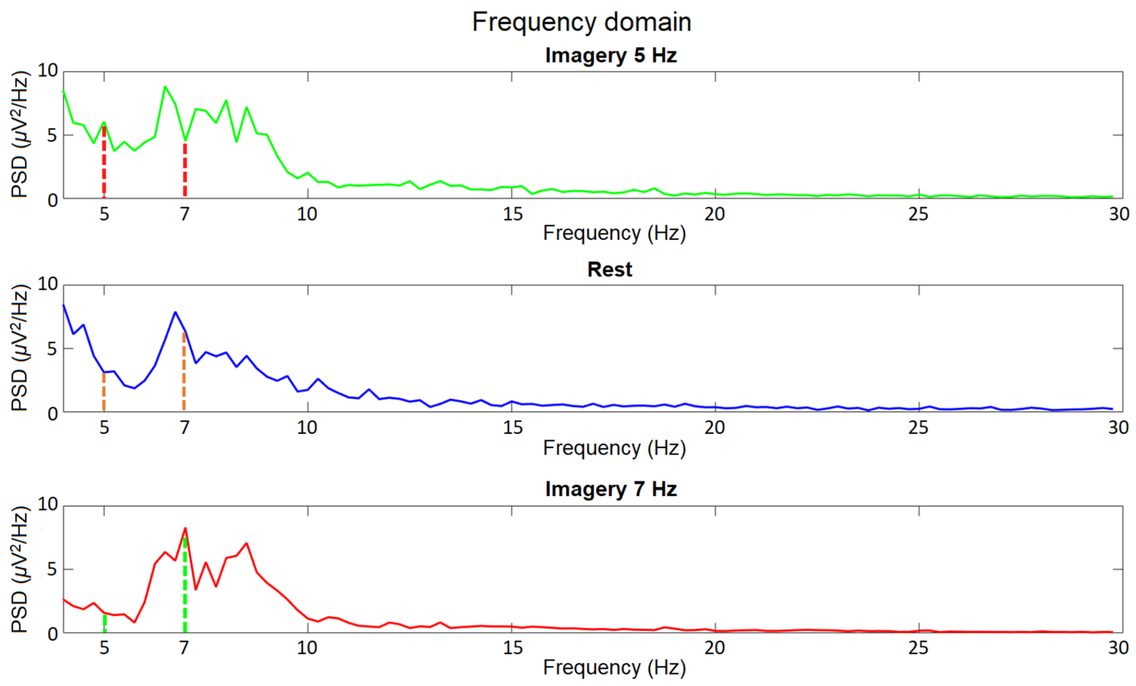



## Addressed research questions/problems

- We developed a new BCI paradigm that is based on Visual Imagery (VI) signals, where the subject by simply imaging a flickering pattern triggers an EEG signal that we can classify, avoiding the need of external stimuli;
- We used SSVEP and Auditory Steady-State Response (ASSR) to help the subject in the training required to use the VI based BCI.




*Brain areas involved in the different brain signals.*




## Submitted and published works

- S. B. Adrian, A. Dély, D. Consoli, A. Merlini and F. P. Andriulli, "*Electromagnetic Integral Equations: Insights in Conditioning and Preconditioning"* in IEEE Open Journal of Antennas and Propagation, vol. 2, 2021, pp. 1143-1174
- D. Consoli, A. Merlini and F. P. Andriulli, "*A Fast Quasi-Conformal Mapping Preconditioner for Electromagnetic Integral Equations*" 2021 International Conference on Electromagnetics in Advanced Applications (ICEAA), pp. 412-412, 2021
- Micheli, A., Consoli, D., Merlini, A., Ricci, P., & Andriulli, F. P. B "*Brain-Computer Interfaces: Investigating the Transition from Visually Evoked to Purely Imagined Steady-State Potentials*", IEEE EMBC, Glasgow, Scotland, 2022
- Merlini, A., Henry, C., Consoli, D., Rahmouni, L., & Andriulli, F. P.. "*Laplacian Filters for Integral Equations: Further Developments and Fast Algorithms*", IEEE AP-S, Denver, Colorado, 2022
- D. Consoli, C. Henry, M. Monin, L. Rahmouni, P. Ricci, A. Merlini, & Andriulli, F. P.. "*Recent Advances in Computational Electromagnetics for High Resolution Neuroimaging*", IEEE AP-S, Denver, Colorado, 2022
- Consoli, D.; Henry, C.; Dély, A.; Rahmouni, L.; Ortiz Guzman, J. E.; Chhim, T. L.; Adrian, Simon B.; Merlini, A.; Andriulli, F. P. "*On the Fast Direct Solution of a Preconditioned Electromagnetic Integral Equation*", ICEAA/IEEE APWC, Cape Town, South Africa, 2022
- C. Henry; D. Consoli; A. Dely; L. Rahmouni; A. Merlini; F. P. Andriulli, "*Fast Direct Solvers Based on the Quasi-Helmholtz Laplacian Filters*", IEEE CAMA, Guangzhou, China, 2022

## Novel contributions

5Hz W/ Sound

| True Class \ Predicted Class | VI 5Hz | Rest | SSVEP 5Hz |
|---|---|---|---|
| VI 5Hz | 48 | 1 | 11 |
| Rest | 8 | 51 | 1 |
| SSVEP 5Hz | 12 | 1 | 47 |

7Hz W/o Sound

| True Class \ Predicted Class | VI 7Hz | Rest | SSVEP 7Hz |
|---|---|---|---|
| VI 7Hz | 51 | 2 | 7 |
| Rest | 12 | 46 | 2 |
| SSVEP 7Hz | 14 | 7 | 39 |

5Hz W/o Sound

| True Class \ Predicted Class | VI 5Hz | Rest | SSVEP 5Hz |
|---|---|---|---|
| VI 5Hz | 48 | 4 | 8 |
| Rest | 2 | 57 | 1 |
| SSVEP 5Hz | 9 | 3 | 48 |

7Hz W/ Sound

| True Class \ Predicted Class | VI 7Hz | Rest | SSVEP 7Hz |
|---|---|---|---|
| VI 7Hz | 79 | 6 | 5 |
| Rest | 2 | 85 | 3 |
| SSVEP 7Hz | 6 | 10 | 74 |

- We designed a protocol including six sessions that at the last stage consists of only VI classes;
- The results show that we are already capable to distinguish between two different VI tasks and rest with good accuracy.

Mult. Freq.

| True Class \ Predicted Class | Rest | SSVEP 5Hz | SSVEP 7Hz | VI 5Hz | VI 7Hz |
|---|---|---|---|---|---|
| Rest | 72 | 2 | 10 | 20 | 4 |
| SSVEP 5Hz | 4 | 101 | 1 | 2 | |
| SSVEP 7Hz | 6 | 1 | 98 | 1 | 2 |
| VI 5Hz | 17 | | 2 | 66 | 23 |
| VI 7Hz | 16 | | 1 | 35 | 56 |

Only VI

| True Class \ Predicted Class | Rest | VI 5Hz | VI 7Hz |
|---|---|---|---|
| Rest | 112 | 3 | 5 |
| VI 5Hz | 17 | 56 | 47 |
| VI 7Hz | 11 | 20 | 89 |

## Adopted methodologies

Electrodes selection:

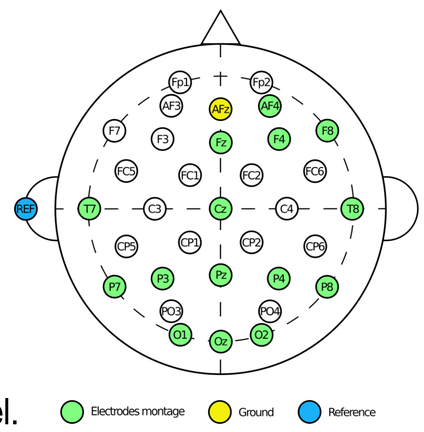
- Anatomical based pre-selection;
- Heuristic ad-hoc data-based algorithm for fine selection.

Signals processing:

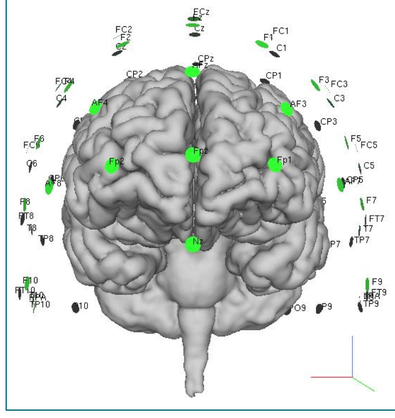
- Filters for electromyographic and line noise attenuation;
- Computing the average Power Spectral Density (PSD) for each electrode in the range 2–36 Hz for each trial.

Classification:

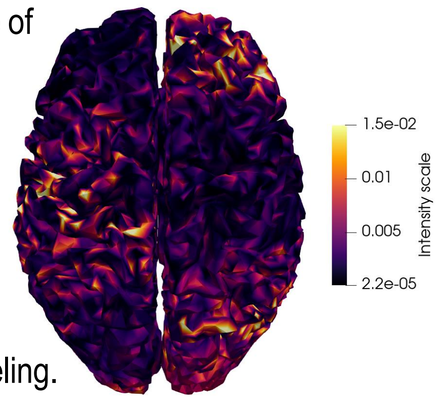
- These vectors were fed as features to a regularized Support Vector Machine (SVM) classifier with linear kernel.




## Future work



We are investigating the usage of features based on the electric current on the brain to feed the classifier to improve the performances.
The electric current is estimated via non-invasive inverse source imaging techniques and realistic brain modeling.




## List of attended classes

- 02LWHRV – Communication (7/1/2020, 6.67)
- 01SHMRV – Entrepreneurial Finance (8/3/2022, 6.67)
- 01UNWRP – Intercultural & interpersonal management (31/7/2020, 10.67)
- 01UNYRV – Personal branding (14/3/2022, 1.33)
- 08IXTRV – Project management (17/3/2022, 6.67)
- 01RISRV – Public speaking (13/9/2021, 6.67)
- 01SYBRV – Research integrity (15/9/2021, 6.67)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (8/3/2022, 8)
- 01UNXRV – Thinking out of the box (3/8/2021, 1.33)
- 01SWPRV – Time management (8/3/2022, 2.67)
- 01UZHPQ – Aspetti psicologici ed educativi dello sviluppo e dell'apprendimento (23/6/2022, 40)
- IEEE Italy Authorship Symposium (1/12/2020, 1)
- 02SILPQ – Pedagogia della scuola e dell'inclusione (27/6/2022, 40)
- 01UJDRV – Integral operators and fast solvers: a cross-disciplinary excursus on the best of FFT'companions (26/11/2020, 33.33)
- 01DPJRV – Lens antennas: Fundamentals and present applications (7/12/2021, 13.33)
- 01QUWRV – Mathematical-physical aspects of electromagnetism (26/10/2020, 25)
- 01UIZRV – Microwave sensing and imaging for innovative applications in health and food industry (9/10/2020, 33.33)
- 01MMRRV – Tecniche numeriche avanzate per l'analisi ed il progetto di antenne (9/6/2021, 33.33)
- ESoA course Advanced Mathematics for Antenna Analysis – (17/5/2021, 66.67)
- Computing@PoliTO Workshop – (17/1/2020, 6.68)
- "PitchD - the PhD's pitch" organized by the IEEE Politecnico di Torino S.B. – (29/1/2020, 1)

Politecnico di Torino

1859

PhD program in

**Electrical, Electronics and Communications Engineering**