Structured project outline including time and work schedule

Scientific background

Learning rewarded contingencies have been long linked with dopaminergic encoding of prediction error in the midbrain, allowing the building of representations in the striatum (Daw & Tobler, 2014). However, the hippocampus, previously thought to be mostly linked with higher types of memory have been recently linked to some types of associative learning (Ballard et al., 2019). Its involvement seems to be particularly related to reactivations of previous experience that facilities later inferences of indirectly experienced contingencies (Zeithamova et al., 2012). Similarly, this kind of replay could have an important role in model-based reinforcement learning (Liu et al., 2021).

The encoding of abstract states and their relations have also been found to rely greatly on an hippocampus-ventromedial prefrontal cortex axis (Boorman et al., 2016; Wang et al., 2020; Zeithamova et al., 2012), and lesions seem to impair inference ability(Bradfield et al., 2015; Pajkert et al., 2017; Spalding et al., 2018; Vikbladh et al., 2019). Abstraction is important for different types of learning-related processes, including building cognitive maps (e.g. to infer value from relationships) and generalization (e.g. to infer value of new stimuli). These processes also rely on the dopamine system in the midbrain and striatum (Kahnt et al., 2012; Kahnt & Tobler, 2016)

Interestingly, preexisting semantic associations seem to facilitate associative learning, but not for people with hippocampal lesions (Ryan et al., 2016). However, the way preexisting associations in memory interacts with learning new associations is unclear, as are the neural bases underlying these processes.

Objectives

Understanding the interaction of existing semantic association with learning processes, such as associative learning, reinforcement learning, and generalisation.

The following experiments are planned:

- **A.** fMRI and behavioral investigation of semantic facilitation and interference in associative learning
- **B.** fMRI and behavioral investigation of semantic knowledge on generalisation and reinforcement learning
- **C.** Modelling behavior and neural processes underlying it

Work Plan

Month 1-2:

- Literature survey, definition of research questions
- Design and planning of experiments
- Training: “fMRI safety”

Month 3-12:

- Training Beginner fMRI: “fMRI practical”, “fMRI theoritical”
- Training Advanced fMRI: “Perceptual Neuroimaging in Practice”
- Possible training “Scientific writing”, “Writing Papers and Theses in the Life Sciences”, “tACS”
- Training German Language
- Teaching, “Seminar Biologische Psychologie”
- Attending talks: “Neurokollokiums”, “Statistics revisited”
- Pre-tests and pilots
- Experiment A : semantic facilitation of associative learning
- Statistics and data interpretation
- Presentation at scientific conference

Month 13-20:

- Possible Lab rotation to Dr. Nathaniel Daw for modelling
- Data interpretation and statistics
- Experiment B: semantic knowledge, reinforcement learning and generalisation

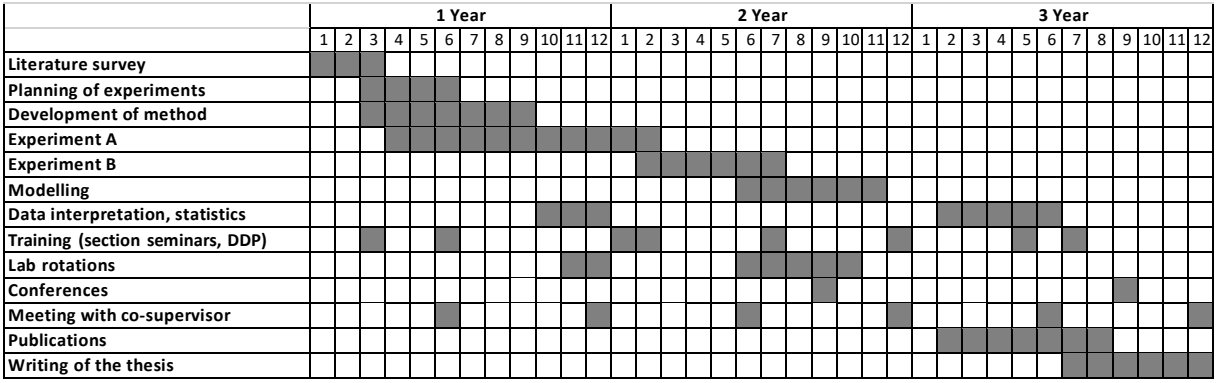
Month 20-30:

- Final experiments
- Data interpretation and statistics
- Writing manuscript for publication
- Training, e.g. “Job application”, “Successful Grant Proposal Writing”

Month 31-36:

- Writing manuscript for publication
- Writing of thesis
- Presentation at scientific conference

Schedule



References

Ballard, I. C., Wagner, A. D., & McClure, S. M. (2019). Hippocampal pattern separation supports reinforcement learning. *Nature Communications*, *10*(1), 1073. https://doi.org/10.1038/s41467-019-08998-1

Boorman, E. D., Rajendran, V. G., O’Reilly, J. X., & Behrens, T. E. (2016). Two Anatomically and Computationally Distinct Learning Signals Predict Changes to Stimulus-Outcome Associations in Hippocampus. *Neuron*, *89*(6), 1343–1354. https://doi.org/10.1016/j.neuron.2016.02.014

Bradfield, L. A., Dezfouli, A., van Holstein, M., Chieng, B., & Balleine, B. W. (2015). Medial Orbitofrontal Cortex Mediates Outcome Retrieval in Partially Observable Task Situations. *Neuron*, *88*(6), 1268–1280. https://doi.org/10.1016/j.neuron.2015.10.044

Daw, N. D., & Tobler, P. N. (2014). Value Learning through Reinforcement. In *Neuroeconomics* (pp. 283–298). Elsevier. https://doi.org/10.1016/B978-0-12-416008-8.00015-2

Kahnt, T., Park, S. Q., Burke, C. J., & Tobler, P. N. (2012). How Glitter Relates to Gold: Similarity-Dependent Reward Prediction Errors in the Human Striatum. *Journal of Neuroscience*, *32*(46), 16521–16529. https://doi.org/10.1523/JNEUROSCI.2383-12.2012

Kahnt, T., & Tobler, P. N. (2016). Dopamine regulates stimulus generalization in the human hippocampus. *ELife*, *5*, e12678. https://doi.org/10.7554/eLife.12678

Liu, Y., Mattar, M. G., Behrens, T. E. J., Daw, N. D., & Dolan, R. J. (2021). Experience replay is associated with efficient nonlocal learning. *Science*, *372*(6544), eabf1357. https://doi.org/10.1126/science.abf1357

Pajkert, A., Finke, C., Shing, Y. L., Hoffmann, M., Sommer, W., Heekeren, H. R., & Ploner, C. J. (2017). Memory integration in humans with hippocampal lesions. *Hippocampus*, *27*(12), 1230–1238. https://doi.org/10.1002/hipo.22766

Ryan, J. D., D’Angelo, M. C., Kamino, D., Ostreicher, M., Moses, S. N., & Rosenbaum, R. S. (2016). Relational learning and transitive expression in aging and amnesia. *Hippocampus*, *26*(2), 170–184. https://doi.org/10.1002/hipo.22501

Spalding, K. N., Schlichting, M. L., Zeithamova, D., Preston, A. R., Tranel, D., Duff, M. C., & Warren, D. E. (2018). Ventromedial prefrontal cortex is necessary for normal associative inference and memory integration. *Journal of Neuroscience*, *38*(15), 3767–3775.

Vikbladh, O. M., Meager, M. R., King, J., Blackmon, K., Devinsky, O., Shohamy, D., Burgess, N., & Daw, N. D. (2019). Hippocampal Contributions to Model-Based Planning and Spatial Memory. *Neuron*, *102*(3), 683-693.e4. https://doi.org/10.1016/j.neuron.2019.02.014

Wang, F., Schoenbaum, G., & Kahnt, T. (2020). Interactions between human orbitofrontal cortex and hippocampus support model-based inference. *PLOS Biology*, *18*(1), e3000578. https://doi.org/10.1371/journal.pbio.3000578

Zeithamova, D., Dominick, A. L., & Preston, A. R. (2012). Hippocampal and Ventral Medial Prefrontal Activation during Retrieval-Mediated Learning Supports Novel Inference. *Neuron*, *75*(1), 168–179. https://doi.org/10.1016/j.neuron.2012.05.010