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Upper Limb Movement Encoding by Intracortical Recordings in Human Sensorimotor Cortex

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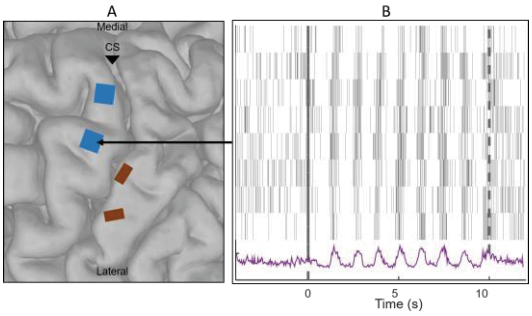
Introduction: In recent years, neuroprosthetics driven by brain-computer interfaces (BCI) have emerged as a potential tool for restoring independence to people paralyzed by disease and injury. Extracting command signals from intracortical recordings in primary motor cortex (M1) allows complex motor commands to be decoded. Here we investigate the distribution of movement-related information in recordings from the motor and somatosensory cortex of a person with chronic tetraplegia.

Materials, Methods, and Results: Two 88-channel arrays were implanted in M1 and two 32-channel arrays were implanted in the somatosensory cortex (S1) of a 27-year old individual with chronic tetraplegia due to C5/C6 SCI (Fig 1A). Implant locations were targeted to arm and hand regions of M1/S1 based on pre-surgical functional neuroimaging. Intracortical recordings were collected once monthly for 7 months while the subject attempted to move in time with videos of arm and hand movements, although most movements could not be performed overtly. Unit tuning was defined by the R^2 coefficient of the linear fit between single-unit firing rates and a 0.5Hz sine wave matching the pacing of stimulus videos (significance $p<0.05$, Bonferroni corrected).

We found robust single-unit tuning to all attempted movements across the entire 7-moth testing period (see Table 1). Single-unit firing rates were tightly correlated with the time-course of attempted movements, including those of fingers paralyzed by the SCI (Fig 1B). Units tuned to finger- and wrist-related movements were fairly evenly distributed between motor arrays, while those tuned to elbow and shoulder movements were highly biased towards the medial array. While there were overall fewer significantly tuned units on the S1 arrays, we identified single sensory neurons tuned to both overt and attempted movements, and both sensory arrays had more units tuned to attempted than overt movements.

Movement	Motor Medial [#units]	Motor Lateral [#units]	Sensory Medial [#units]	Sensory Lateral [#units]
(A)Pinky	11.71	10.00	6.28	4.00
(A)Ring	31.00	25.00	8.50	7.33
(A)Middle	26.33	27.00	10.33	7.83
(A)Index	22.43	20.29	9.43	4.00
(O)Thumb	32.80	35.80	13.4	11.60
(A)Grasp	16.86	14.14	5.43	4.14
(O)Wrist	16.38	18.13	5.00	3.87
(O)Elbow	17.33	12.00	4.33	3.83
(O)Shoulder	35.00	10.33	3.67	2.00



(Left) Table 1: Number of units significantly tuned to each movement, averaged across days. (A) = attempted movement, (O) = overt movement. **(Right) Figure 1 - A**: Placement of microelectrode arrays in M1/S1, plotted on cortical surface render. Blue = motor, red = sensory. **B**: Single-unit activity on the lateral motor array during attempted pinky movement. Purple line represents smoothed across-trial spike count.

Discussion: These results demonstrate the preservation of volitional single-unit sensorimotor activity during both intact and paralyzed movements. The spatial distribution of tuned units shows that while a degree of somatotopy exists, units separated by centimeters of cortex can be similarly tuned to the same movement, suggesting that even simple movements can be encoded by large areas of cortex.

Significance: BCI control is predicated on the ability to decode motor commands from single-unit activity. Understanding how those commands are represented in the sensorimotor cortex of BCI users is an important step towards developing more effective neuroprosthetic control.

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