Studying the role of the cerebellum in spatial cognition through a neurocomputational approach

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I. Context

Recent experimental findings have begun to unravel the implication of the cerebellum in high-level functions such as spatial cognition [1,2]. We focus on behavioural genetic data showing that L7-PKCI mice (lacking LTD at parallel fibre–Purkinje cell synapses) have a spatial learning impairment in the Morris Watermaze (MWM), whereas they exhibit normal performances in the Starmaze, a paradigm that reduces the procedural demand of the task [3]. These results suggest that cerebellar learning may prominently contribute to the procedural component of spatial learning [3].

II. Methods

We model the main information processing components of the cerebellar microcomplex via a large-scale network of spiking neurons. We test the performances of artificial L7-PKCI mice in simulated MWM and Starmaze environments. Importantly, we isolate the purely procedural component of the learning process by endowing simulated controls and mutants with identical declarative learning capabilities.

III. Results

The model reproduces most of the experimental results on the learning impairments of L7-PKCI mice: in the MWM, the mean escape latency and the mean angular deviation between the optimal direction to the target and the actual motion direction of the animal are both significantly larger compared to controls. These differences are not due to swim capability deficits. Furthermore - consistent with experimental data - simulated mutants and controls exhibit comparable learning capabilities in the Starmaze paradigm.

On the other hand, our simulations cannot reproduce the experimentally observed difference between the goal-searching behaviour of mutants and controls in the MWM [3]. In fact, our results suggest that a purely local impairment of the procedural component cannot explain this latter deficit.

IV. The cerebellum and the exploration - exploitation trade-off

To explain the experimental discrepancy between control and L7-PKCI, we have put forth a hypothesis according to which the mutants' impairment in optimizing their goal-searching behaviour could be due to a deficit in trading-off exploration and exploitation strategies [4]. This hypothesis has been tested by perturbating the ability of simulated mutants to properly balance their exploration-exploitation behaviour when solving the MWM and Starmaze tasks. By simulating this deficit, we could reproduce all the differences observed experimentally between control and mutant performances [3].

V. Cerebellum and spatial learning

The cerebellum plays an important role in integrating proprioceptive information to predict future state variables, such as body orientation and position, given a motor command [5]. A hypothesis being tested with our model is that the ability of L7-PKCI mice to integrate idiothetic (e.g. proprioceptive) signals might be impaired. This would indirectly affect the path integration process [6,7]. Since the latter contributes to the learning of stable spatial representations [6,8], we therefore propose that L7-PKCI mice might have a deficit in acquiring spatial representations that remain stable under different environmental conditions. This hypothesis is being evaluated by coupling our cerebellar model to an existing model of the hippocampal spatial learning function [8,9]. Preliminary results suggest that the cerebellum might be critical to build declarative spatial knowledge when idiothetic inputs are the most reliable source of information (e.g. when navigating in darkness).

VI. References

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