Hippocampal pattern separation: Insights from a combined behavioural and neurocomputational approach

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The formation of memory requires encoding, consolidation and recall of information by structures of the brain. Before new information can be processed, it must be attributed as new. This process requires the discrimination between old, new, and similar (ambiguous) information. This discrimination is dependent on cognitive processes called pattern separation and pattern completion.

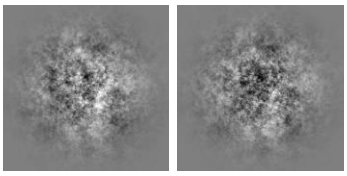

Fig. 1. Visual pink noise stimuli with 1/f filtering of spatial frequencies and a Gaussian contrast envelope: a) Target, b) Lure with blending quota q = 0.6, resulting in a correlation of r^2=0.69

Recently memory tasks have been developed which are thought to test these processes, containing pictures of everyday objects: old (targets), new (foils), and similar stimuli (lures). In these tasks, similarity is unpredictable. We have developed a task that is based on pink noise (Fig. 1). The stimuli can be blended to construct lures with any degree of physical congruence with targets. It is the first memory task testing pattern separation with quantifiable congruence of old and similar stimuli.

We have collected data with this novel task and analyzed them with a Gaussian signal detection (SDT) model that fits the behavioral data (Fig. 2). The data show that participants can well remember these stimuli and distinguish them from similar stimuli. The SDT model reveals that psychological similarity is a power function of the correlation between similar and old stimuli. While signal detection theory allows to model the data mathematically, it does not tell us about the algorithm that is used by the brain to perform this task, nor how to implement it.

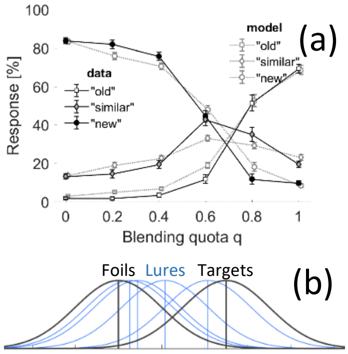

Fig. 2. a) Behavioral data and model fit. b) Gaussian SDT model

We mimicked human performance in this memory task using a simulated artificial neural network. This network is inspired by the trisynaptic circuit of the human hippocampus (Fig. 3). The entorhinal cortex (EC) serves as input structure. The dentate gyrus (DG) performs a decorrelation of similar input patterns as a basis of pattern separation. The cornu ammonis 3 (CA3) performs a resynthesis corresponding to pattern completion. Here we modelled pattern separation, i.e., the DG-EC circuit. The output of this subcircuit is compared to human pattern separation performance. The core of this circuit model is that it uses a memristive device model for the emulation of synaptic functionality, as well as leaky-integrate-and-fire neuron models, which serve as a basis for a real-time hardware implementation with neuromorphic hardware.

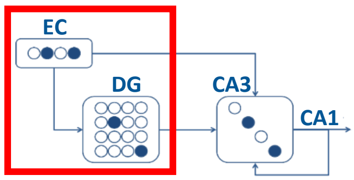

Fig. 3. Network model of the trisynaptic hippocampal circuit. The red rectangle shows the part simulated in the present study.

As the EC does not represent retinal information in a topological way, we dismissed the spatial 1/f filtering and stimulated the network with fixed white noise stimuli during learning and testing. Adding variable noise during learning and testing results in an outcome of this network that can simulate human memory performance quite well (Fig. 4). Details differ – especially so the relation of lure composition to SDT sensitivity –, but this has to be expected given the focus on the hippocampal network, discounting details of the sensory preprocessing of the stimuli.

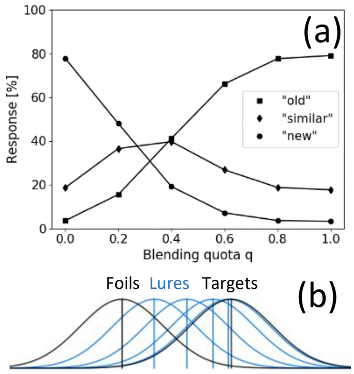

Fig. 4. a) Response frequencies and b) Gaussian SDT representation of the output of the simulated hippocampal subcircuit.

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