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An epidural electrical stimulation protocol to restore natural arm and hand movements in monkeys with cervical spinal cord injury

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In the United States alone, there are currently more than 200’000 people living with spinal cord injury, with an average rate of 17000 new cases each year. Of those, almost 50% will retain both upper limb and lower limb impairments. The loss of motor control and sensation in all four limbs is defined tetraplegia. Tetraplegia is a particularly impairing condition. Without arm and hand control, even the simplest actions required during daily life become an unsurmountable hurdle, from brushing one’s teeth to typing on a keyboard. People living with tetraplegia struggle to regain an active working life and often remain excluded from a normal social life. For these people, the recovery of arm control is a top priority. Unfortunately, the complexity of the neural mechanisms underlying arm control have limited the efficacy of neurotechnology approaches for restoring movement. Existing approaches could restore a limited range of functionalities, such as hand grasping. However, no currently existing therapy can restore the totality of functions that patients would need to autonomously go through a standard daily routine. In my thesis I propose to use epidural electrical stimulation (EES) of the cervical spinal cord to recover natural, complex arm and hand movements. I used a non-human primate model which, due to the anatomical and behavioral similarities with humans, represents the ideal model to study in depth unconstrained arm and hand function. First, I studied the potential of EES to elicit contractions of specific arm and hand muscles. I found that stimulating specific spinal cord segments I could selectively activate groups of muscles devoted to a specific function, such as arm extension, arm flexion or hand grasp. Second, I designed and implemented a robotic platform that allowed to precisely characterize arm and hand function in non-human primates while leaving the animals completely unconstrained and free to decide their movement strategy. Animals were trained to reach to a custom-designed object attached to the end-effector of a robotic arm, while we recorded intracortical neural signals as well as kinematic, kinetic and electromyographic activity of the arm and hand. This rich portfolio of signals allowed us to characterize the arm and hand movement as composed mainly of three phases: reach (or arm extension), grasp (or hand flexion) and pull (or arm flexion). We designed a neural interface that leveraged the functional organization of the dorsal roots to stimulate relevant spinal segments at appropriate movement phases. Stimulation bursts, triggered by intracortical signals produced sustained arm movements enabling monkeys with arm paralysis to perform an unconstrained, three-dimensional reach-and-grasp task. Stimulation specifically improved strength, task performances and movement quality. The efficacy and reliability of our approach hold realistic promise of clinical translation.

Jury:
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