MECHANICAL & MATERIAL COLLOQUIUM

Cyborg Neurons: A New Noninvasive Research Platform to Study Neuroprosthetic Hand Interfaces

by Erik Engeberg (Ocean and Mechanical Engineering, Florida Atlantic University)

People who have experienced a spinal cord injury or an amputation have limited recovery of sensation and motor control even with the most sophisticated neuroprosthetic devices. Advances enabled by invasive neural interfaces come with inherent risk and high cost. As a result, the number of people outfit with neuroprosthetic limbs is rather small and optimal strategies to restore sensation and control are not fully understood. The objective of this study was to explore the feasibility of a novel noninvasive biohybrid robotic hand model to investigate restoration of tactile sensation and motor control with minimal risk.

To that end, a new biohybrid model was developed that couples a dexterous robotic hand with biological neural networks (BNN) cultured in a multichannel microelectrode array (MEA). First, the extent to which the BNNs could integrate tactile sensations with motor control of the artificial hand was explored. To that end, afferent and efferent robosynaptic interfaces were developed to translate between the biological and artificial domains.

Next, human subjects were integrated within the feedback control loop of the artificial hand and neurons cultured in the MEA. Four models of touch sensation were coded that have been prevalently used in the neuroprosthetic hand literature for electrical stimulation of afferent nerves based on touch sensations from prosthetic hands. The neuronal cultures were stimulated at one location (electrode) and the evoked neural activity from a different electrode was decoded and used to convey touch sensations to the human subjects that were processed by the cultures of neurons. The neuronal cultures were highly effective at processing touch sensations that were encoded with both a rapidly adapting mechanoreceptor model as well as a biomimetic model of aggregated mechanoreceptor signals as evidenced by a tight correlation between the touch sensations and robotic hand control actions of the human subjects. These findings were compared to the baseline condition where touch feedback signals for the subjects bypassed the neuronal cultures using a purely robotic system. A two-sample Kolmogorov-Smirnov test showed that the rapidly adapting encoding method of touch sensations processed by the neuronal cultures was not significantly different than the purely human-robotic system ($p<0.05$). These findings provide strong evidence that cultures of neurons can process robotic sensations of touch to provide meaningful haptic feedback for amputees who control dexterous artificial hands. This exciting result has profound ramifications for reducing the risk and cost associated with neuroprosthetic hand research with the noninvasive biohybrid hand. The new noninvasive biohybrid dexterous artificial hand system demonstrates strong potential to be used as a pre-clinical research platform to investigate human neural interfaces with minimal risk.

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