Engineering Memories: A Cognitive Neural Prosthesis for Restoring and Enhancing Memory Function

Saturday September 21, 7:00-8:00pm
Nissan Lecture Theatre
St Anthony's College
62 Woodstock Rd, Oxford, OX2 6JF, UK

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Abstract

Theodore Berger leads a multi-disciplinary collaboration with Drs. Marmarelis, Song, Granacki, Heck, and Liu at the University of Southern California, Dr. Cheung at City University of Hong Kong, Drs. Hampson and Deadwyler at Wake Forest University, and Dr. Gerhardt at the University of Kentucky, that is developing a microchip-based neural prosthesis for the hippocampus, a region of the brain responsible for long-term memory. Damage to the hippocampus is frequently associated with epilepsy, stroke, and dementia (Alzheimer's disease), and is considered to underlie the memory deficits characteristic of these neurological conditions. The essential goals of Dr. Berger's multi-laboratory effort include: (1) experimental study of neuron and neural network function during memory formation -- how does the hippocampus encode information?, (2) formulation of biologically realistic models of neural system dynamics -- can that encoding process be described mathematically to realize a predictive model of how the hippocampus responds to any event?, (3) microchip implementation of neural system models -- can the mathematical model be realized as a set of electronic circuits to achieve parallel processing, rapid computational speed, and miniaturization?, and (4) creation of conformal neuron-electrode interfaces -- can cytoarchitectonic-appropriate multi-electrode arrays be created to optimize bi-directional communication with the brain? By integrating solutions to these component problems, the team is realizing a biomimetic model of hippocampal nonlinear dynamics that can perform the same function as part of the hippocampus. Through bi-directional communication

with other neural tissue that normally provides the inputs and outputs to/from a damaged hippocampal area, the biomimetic model can serve as a neural prosthesis. A proof-of-concept is presented using rats that have been chronically implanted with stimulation/recording micro-electrodes throughout multiple regions of the CA3 and CA1 hippocampus, and that have been trained using a delayed, non-match-to-sample task. Normal hippocampal functioning is required for successful delayed non-match-to-sample memory. Memory-behavioral function of the hippocampus is blocked pharmacologically, and then in the presence of that blockade, *hippocampal memory/behavioral function is restored by a multi-input, multi-output model of hippocampal nonlinear dynamics that interacts bi-directionally with the in vivo hippocampus*. The model is used to predict output of the CA1 hippocampus in the form of spatio-temporal patterns of neural activity – hippocampal memory codes; electrical stimulation of CA1 cells is used to "drive" the output of hippocampus to the desired (predicted) state. Using the same procedures in implanted animals with an intact, normally functioning hippocampus substantially enhances memory strength and thus, learned behavior is improved. Extension of these studies to the hippocampus and prefrontal cortex of behaving monkeys also is demonstrated. Finally, preliminary recordings from the human hippocampus, both *in vitro* and *in vivo*, will be presented. These results show for the first time that it is possible to create "hybrid electronic-biological" systems that mimic physiological properties, and thus, may be used as neural prostheses to restore damaged brain regions – even those regions that underlie cognitive function.