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GRASP FORCE IS ENCODED IN DYNAMICAL PATTERNS OF ACTIVITY IN THE MOTOR CORTEX OF MONKEYS AND HUMANS

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Introduction: From prehension to pianism, object interactions require precise control of both the movements of the hand and of the forces it exerts on objects. Recent work shows that time-varying posture of the hand is encoded in the activity of populations of neurons in primary motor cortex (M1) and these signals can be harnessed to decode hand kinematics for intracortical Brain Computer Interfaces (iBCI) to restore limb function to patients with spinal cord injury. However, much less is known about how manual forces are encoded in M1, which severely limits the capability of iBCIs to support object interactions that require precise and graded force application. The aim of this study is to first understand how manual forces are encoded in M1 of able-bodied behaving macaques and then apply the insights gleaned from our experiments to build biomimetic decoders of manual force in patients with tetraplegia.

Material, Methods and Results: To investigate how manual forces are encoded in M1 during object interactions, we first recorded the neural activity in M1 as monkeys grasped sensorized objects and characterized the force signal in this population. We found that dependence between force and motor signals is governed by non-linear dynamics that can be exploited for force decoder design. Next, we applied the insights gleaned from our experiments with able-bodied macaques to build decoders of manual force in three human participants with tetraplegia. In brief, we instructed the participants to grasp virtual objects with varying amounts of force while we monitored their M1 activity via chronically implanted electrode arrays. We found that the patterns of responses in human M1 during imagined force application were similar to those in monkey M1 during physical force application. We then built real time decoders that harness force signals in M1 to allow the participants to exert forces with the virtual hand. We show that decoders of force that can exploit non-linear dynamics in the M1 response significantly outperform standard linear or non-linear methods both offline and in real time applications.

Discussion and Significance: These results pave the way for brain-controlled bionic hands that allow the user not only to precisely shape the hand but also to apply well-controlled forces with it.

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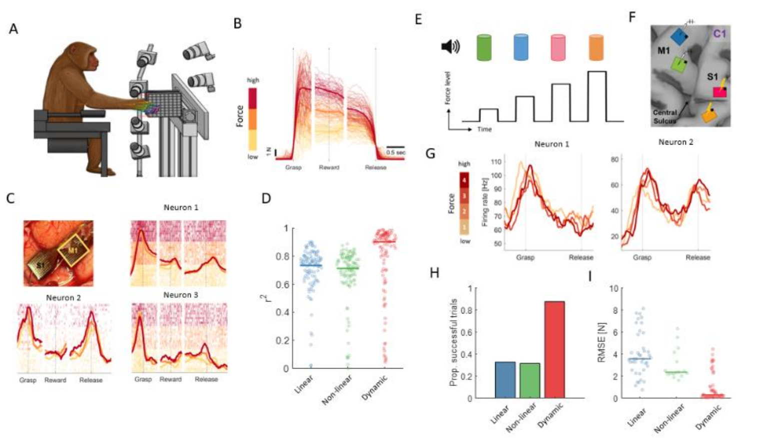

Figure 1. A-D Monkey experiments. E-I Human experiments. A| Experiment setup. Two monkeys were trained to reach for and grasp an object with instructed amount of force. B| Single trial force profiles color-coded by instructed force level. C| Three example raster plots and PSTHs of motor cortical neurons color-coded by target force. Inset: Utah electrode array placement in one of the monkeys. D| Distribution of cross-validated correlations for all trials decoded with Linear, Non-linear and Dynamics decoders in monkey data. E| Human BCI experiment. The subject is instructed to attempt to grasp the virtual object with one of four linearly spaced force levels cued by the color and a verbal command. F| Array placement in one of the subjects. G| Example PSTHs aligned to onset of virtual movement of the avatar limb during observation stage. Lines are color-coded by target force level. H| Proportion of correct trials with Linear, Non-linear and Dynamics decoders. I| Error of online force production with Linear, Non-linear and Dynamics decoders.

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