Machine Learning Applications for Enhancing Rehabilitation

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INTRODUCTION

- *Acquired Brain Injury (ABI)*, a leading cause of disability worldwide, often leaves survivors with attentional deficits such as hemispatial neglect that manifest in eye gaze patterns [1].
- Understanding the neural mechanisms behind these deficits is key to creating more effective and personalized rehabilitation strategies [2].
- Computational models, such as *Deep Reinforcement Learning (DRL)*, can simulate and predict complex brain behaviors, including how attention is oriented toward a target [3].

Objectives:

1. Developing a DRL model that captures the complexity of human attentional systems and reproduces healthy individuals' eye gaze patterns.
2. Adapting the model to simulate specific post-stroke attentional deficits in order to inform on the functional impact from the in vivo performance and behaviour.

METHODS

- In our work, we focus on a simple spatial and selective attention task, identifying a target among distractors.
- We will refer to this task as the *Spatial and Selective Attention Environment (SSAE)* task.

To achieve this, we introduce the following tools and methods:

- **SSAE**: Virtual grid environment with a target, distractors and a field of view
- **In vivo**: *Virtual Reality (VR)* headset
- **In silico**:
  - *Convolutional Neural Network (CNN)*
  - DRL: *Proximal Policy Optimization (PPO)*

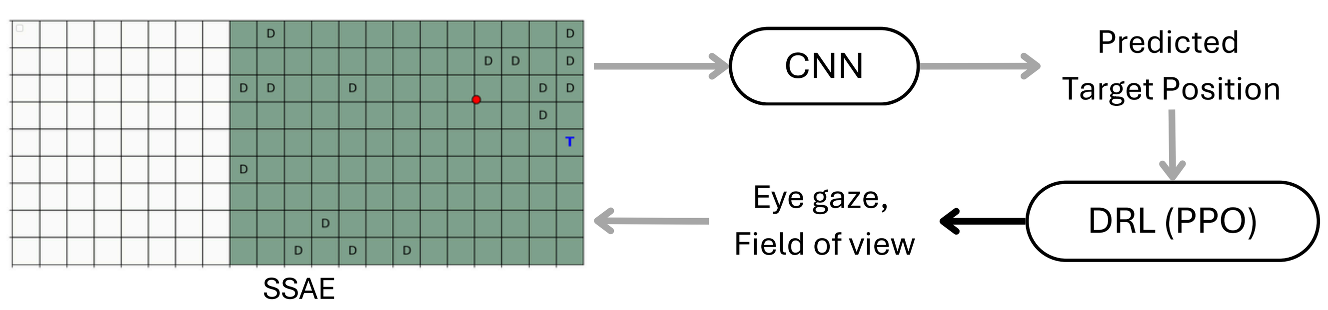

***Fig. 1**: Experimental pipeline.*

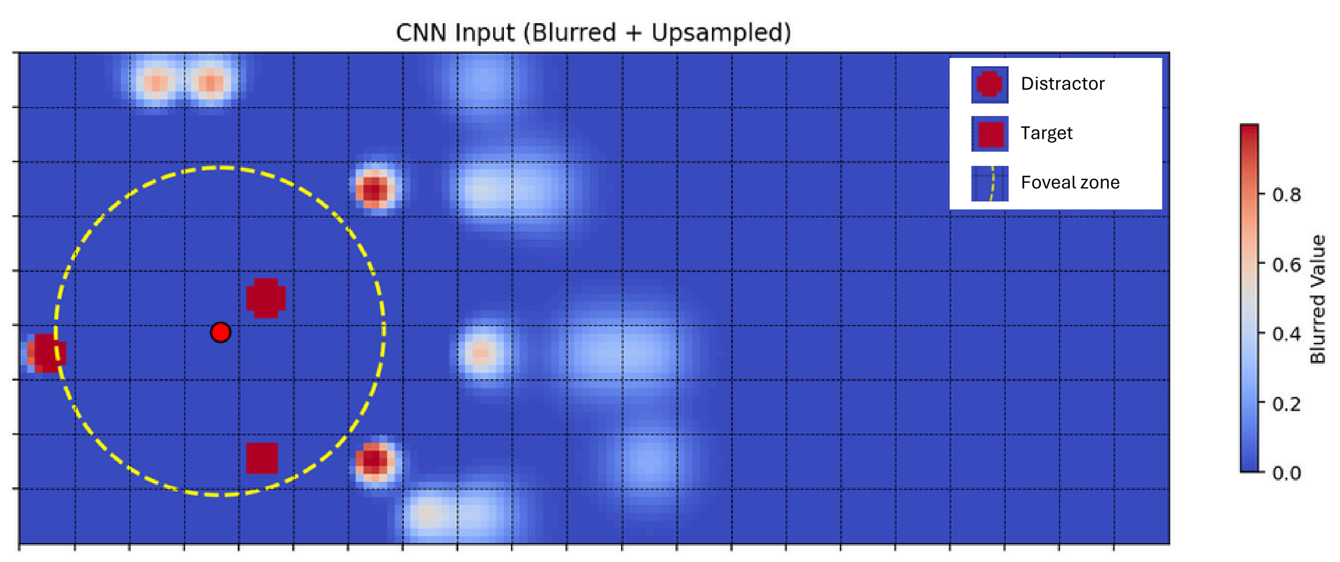

***Fig. 2**: SSAE seen by the CNN with foveal region in yellow.*

Our Model:

- CNN: Processes visual input and manages spatial attention.
- PPO: Controls motor output and guides eye-movement actions.
- Together, they reproduce biological mechanisms of gaze, including fixation and saccades.

RESULTS

In vivo and silico behavioral examples

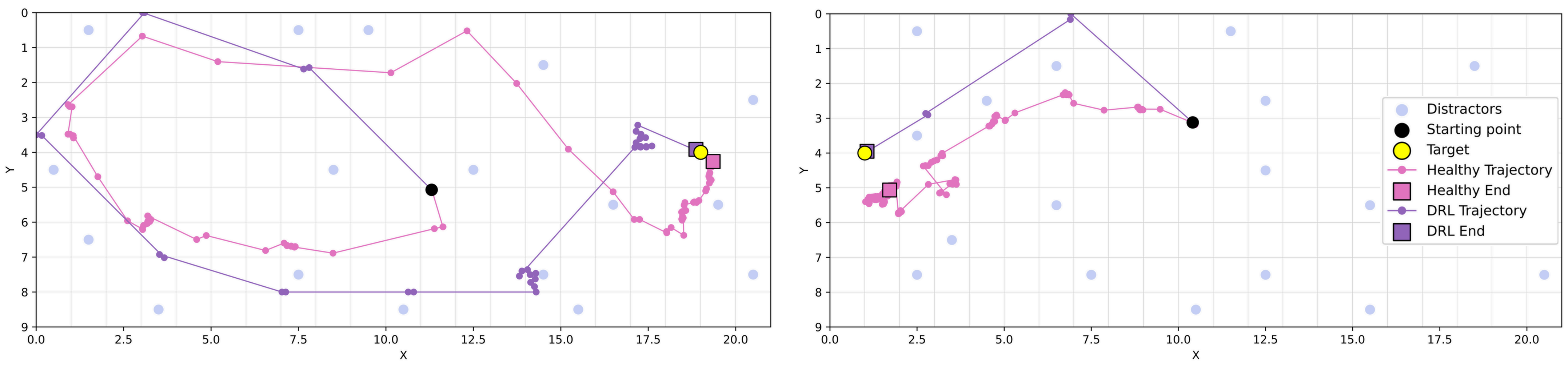

***Fig. 3**: SSAE task resolution's trajectories examples: Healthy, DRL.* → Both groups behave similarly.

Task performance across targets comparison

- We monitor the model's ability to match healthy humans in term of: **reaction time** (steps), **accuracy** (or conversely, miss rate) and **trajectory similarity**.
- To assess trajectory similarity between two groups, we use *Dynamic Time Warping (DTW)*, a method for measuring similarity between two time series.

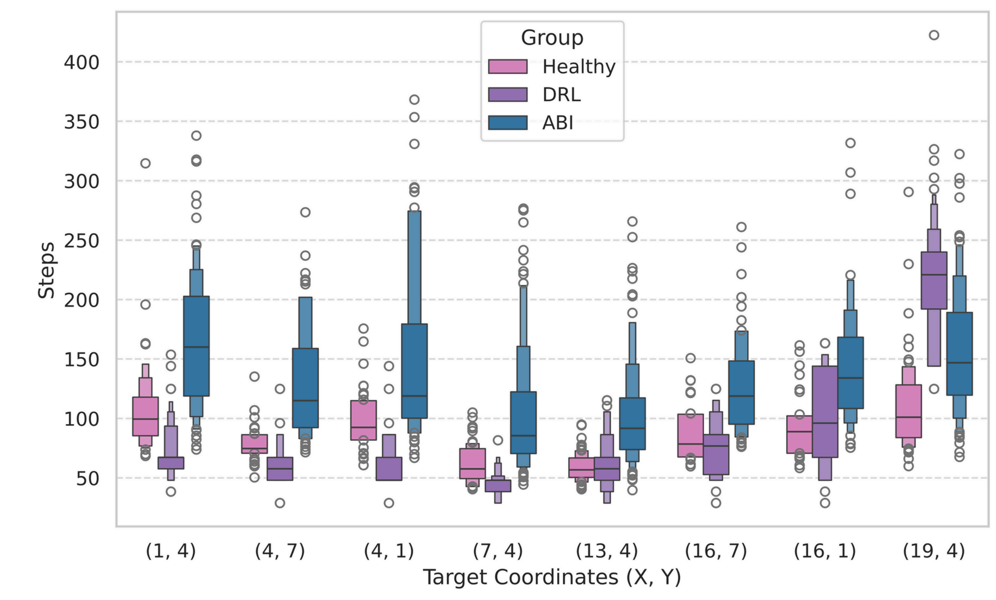

***Fig. 5**: Reaction time distributions (in number of steps until completion), for each possible target: Healthy, DRL, ABI.*

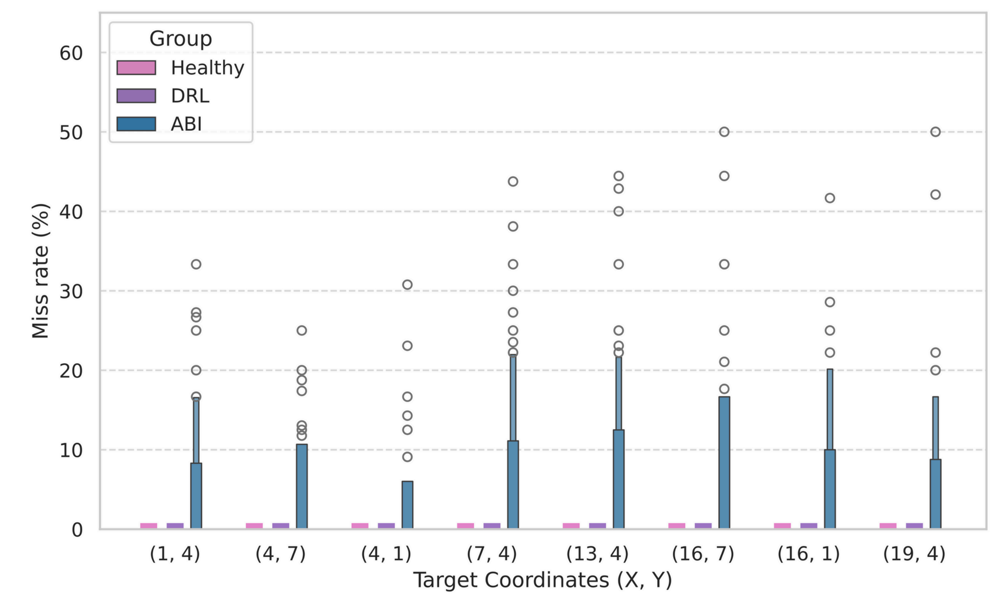

***Fig. 6**: Target miss rate distribution in percentage, for each possible target: Healthy, DRL, ABI.*

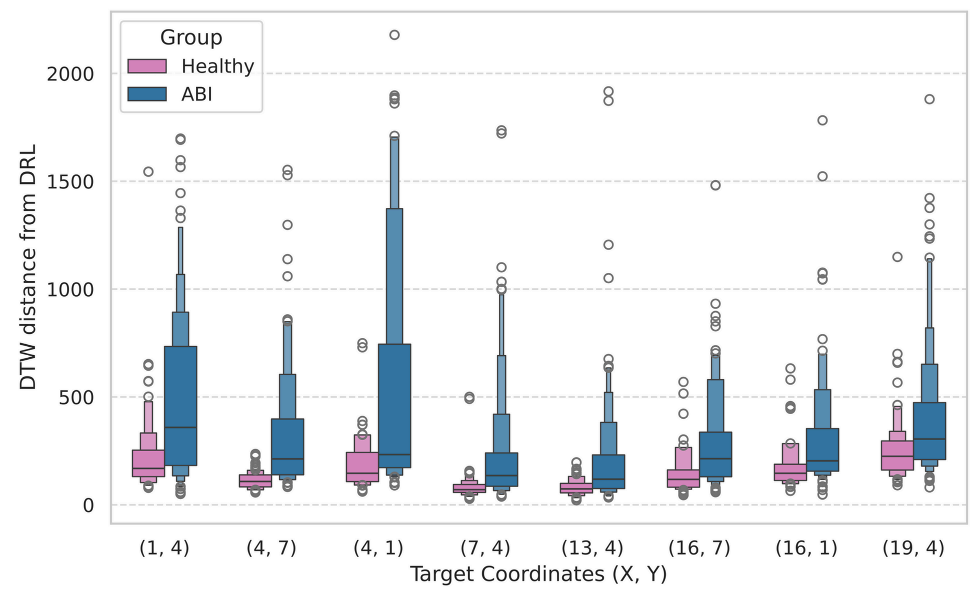

***Fig. 7**: Trajectory similarity with DRL distributions, for each possible target: Healthy, ABI.*

The model in action!

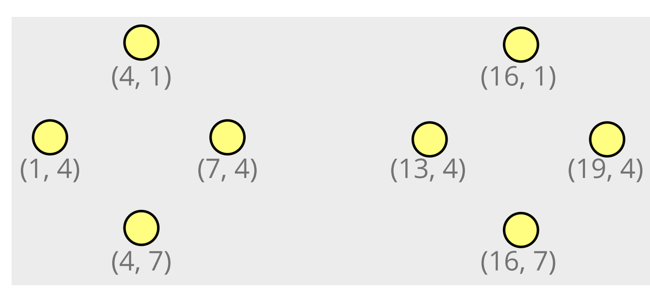

***Fig. 8**: Target Coordinates (X, Y) in SSAE (origin at the top left).*

→ The DRL model demonstrates performance comparable to Healthy patients, which meets our primary objective. Moreover, DTW distances are lower in Healthy patients than in ABI patients, indicating that our 'healthy' DRL model behaves more like a healthy individual.

PERSPECTIVES

1. **Creating a lesioned model:**
Artificially freezing multiple neurons configurations in the healthy gaze model's Neural Network to simulate attentional lesions.

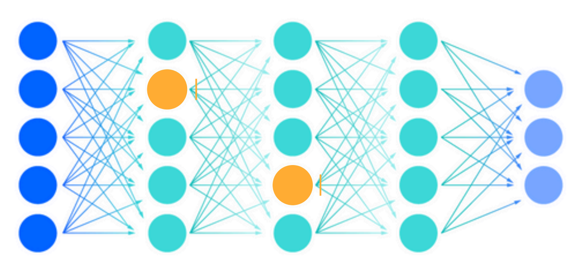

***Fig. 8**: Generating in-silico lesions by freezing neurons (in orange).*

2. **Constructing a new model to predict lesions:**
Use Machine Learning to predict lesions and attentional deficits from behavioral metrics.

3. **Decoding the Model**
Interpreting and visualizing the lesioned model's internal representations to investigate its functional sub-networks.

4. **An attentional model for rehabilitation**
The model could be used to diagnose attention deficits, comprehend it more thoroughly and propose tailored rehabilitation strategies.

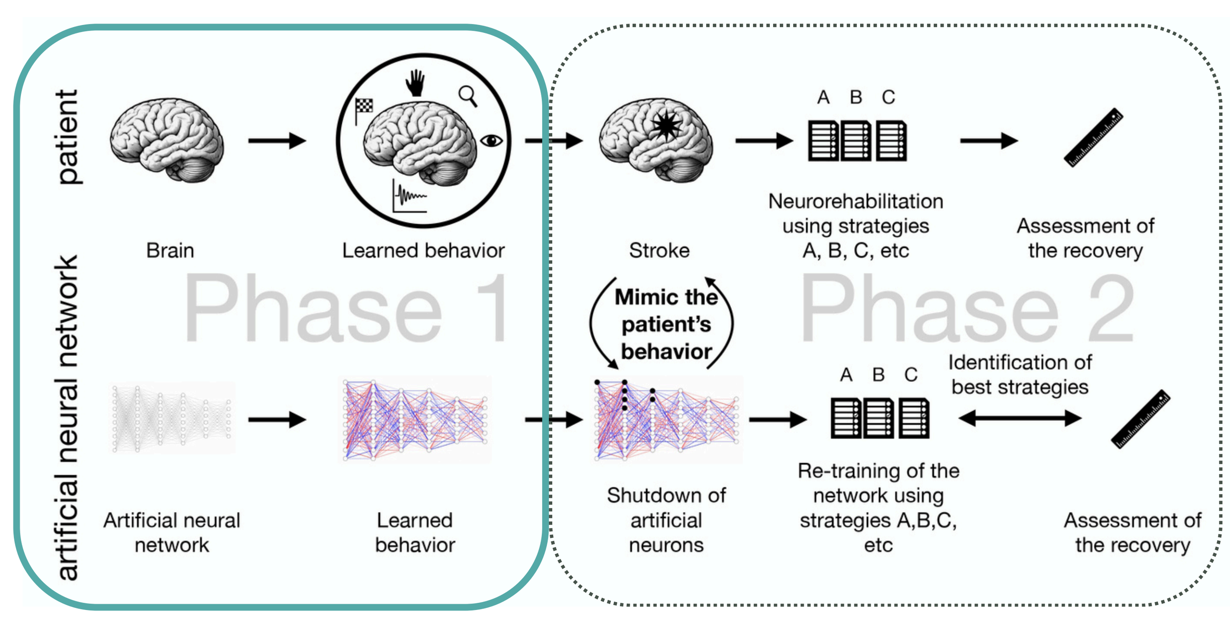

***Fig. 9**: Schematic representation of the project.*

CONCLUSION

- Our model reproduces key features of healthy eye-movement patterns.
- The comparison of in vivo behavior with in silico behavior highlights the model's ability to approximate human performance in terms of reaction time, accuracy, and trajectory similarity.
- It will be adapted to simulate attentional deficits, such as hemispatial neglect, by introducing artificial lesions.
- This approach provides a novel framework to study the neural mechanisms underlying attentional deficits and could be used as a foundation for designing personalized rehabilitation strategies.

References: [1] Davide Nardo, Maria De Luca, Francesca Rotondaro, Barbara Spanò, Marco Bozzali, Fabrizio Doricchi, Stefano Paolucci, Emiliano Macaluso, Left hemispatial neglect and overt orienting in naturalistic conditions: Role of high-level and stimulus-driven signals, Cortex, Volume 113, 2019, Pages 329-346.
[2] Faria, A.L., Pinho, M.S. & Bermúdez i Badia, S. A comparison of two personalization and adaptive cognitive rehabilitation approaches: a randomized controlled trial with chronic stroke patients. J NeuroEngineering Rehabil 17, 78 (2020).
[3] Cross, L., Cockburn, J., Yue, Y., & O'Doherty, J. P. (2021). Using deep reinforcement learning to reveal how the brain encodes abstract state-space representations in high-dimensional environments. Neuron, 109(4), 724-738.

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