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Bimodal structural plasticity can explain the spacing effect in long-term memory tasks. [1]

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The spacing effect means the finding that learning is more efficient if rehearsal is spread over time compared to single block rehearsal. The spacing effect has been reported to be very robust occurring in many explicit and implicit memory tasks in humans and many animals being effective over many time scales from single days to months. For these reasons it has long been speculated about a common underlying mechanism at the cellular level.

We propose that structural plasticity in synaptic networks is this common mechanism. According to our model, ongoing structural plasticity can reorganize networks by replacing obsolete synapses and growing new synapses at locations that are potentially more useful for storing a given set of memories. We have recently shown that such models can increase storage capacity of neural networks with n neurons from less than one bit per synapse found in common Hopfield-type learning models to diverging log(n) bits per synapse (A.Knoblauch, F.T.Sommer, G.Palm, Neural Computation, in press). Besides this massive performance increase, the model was also able to qualitatively explain several memory phenomena such as Ribot gradients in retrograde amnesia, absence of catastrophic forgetting, and the spacing effect (A.Knoblauch, Connectionist Models of Behavior and Cognition II, pp 79-90, World Scientific, 2009).

Here we focus on quantitatively modeling recent psychological findings concerning long-term spacing effects (N.J.Cepeda et al., Psychological Science 19:1095-1102, 2008). There, probants had to memorize a given set of facts in two rehearsal sessions separated by a time gap of variable length. After an additional retention interval (RI) of up to one year the final recall rate was evaluated. The experiments revealed several characteristics of the spacing effect: 1) For any gap duration, recall performance decays according to the well known forgetting curve. 2) For any RI there is an optimal gap maximizing recall rate. 3) The spacing effect is large, e.g., optimal gaps can double recall rate. 4) The spacing effect is asymmetric, i.e., shorter gaps impair performance more severly than longer gaps. 5) As RI increases the optimal gap increases. 6) As RI increases, the ratio of optimal gap to RI declines.

In a first attempt we simulated our original model to reproduce these characteristics. The model easily reproduced characteristics 1-4 but not 5-6 because optimal gaps were independent of RI as confirmed by a theoretical analysis. In an extended model variant we included two synapse populations with two different rates of structural plasticity per time unit. The first synapse population consisted of motile synapses well suited for short-term storage corresponding to small optimal gaps, whereas the other one consisted of more stable synapses better suited for long-term storage corresponding to longer optimal gaps. Simulation experiments of several network variants revealed that such bimodal structural plasticity can account for all six characteristics of the spacing effect. This was true when the two synapse populations were mixed within a single synaptic network, and also when fast and slow plasticity was segregated into two different networks, e.g., corresponding to hippocampus and neocortex.

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