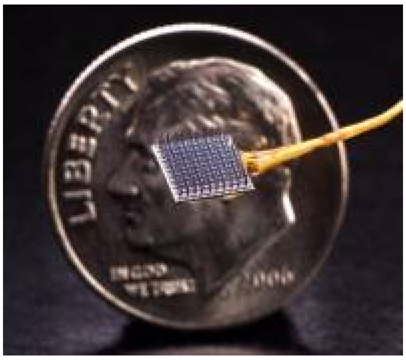
BrainGate2



Ongoing study that obtains safety information regarding an intracortical neural interface device, and investigates the feasibility of people with tetraplegia controlling assistive devices using their cortical signals.

Using data from the BrainGate2 pilot clinical trial, Willett et al. measured how a steady-state velocity Kalman filter decoder was affected by the choice of intention estimation method. They examined three separate components of the Kalman filter: dimensionality reduction, temporal smoothing, and output gain (speed scaling).

The decoder's dimensionality reduction properties were largely unaffected by the intention estimation method. Decoded velocity vectors differed by <5% in terms of angular error and speed vs. target distance curves across methods. In contrast, the smoothing and gain properties of the decoder were greatly affected (> 50% difference in average values). Since the optimal gain and smoothing properties are task-specific (e.g. lower gains are better for smaller targets but worse for larger targets), no one method was better for all tasks.

The results show that, when gain and smoothing differences are accounted for, current intention estimation methods yield nearly equivalent decoders and that simple models of user intent, such as a position error vector (target position minus cursor position), perform comparably to more elaborate models. Our results also highlight that simple differences in gain and smoothing properties have a large effect on online performance and can confound decoder comparisons [1].

Even-Chen et al. analyzed posthoc the intracortical neural activity of two BrainGate2 clinical trial participants who were neurally controlling a computer cursor to perform a grid target selection task and a keyboard-typing task.

The key findings are that: 1) there exists a putative outcome error signal reflected in both the action potentials and local field potentials of the human hand area of motor cortex, and 2) target selection outcomes can be classified with high accuracy (70-85%) of errors successfully detected with minimal (0-3%) misclassifications of success trials, based on neural activity alone.

These offline results suggest that it will be possible to improve the performance of clinical intracortical BCIs by incorporating a real-time error detect-and-undo system alongside the decoding of movement intention [2].

General-purpose computers have become ubiquitous and important for everyday life, but they are difficult for people with paralysis to use. Specialized software and personalized input devices can improve access, but often provide only limited functionality.

In a study, three research participants with tetraplegia who had multielectrode arrays implanted in motor cortex as part of the BrainGate2 clinical trial used an intracortical brain-computer interface (iBCI) to control an unmodified commercial tablet computer. Neural activity was decoded in real-time as a point-and-click wireless Bluetooth mouse, allowing participants to use common and recreational applications (web browsing, email, chatting, playing music on a piano application, sending text messages, etc.). Two of the participants also used the iBCI to “chat” with each other in real-time. This study demonstrates, for the first time, high-performance iBCI control of an unmodified, commercially available, general-purpose mobile computing device by people with tetraplegia [3].

One participant in the BrainGate2 pilot clinical trial had two intracortical microelectrode arrays placed in the motor cortex, and thirty-six stimulating intramuscular electrodes placed in the muscles of the contralateral limb. We characterized intracortically recorded electrical artifacts during both intramuscular and surface stimulation. We compared the performance of three artifact reduction methods: blanking, common average reference (CAR) and linear regression reference (LRR), which creates channel-specific reference signals, composed of weighted sums of other channels.

Electrical artifacts resulting from surface stimulation were 175 × larger than baseline neural recordings (which were 110 µV peak-to-peak), while intramuscular stimulation artifacts were only 4 × larger. The artifact waveforms were highly consistent across electrodes within each array. Application of LRR reduced artifact magnitudes to less than 10 µV and largely preserved the original neural feature values used for decoding. Unmitigated stimulation artifacts decreased iBCI decoding performance, but performance was almost completely recovered using LRR, which outperformed CAR and blanking and extracted useful neural information during stimulation artifact periods.

The LRR method was effective at reducing electrical artifacts resulting from both intramuscular and surface FES, and almost completely restored iBCI decoding performance (>90% recovery for surface stimulation and full recovery for intramuscular stimulation). The results demonstrate that FES-induced artifacts can be easily mitigated in FES + iBCI systems by using LRR for artifact reduction, and suggest that the LRR method may also be useful in other noise reduction applications [4].

Ajiboye et al. recruited a participant into the BrainGate2 clinical trial.

Surgical procedures were performed at University Hospitals Cleveland Medical Center (Cleveland, OH, USA). Study procedures and data analyses were performed at Case Western Reserve University (Cleveland, OH, USA) and the US Department of Veterans Affairs, Louis Stokes Cleveland Veterans Affairs Medical Center (Cleveland, OH, USA). The study participant was a 53-year-old man with a spinal cord injury (cervical level 4, American Spinal Injury Association Impairment Scale category A). He received two intracortical microelectrode arrays in the hand area of his motor cortex, and 4 months and 9 months later received a total of 36 implanted percutaneous electrodes in his right upper and lower arm to electrically stimulate his hand, elbow, and shoulder muscles. The participant used a motorised mobile arm support for gravitational assistance and to provide humeral abduction and adduction under cortical control. We assessed the participant's ability to cortically command his paralysed arm to perform simple single-joint arm and hand movements and functionally meaningful multi-joint movements. We compared iBCI control of his paralysed arm with that of a virtual three-dimensional arm. This study is registered with ClinicalTrials.gov, number NCT00912041.

FINDINGS: The intracortical implant occurred on Dec 1, 2014, and we are continuing to study the participant. The last session included in this report was Nov 7, 2016. The point-to-point target acquisition sessions began on Oct 8, 2015 (311 days after implant). The participant successfully cortically commanded single-joint and coordinated multi-joint arm movements for point-to-point target acquisitions (80-100% accuracy), using first a virtual arm and second his own arm animated by FES. Using his paralysed arm, the participant volitionally performed self-paced reaches to drink a mug of coffee (successfully completing 11 of 12 attempts within a single session 463 days after implant) and feed himself (717 days after implant).

This is the first report of a combined implanted FES+iBCI neuroprosthesis for restoring both reaching and grasping movements to people with chronic tetraplegia due to spinal cord injury, and represents a major advance, with a clear translational path, for clinically viable neuroprostheses for restoration of reaching and grasping after paralysis [5)].

Two participants in the BrainGate2 pilot clinical trial made cortically controlled cursor movements with a linear velocity decoder and acquired targets by dwelling on them. We investigated whether the movement times were well described by Fitts' law.

We found that movement times were better described by the equation [Formula: see text], which captures how movement time increases sharply as the target radius becomes smaller, independently of distance. In contrast to able-bodied movements, the iBCI movements we studied had a low dynamic range of accuracy (absence of logarithmic proportionality) and were sensitive to the absolute scale of the task (small targets had long movement times regardless of the [Formula: see text] ratio). We argue that this relationship emerges due to noise in the decoder output whose magnitude is largely independent of the user's motor command (signal-independent noise). Signal-independent noise creates a baseline level of variability that cannot be decreased by trying to move slowly or hold still, making targets below a certain size very hard to acquire with a standard decoder.

The results give new insight into how iBCI movements currently differ from able-bodied movements and suggest that restoring a Fitts' law-like relationship to iBCI movements may require non-linear decoding strategies [6)].

Across 18 sessions from two people with tetraplegia enrolled in the BrainGate2 pilot clinical trial, we found that threshold crossing events extracted using this non-causal filtering method were significantly more informative of each participant's intended cursor kinematics compared to threshold crossing events derived from causally filtered signals. This new method decreased the mean angular error between the intended and decoded cursor direction by 9.7° for participant S3, who was implanted 5.4 years prior to this study, and by 3.5° for participant T2, who was implanted 3 months prior to this study.

CONCLUSIONS: Non-causally filtering neural signals prior to extracting threshold crossing events may be a simple yet effective way to condition intracortically recorded neural activity for direct control of external devices through BCIs [7)].

Two people with tetraplegia enrolled in the BrainGate2 pilot clinical trial performed a center-out-back task using an intracortical BCI, switching between decoders that had been calibrated on OL versus CL data.

Even when all other variables were held constant, CL calibration improved neural control as well as the accuracy and strength of the tuning model. Updating the CL decoder using additional and more recent data resulted in further improvements.

Differences in neural activity between OL and CL contexts contribute to the superiority of CL decoders, even prior to their additional 'adaptive' advantage. In the near future, CL decoder calibration may enable robust neural control without needing to pause ongoing, practical use of BCIs, an important step toward clinical utility [8].

1)

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6)

Willett FR, Murphy BA, Memberg WD, Blabe CH, Pandarinath C, Walter BL, Sweet JA, Miller JP, Henderson JM, Shenoy KV, Hochberg LR, Kirsch RF, Ajiboye AB. Signal-independent noise in intracortical brain-computer interfaces causes movement time properties inconsistent with Fitts' law. J Neural Eng. 2017 Apr;14(2):026010. doi: 10.1088/1741-2552/aa5990. Epub 2017 Feb 8. PubMed PMID: 28177925; PubMed Central PMCID: PMC5371026.

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