The Computational Impact of Adult Neurogenesis in the Dentate Gyrus on Memory Formation

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The dentate gyrus region of the hippocampus (DG) is one of two brain regions that incorporates newly born neurons throughout adulthood. Neurogenesis is limited to the principal cell type of the DG, the glutamatergic granule cells, and after about two months of maturation, adult born neurons appear to become anatomically and physiologically similar to those that were born embryonically and postnatally. Although the integration of a considerable number of new neurons into the hippocampus suggests that neurogenesis may be a key form of plasticity in the creation of new memories, the function of these new neurons has proven difficult to establish.

By virtue of its large size and sparse firing rates, the DG region is believed to be involved in the separation of cortical inputs during memory formation. This pattern separation is critical in the formation of new memory attractors in the downstream hippocampal layers (CA3 and CA1). The requirement of neurogenesis in such a process remains unclear, but we have hypothesized that the immature neurons may have a direct influence on this pattern separation function, possibly even contributing temporal information to new memories [1].

We designed a computational model to investigate whether adding these new neurons to the dentate gyrus could affect memory formation in a manner consistent with what our hypothesis predicted. The model we generated focuses on the DG region itself, including several feedback neuron populations (basket cells, mossy cells, hilar interneurons) in addition to the neurogenic granule cell layer. The input layer of the model is the entorhinal cortex, which we simulate in part by using the "grid cell" behavior that has been recently described in that region. We implement neurogenesis in the model in a biologically realistic manner, with new neurons being incorporated into the network gradually over several months in the simulation. This includes passing through the multiple stages of development observed in the biological system, including an early GABA excitatory phase and a transient increased LTP phase.

Here we will show how immature neurons affect pattern separation at short and long time scales. Our results demonstrate that pattern separation by the DG is reduced in specific conditions because of neurogenesis. We refer to this effect as pattern integration (as opposed to the existing pattern separation and pattern completion concepts used in theories of memory formation), and will discuss the potential ramifications of this in learning. Furthermore, we will extend the modeling results to show how dentate gyrus function can be improved by the long-term survival of these new neurons and their experience-dependent integration into the network.

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References