Ventral hippocampus inactivation impairs goal-directed spatial navigation in obstacle-laden environments

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1. Introduction

- It is generally believed that dorsal, but not ventral hippocampus supports spatial learning and that ventral, but not dorsal hippocampus is involved in emotional and motivational processes (1).

- Spatial scale representation increases along the dorso-ventral axis of the hippocampus (2).

- Modeling studies have suggested ways in which information can be processed along the dorso-ventral axis and used for spatial navigation (3,4,5,6).

- We hypothesize that the dorsal and ventral levels of the hippocampus are differentially involved in trajectory planning and memory-guided decision-making in complex spatial tasks.

- We used a learning task in which animals memorize the location of a set of rewarded feeders, and recall these locations in the presence of small or large obstacles.

2. Methods

Animals

- Male rats, 7-8 months old.
- Bilateral cannulae in dorsal or ventral hippocampus.

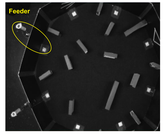
Behavioral Apparatus

- Open field arena with 8 equally spaced feeders containing sugar water.

Memory Item= Set: 1,4,6
(in no particular order)

- Obstacles: Lego blocks

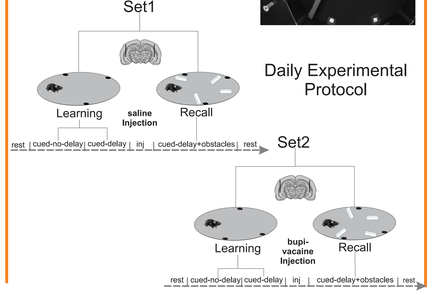
Small obstacles



Large obstacles

Hippocampus Inactivation

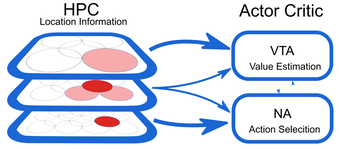
Infusion: Bupivacaine hydrochloride (bilateral, 2.5%, 1µl/side)



Daily Experimental Protocol

Computational Modeling

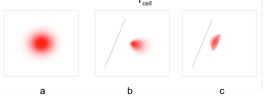
- Actor critic (AC) architecture (7) over an ensemble of conjunctive cells modulated by location, heading (8,9) and phase of the task (multiple maps hypothesis) (10).
- Ventral HPC is strongly connected to the value estimation portion of the AC algorithm (VTA), whereas the dorsal portion is strongly connected to the action selection portion (Nuc. Accumbens, NA).



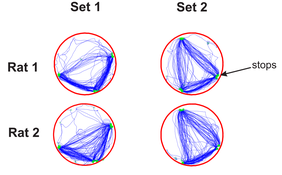
When an obstacle is put into a normal cell's field, its firing is negatively modulated (11,12) by a sigmoid function m() of the distance to the obstacle, as shown in the following equations, where dtco is the distance to the closest obstacle.

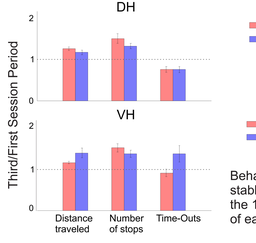
$$d=\frac{dtco}{r_{cell}} \qquad m(d)=\frac{1}{e^{10*(d'-w)}+1}$$

$$d'=\max(0,d-\frac{dist(currLoc,c_{cell})}{r_{cell}})$$



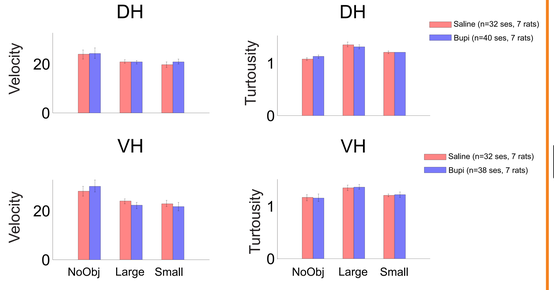
3. Behavioral performance (recall without obstacles)



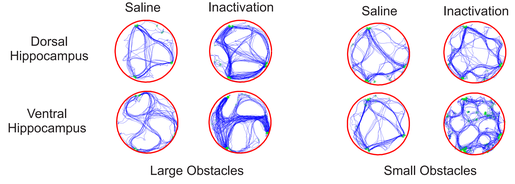


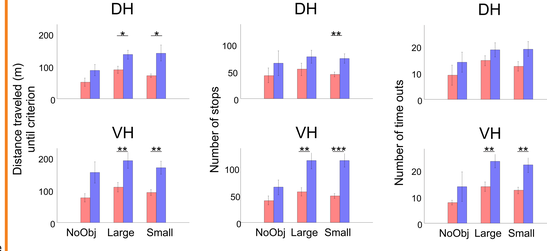
Behavioral measures were stable when comparing the 1st third and last third of each session.

4. HP inactivation did not produce any motor impairment



5. Dorsal and Ventral Hippocampal inactivation impaired spatial performance in complex environments

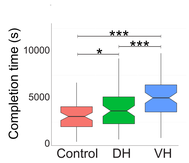




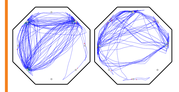
Both DH and VH are required as maze complexity increases

6. Computational model

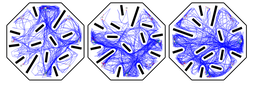
Completion times for the small obstacles trial. A kruscal wallis test with Dunn pairwise was made and a significant difference was found between Ventral and Control group ($p < 10e-5$), Ventral and Dorsal ($p = 0.0011$) and Dorsal and Control ($p = 0.0457$).



Learning (no obstacles)



Recall



7. Conclusions

- Ventral hippocampus inactivation produced significant impairments in both small and large obstacles conditions. Dorsal inactivation had less effect than ventral inactivation on recall with large obstacles.
- These deficits were not due to impairments in recalling reward locations, therefore suggesting that they were due to impairments in spatial navigation computations in the face of obstacles.
- These results show that the ventral hippocampus supports goal-directed spatial navigation in complex environments.
- Our reinforcement learning model of navigation showed that the inactivation of both ventral and dorsal hippocampus can disrupt navigation in the presence of small obstacles while ventral inactivation alone produced significantly more impairments. Our model suggests that ventral inactivation can interfere with navigational processes and that this structure is mostly involved in value estimation rather than action selection.
- Future work will involve electrophysiological recordings in VH and DH and the implementation of the model on a mobile robot presented with realistic and noisy navigational challenges.

8. References

1 Strange BA, Witter MP, Lein ES, Moser EI. (2014) Functional organization of the hippocampal longitudinal axis. Nat Rev Neurosci. 15(10):655-69.
2 Kjelstrup KB, et al. (2008) Finite scale of spatial representation in the hippocampus. Science 321(5885):140-143.
3 Lyttle D, Gerstek B, Lin KK, Fellous JM (2013) Spatial scale and place field stability in a grid-to-place cell model of the dorsoventral axis of the hippocampus. Hippocampus, 23(9):729-44.
4 Erdem UM & Hasselmo ME (2014) A biologically inspired hierarchical goal directed navigation model. J Physiol Paris 108(1):28-37.
5 de Almeida L, Idiart M, Lisman JE (2012) The single place fields of CA3 cells: A two-stage transformation from grid cells. Hippocampus, 22(2):200-8.
6 Monaco JD, Rao G, Roth ED, Knierim JJ (2014) Attentive scanning behavior drives one-trial potentiation of hippocampal place fields. J Neurosci 31(25):9414-9425.
7 Sutton RS, Barto AG. (1998) Reinforcement learning: An introduction (vol. 1, No. 1). Cambridge: MIT press.
8 Sargolini et al. (2006) Conjunctive Representation of Position, Direction, and Velocity in Entorhinal Cortex. Science 312(5774):758-62.
9 Rubin A, Yartsev MM, Ulanovsky N. (2014) Encoding of Head Direction by Hippocampal Place Cells in Bats. J Neurosci.34(3):1067-80.
10 Redish AD. (1999). Beyond the cognitive map: from place cells to episodic memory. Cambridge, MA: MIT Press.
11 Muller RU, Kubie JL. (1987) The effects of changes in the environment on the spatial firing of hippocampal complex-spike cells.J Neurosci. 7(7):1951-68.
12 Rivard B1, Li Y, Lenck-Santini PP, Poucet B, Muller RU. (2004) Representation of Objects in Space by Two Classes of Hippocampal Pyramidal Cells. J Gen Physiol. 124(1):9-25.

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