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Two-stage model of memory trace formation: A role for â€œnoisyâ€ brain states

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Abstract

Review of the normally occurring neuronal patterns of the hippocampus suggests that the two principal cell types of the hippocampus, the pyramidal neurons and granule cells, are maximally active during different behaviors. Granule cells reach their highest discharge rates during theta-concurrent exploratory activities, while population synchrony of pyramidal cells is maximum during immobility, consummatory behaviors, and slow wave sleep associated with field sharp waves. Sharp waves reflect the summed postsynaptic depolarization of large numbers of pyramidal cells in the CA1 and subiculum as a consequence of synchronous discharge of bursting CA3 pyramidal neurons. The trigger for the population burst in the CA3 region is the temporary release from subcortical tonic inhibition.

An overview of the experimentally explored criteria of synaptic enhancement (intensity, frequency, and pattern of postsynaptic depolarization, calcium influx, cooperativity

frequency, and pattern of postsynaptic depolarization, calcium influx, cooperativity, threshold) suggests that these requirements may be present during sharp wave-concurrent population bursts of pyramidal cells. Experimental evidence is cited showing that (a) population bursts in CA3 may lead to long-term potentiation in their postsynaptic CA1 targets, (b) tetanizing stimuli are capable of increasing the synchrony of the sharp wave-burst, and (c) activity patterns of the neocortical input to the hippocampus determine which subgroup of CA3 neurons will trigger subsequently occurring population bursts (initiator cells).

Based on the experimental evidence reviewed a formal model of memory trace formation is outlined. During exploratory (theta) behaviors the neocortical information is transmitted to the hippocampus via the fast-firing granule cells which may induce a weak and transient heterosynaptic potentiation in a subgroup of CA3 pyramidal cells. The weakly potentiated CA3 neurons will then initiate population bursts upon the termination of exploratory activity (sharp wave state). It is assumed that recurrent excitation during the population burst is strongest on those cells which initiated the population event. It is suggested that the strong excitatory drive brought about by the sharp wave-concurrent population bursts during consummatory behaviors, immobility, and slow wave sleep may be sufficient for the induction of long-term synaptic modification in the initiator neurons of the CA3 region and in their targets in CA1. In this two-stage model both exploratory (theta) and sharp wave states of the hippocampus are essential and any interference that might modify the structure of the population bursts (e.g. epileptic spikes) is detrimental to memory trace formation.

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Abbreviations

CA, cornu Ammonis; EEG, electroencephalogram; EPSP, excitatory postsynaptic potential; IPSP, inhibitory postsynaptic potential; LTP, long-term potentiation; NMDA, *N*-methyl-D-aspartate; RSA, rhythmic slow activity; SPW, sharp wave

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Dr BuzsÃ¡ki wishes to dedicate this paper to his mentor and friend, the late Endre GrastyÃ n.

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