Title: Discovery of a robust encoding scheme for delivering artificial sensory information directly to the brain

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Abstract: Current users of brain-computer interface (BCI) technology rely primarily on visual feedback of cursor or robotic arm movement[1–9]. We believe the lack of tactile perception and proprioceptive input imposes a fundamental limit on speed and accuracy of BCI-controlled prostheses or re-animated limbs[10]. By artificially recreating a high-resolution sensory pathway via electrical stimulation of cortical sensory areas, BCI stability and control can be substantially improved[11,12]. The high dimensional parameter space of possible stimulation patterns poses a unique challenge for identification of a robust, high bandwidth sensory encoding scheme. A single dimension in the parameter space can encoded low bandwidth sensory information[13–19], but no comparison has been performed across parameters, nor with update rates suitable for real-time operation in a neuroprosthesis. Here we report the first comprehensive measurement of the resolution of key stimulation parameters such as pulse amplitude, pulse width, frequency, train interval and number of pulses delivered to the same cortical sensory network. Surprisingly, modulation of the stimulation frequency was largely undetectable. Rather, the charge-per-phase of each pulse yields the highest resolution sensory signal, and is the key parameter modulating perceived intensity. The stimulation encoding patterns tested were designed to deliver and update at a fast rate, making them ideal candidates for bi-directional BCI's. The discovery of the critical stimulation features which best encode sensory intensity have significant implications for design of any neural interface seeking to manipulate cortical networks through electrical stimulation.

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