

Stanford



Paul Nuyujukian

Assistant Professor of Bioengineering and of Neurosurgery and, by courtesy, of Electrical Engineering

Bio

BIO

Our group, the Brain Interfacing Laboratory, is interested in the applicability of brain-machine interfaces as a platform technology for a variety of brain-related medical conditions, particularly stroke and epilepsy. This research spans both preclinical models and human clinical studies.

My graduate work focused on the development of intracortical neural prostheses. These systems interface with the brain and use mathematical models to control computer cursors and robotic arms. These efforts yielded the highest performing communication brain-machine interfaces demonstrated to date. Based on these results, we entered into a clinical trial and successfully translated our earlier findings to high-performance neural prostheses with human participants.

ACADEMIC APPOINTMENTS

- Assistant Professor, Bioengineering
- Assistant Professor, Neurosurgery
- Assistant Professor (By courtesy), Electrical Engineering
- Member, Bio-X
- Member, Wu Tsai Neurosciences Institute

HONORS AND AWARDS

- Medical Scientist Training Program (MSTP), Stanford (2009-2014)
- Paul and Daisy Soros Fellowship for New Americans, Open Society Institute (2008)
- Medical Research Fellows Program, Howard Hughes Medical Institute (HHMI) (2008)
- Medical Scholars Research Program, Stanford (2007-2009)
- Undergraduate Research Program in Electrical Engineering, UCLA (2004, 2005)

PROFESSIONAL EDUCATION

- MD, Stanford University (2014)
- PhD, Stanford University, Bioengineering (2012)
- BS, UCLA (2006)

PATENTS

- Jonathan C Kao, Paul Nuyujukian, Mark M Churchland, John P Cunningham, Krishna V Shenoy. "United States Patent 20140257520 Brain Machine Interfaces incorporating Neural Population Dynamics", The Board Of Trustees Of The Leland Stanford Junior University, Feb 24, 2014
- Paul Nuyujukian, Jonathan C Kao, Krishna V Shenoy. "United States Patent US20140081454 Brain Machine Interface utilizing a Discrete Action State Decoder in Parallel with a Continuous Decoder for a Neural Prosthetic Device", Stanford University, Sep 12, 2013

- Vikash Gilja, Paul Nuyujukian, Cynthia A Chestek, John P Cunningham, Byron M Yu, Stephen I Ryu, Krishna V Shenoy. "United States Patent 20110224572 Brain machine interface", Stanford University, Feb 18, 2010

LINKS

- Brain Interfacing Laboratory: <http://bil.stanford.edu>
- Graduate and Postdoctoral Research: <http://npl.stanford.edu/~paul/index.html>

Research & Scholarship

CURRENT RESEARCH AND SCHOLARLY INTERESTS

Our group explores neuroengineering and its application to both basic and clinical neuroscience. Our goal is to develop brain-machine interfaces as a platform technology for a variety of brain-related medical conditions including stroke and epilepsy.

Teaching

COURSES

2018-19

- Quantitative Physiology: BIOE 300B (Aut)

2017-18

- Engineering Concepts Applied to Physiology: BIOE 300B (Aut)

STANFORD ADVISEES

Postdoctoral Faculty Sponsor

Stephen Clarke

Doctoral Dissertation Advisor (AC)

Iliana Bray

Doctoral (Program)

Amin Aalipour, Christian Choe, Charles Huang, Ileana Pirozzi, Lu Yang

GRADUATE AND FELLOWSHIP PROGRAM AFFILIATIONS

- Bioengineering (Phd Program)
- Medicine (Masters Program)
- Neurosciences (Phd Program)

Publications

PUBLICATIONS

- **Cortical control of a tablet computer by people with paralysis** *PLOS ONE*
Nuyujukian, P., Sanabria, J., Saab, J., Pandarinath, C., Jarosiewicz, B., Blabe, C. H., Franco, B., Mernoff, S. T., Eskandar, E. N., Simeral, J. D., Hochberg, L. R., Shenoy, K., Henderson, et al
2018; 13 (11)
- **Cortical control of a tablet computer by people with paralysis.** *PLoS one*
Nuyujukian, P., Albitres Sanabria, J., Saab, J., Pandarinath, C., Jarosiewicz, B., Blabe, C. H., Franco, B., Mernoff, S. T., Eskandar, E. N., Simeral, J. D., Hochberg, L. R., Shenoy, K. V., Henderson, et al
2018; 13 (11): e0204566
- **High performance communication by people with paralysis using an intracortical brain-computer interface.** *eLife*

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- Pandarinath, C., Nuyujukian, P., Blabe, C. H., Sorice, B. L., Saab, J., Willett, F. R., Hochberg, L. R., Shenoy, K. V., Henderson, J. M.
2017; 6
- **A high-performance neural prosthesis enabled by control algorithm design** *NATURE NEUROSCIENCE*
Gilja, V., Nuyujukian, P., Chestek, C. A., Cunningham, J. P., Yu, B. M., Fan, J. M., Churchland, M. M., Kaufman, M. T., Kao, J. C., Ryu, S. I., Shenoy, K. V.
2012; 15 (12): 1752-1757
 - **Brain-machine interface cursor position only weakly affects monkey and human motor cortical activity in the absence of arm movements (vol 8, 16357, 2018)** *SCIENTIFIC REPORTS*
Stavisky, S. D., Kao, J. C., Nuyujukian, P., Pandarinath, C., Blabe, C., Ryu, S. I., Hochberg, L. R., Henderson, J. M., Shenoy, K. V.
2019; 9
 - **Brain-machine interface cursor position only weakly affects monkey and human motor cortical activity in the absence of arm movements.** *Scientific reports*
Stavisky, S. D., Kao, J. C., Nuyujukian, P., Pandarinath, C., Blabe, C., Ryu, S. I., Hochberg, L. R., Henderson, J. M., Shenoy, K. V.
2018; 8 (1): 16357
 - **An Open-Source Realtime Computational Platform (Short WIP Paper)**
Mehrotra, P., Dasgupta, S., Robertson, S., Nuyujukian, P.
ASSOC COMPUTING MACHINERY.2018: 109–12
 - **Neural Population Dynamics Underlying Motor Learning Transfer** *NEURON*
Vyas, S., Even-Chen, N., Stavisky, S. D., Ryu, S. I., Nuyujukian, P., Shenoy, K. V.
2018; 97 (5): 1177+
 - **Feasibility of Automatic Error Detect-and-Undo System in Human Intracortical Brain-Computer Interfaces.** *IEEE transactions on bio-medical engineering*
Even-Chen, N., Stavisky, S. D., Pandarinath, C., Nuyujukian, P., Blabe, C. H., Hochberg, L. R., Henderson, J. M., Shenoy, K. V.
2018; 65 (8): 1771–84
 - **A High-Performance Neural Prosthesis Incorporating Discrete State Selection With Hidden Markov Models** *IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING*
Kao, J. C., Nuyujukian, P., Ryu, S. I., Shenoy, K. V.
2017; 64 (4): 935-945
 - **A Nonhuman Primate Brain-Computer Typing Interface** *PROCEEDINGS OF THE IEEE*
Nuyujukian, P., Kao, J. C., Ryu, S. I., Shenoy, K. V.
2017; 105 (1): 66-72
 - **Clinical translation of a high-performance neural prosthesis.** *Nature medicine*
Gilja, V., Pandarinath, C., Blabe, C. H., Nuyujukian, P., Simeral, J. D., Sarma, A. A., Sorice, B. L., Perge, J. A., Jarosiewicz, B., Hochberg, L. R., Shenoy, K. V., Henderson, J. M.
2015; 21 (10): 1142-1145
 - **Single-trial dynamics of motor cortex and their applications to brain-machine interfaces** *NATURE COMMUNICATIONS*
Kao, J. C., Nuyujukian, P., Ryu, S. I., Churchland, M. M., Cunningham, J. P., Shenoy, K. V.
2015; 6
 - **Neural population dynamics in human motor cortex during movements in people with ALS** *ELIFE*
Pandarinath, C., Gilja, V., Blabe, C. H., Nuyujukian, P., Sarma, A. A., Sorice, B. L., Eskandar, E. N., Hochberg, L. R., Henderson, J. M., Shenoy, K. V.
2015; 4
 - **A high performing brain-machine interface driven by low-frequency local field potentials alone and together with spikes.** *Journal of neural engineering*
Stavisky, S. D., Kao, J. C., Nuyujukian, P., Ryu, S. I., Shenoy, K. V.
2015; 12 (3): 036009-?
 - **A high performing brain-machine interface driven by low-frequency local field potentials alone and together with spikes** *JOURNAL OF NEURAL ENGINEERING*
Stavisky, S. D., Kao, J. C., Nuyujukian, P., Ryu, S. I., Shenoy, K. V.
2015; 12 (3)
 - **Comparison of spike sorting and thresholding of voltage waveforms for intracortical brain-machine interface performance.** *Journal of neural engineering*
Christie, B. P., Tat, D. M., Irwin, Z. T., Gilja, V., Nuyujukian, P., Foster, J. D., Ryu, S. I., Shenoy, K. V., Thompson, D. E., Chestek, C. A.
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2015; 12 (1): 016009-?

- **Comparison of spike sorting and thresholding of voltage waveforms for intracortical brain-machine interface performance.** *Journal of neural engineering*
Christie, B. P., Tat, D. M., Irwin, Z. T., Gilja, V., Nuyujukian, P., Foster, J. D., Ryu, S. I., Shenoy, K. V., Thompson, D. E., Chestek, C. A.
2015; 12 (1): 016009-?
- **A High-Performance Keyboard Neural Prosthesis Enabled by Task Optimization** *IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING*
Nuyujukian, P., Fan, J. M., Kao, J. C., Ryu, S. I., Shenoy, K. V.
2015; 62 (1): 21-29
- **Neural population dynamics in human motor cortex during movements in people with ALS.** *eLife*
Pandarinath, C., Gilja, V., Blabe, C. H., Nuyujukian, P., Sarma, A. A., Soric, B. L., Eskandar, E. N., Hochberg, L. R., Henderson, J. M., Shenoy, K. V.
2015; 4
- **Single-trial dynamics of motor cortex and their applications to brain-machine interfaces.** *Nature communications*
Kao, J. C., Nuyujukian, P., Ryu, S. I., Churchland, M. M., Cunningham, J. P., Shenoy, K. V.
2015; 6: 7759-?
- **Performance sustaining intracortical neural prostheses.** *Journal of neural engineering*
Nuyujukian, P., Kao, J. C., Fan, J. M., Stavisky, S. D., Ryu, S. I., Shenoy, K. V.
2014; 11 (6): 066003-?
- **Performance sustaining intracortical neural prostheses** *JOURNAL OF NEURAL ENGINEERING*
Nuyujukian, P., Kao, J. C., Fan, J. M., Stavisky, S. D., Ryu, S. I., Shenoy, K. V.
2014; 11 (6)
- **A freely-moving monkey treadmill model.** *Journal of neural engineering*
D Foster, J., Nuyujukian, P., Freifeld, O., Gao, H., Walker, R., I Ryu, S., H Meng, T., Murmann, B., J Black, M., V Shenoy, K.
2014; 11 (4): 046020-?
- **A freely-moving monkey treadmill model** *JOURNAL OF NEURAL ENGINEERING*
Foster, J. D., Nuyujukian, P., Freifeld, O., Gao, H., Walker, R., Ryu, S. I., Meng, T. H., Murmann, B., Black, M. J., Shenoy, K. V.
2014; 11 (4)
- **Information Systems Opportunities in Brain-Machine Interface Decoders** *PROCEEDINGS OF THE IEEE*
Kao, J. C., Stavisky, S. D., Sussillo, D., Nuyujukian, P., Shenoy, K. V.
2014; 102 (5): 666-682
- **Self-recalibrating classifiers for intracortical brain-computer interfaces.** *Journal of neural engineering*
Bishop, W., Chestek, C. C., Gilja, V., Nuyujukian, P., Foster, J. D., Ryu, S. I., Shenoy, K. V., Yu, B. M.
2014; 11 (2): 026001-?
- **Self-recalibrating classifiers for intracortical brain-computer interfaces.** *Journal of neural engineering*
Bishop, W., Chestek, C. C., Gilja, V., Nuyujukian, P., Foster, J. D., Ryu, S. I., Shenoy, K. V., Yu, B. M.
2014; 11 (2): 026001-?
- **Intention estimation in brain-machine interfaces.** *Journal of neural engineering*
Fan, J. M., Nuyujukian, P., Kao, J. C., Chestek, C. A., Ryu, S. I., Shenoy, K. V.
2014; 11 (1): 016004-?
- **Intention estimation in brain-machine interfaces.** *Journal of neural engineering*
Fan, J. M., Nuyujukian, P., Kao, J. C., Chestek, C. A., Ryu, S. I., Shenoy, K. V.
2014; 11 (1): 016004-?
- **Hybrid decoding of both spikes and low-frequency local field potentials for brain-machine interfaces.** *Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual Conference*
Stavisky, S. D., Kao, J. C., Nuyujukian, P., Ryu, S. I., Shenoy, K. V.
2014; 2014: 3041-3044
- **Hybrid Decoding of Both Spikes and Low-Frequency Local Field Potentials for Brain-Machine Interfaces**
Stavisky, S. D., Kao, J. C., Nuyujukian, P., Ryu, S. I., Shenoy, K. V., IEEE

IEEE.2014: 3041–44

- **Investigating the role of firing-rate normalization and dimensionality reduction in brain-machine interface robustness.** *Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference*
Kao, J. C., Nuyujukian, P., Stavisky, S., Ryu, S. I., Ganguli, S., Shenoy, K. V.
2013; 2013: 293-298
- **Design and validation of a real-time spiking-neural-network decoder for brain-machine interfaces.** *Journal of neural engineering*
Dethier, J., Nuyujukian, P., Ryu, S. I., Shenoy, K. V., Boahen, K.
2013; 10 (3): 036008-?
- **Design and validation of a real-time spiking-neural-network decoder for brain-machine interfaces.** *Journal of neural engineering*
Dethier, J., Nuyujukian, P., Ryu, S. I., Shenoy, K. V., Boahen, K.
2013; 10 (3): 036008-?
- **Neural population dynamics during reaching** *NATURE*
Churchland, M. M., Cunningham, J. P., Kaufman, M. T., Foster, J. D., Nuyujukian, P., Ryu, S. I., Shenoy, K. V.
2012; 487 (7405): 51-?
- **A recurrent neural network for closed-loop intracortical brain-machine interface decoders** *JOURNAL OF NEURAL ENGINEERING*
Sussillo, D., Nuyujukian, P., Fan, J. M., Kao, J. C., Stavisky, S. D., Ryu, S., Shenoy, K.
2012; 9 (2)
- **HermesE: A 96-Channel Full Data Rate Direct Neural Interface in 0.13 mu m CMOS** *IEEE JOURNAL OF SOLID-STATE CIRCUITS*
Gao, H., Walker, R. M., Nuyujukian, P., Makinwa, K. A., Shenoy, K. V., Murmann, B., Meng, T. H.
2012; 47 (4): 1043-1055
- **A framework for relating neural activity to freely moving behavior** *34th Annual International Conference of the IEEE Engineering-in-Medicine-and-Biology-Society (EMBS)*
Foster, J. D., Nuyujukian, P., Freifeld, O., Ryu, S. I., Black, M. J., Shenoy, K. V.
IEEE.2012: 2736–2739
- **A brain machine interface control algorithm designed from a feedback control perspective** *34th Annual International Conference of the IEEE Engineering-in-Medicine-and-Biology-Society (EMBS)*
Gilja, V., Nuyujukian, P., Chestek, C. A., Cunningham, J. P., Yu, B. M., Fan, J. M., Ryu, S. I., Shenoy, K. V.
IEEE.2012: 1318–1322
- **Long-term stability of neural prosthetic control signals from silicon cortical arrays in rhesus macaque motor cortex** *39th Neural Interfaces Conference (NIC2010)*
Chestek, C. A., Gilja, V., Nuyujukian, P., Foster, J. D., Fan, J. M., Kaufman, M. T., Churchland, M. M., Rivera-Alvidrez, Z., Cunningham, J. P., Ryu, S. I., Shenoy, K. V.
IOP PUBLISHING LTD.2011
- **A closed-loop human simulator for investigating the role of feedback control in brain-machine interfaces** *JOURNAL OF NEUROPHYSIOLOGY*
Cunningham, J. P., Nuyujukian, P., Gilja, V., Chestek, C. A., Ryu, S. I., Shenoy, K. V.
2011; 105 (4): 1932-1949
- **Combining Wireless Neural Recording and Video Capture for the Analysis of Natural Gait.** *International IEEE/EMBS Conference on Neural Engineering : [proceedings]. International IEEE EMBS Conference on Neural Engineering*
Foster, J. D., Freifeld, O., Nuyujukian, P., Ryu, S. I., Black, M. J., Shenoy, K. V.
2011; 2011: 613–16
- **Monkey Models for Brain-Machine Interfaces: The Need for Maintaining Diversity** *33rd Annual International Conference of the IEEE Engineering-in-Medicine-and-Biology-Society (EMBS)*
Nuyujukian, P., Fan, J. M., Gilja, V., Kalanithi, P. S., Chestek, C. A., Shenoy, K. V.
IEEE.2011: 1301–1305
- **Spiking Neural Network Decoder for Brain-Machine Interfaces.** *International IEEE/EMBS Conference on Neural Engineering : [proceedings]. International IEEE EMBS Conference on Neural Engineering*
Dethier, J., Gilja, V., Nuyujukian, P., Elassaad, S. A., Shenoy, K. V., Boahen, K.
2011

- **A Brain-Machine Interface Operating with a Real-Time Spiking Neural Network Control Algorithm.** *Advances in neural information processing systems*
Dethier, J., Nuyujukian, P., Eliasmith, C., Stewart, T., Ellassaad, S. A., Shenoy, K. V., Boahen, K.
2011; 2011: 2213-2221
- **Spiking Neural Network Decoder for Brain-Machine Interfaces** *5th International IEEE Engineering-in-Medicine-and-Biology-Society (EMBS) Conference on Neural Engineering (NER)*
Dethier, J., Gilja, V., Nuyujukian, P., Ellassaad, S. A., Shenoy, K. V., Boahen, K.
IEEE.2011: 396-399
- **Combining Wireless Neural Recording and Video Capture for the Analysis of Natural Gait** *5th International IEEE Engineering-in-Medicine-and-Biology-Society (EMBS) Conference on Neural Engineering (NER)*
Foster, J. D., Freifeld, O., Nuyujukian, P., Ryu, S. I., Black, M. J., Shenoy, K. V.
IEEE.2011: 613-616
- **Autonomous head-mounted electrophysiology systems for freely behaving primates** *CURRENT OPINION IN NEUROBIOLOGY*
Gilja, V., Chestek, C. A., Nuyujukian, P., Foster, J., Shenoy, K. V.
2010; 20 (5): 676-686
- **Embedded Neural Recording With TinyOS-Based Wireless-Enabled Processor Modules** *IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING*
Farshchi, S., Pesterev, A., Nuyujukian, P., Guenterberg, E., Mody, I., Judy, J. W.
2010; 18 (2): 134-141
- **Wireless Neural Recording With Single Low-Power Integrated Circuit** *IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING*
Harrison, R. R., Kier, R. J., Chestek, C. A., Gilja, V., Nuyujukian, P., Ryu, S., Greger, B., Solzbacher, F., Shenoy, K. V.
2009; 17 (4): 322-329
- **HermesC: Low-Power Wireless Neural Recording System for Freely Moving Primates** *IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING*
Chestek, C. A., Gilja, V., Nuyujukian, P., Kier, R. J., Solzbacher, F., Ryu, S. I., Harrison, R. R., Shenoy, K. V.
2009; 17 (4): 330-338
- **Neural Prosthetic Systems: Current Problems and Future Directions** *Annual International Conference of the IEEE-Engineering-in-Medicine-and-Biology-Society*
Chestek, C. A., Cunningham, J. P., Gilja, V., Nuyujukian, P., Ryu, S. I., Shenoy, K. V.
IEEE.2009: 3369-3375
- **HermesC: RF wireless low-power neural recording system for freely behaving primates** *IEEE International Symposium on Circuits and Systems*
Chestek, C. A., Gija, V., Nuyujukian, P., Ryu, S. I., Shenoy, K. V., Kier, R. J., Solzbacher, F., Harrison, R. R.
IEEE.2008: 1752-1755
- **A Wireless Neural Interface for Chronic Recording** *IEEE Biomedical Circuits and Systems Conference - Intelligent Biomedical Systems*
Harrison, R. R., Kier, R. J., Kim, S., Rieth, L., Warren, D. J., Ledbetter, N. M., Clark, G. A., Solzbacher, F., Chestek, C. A., Gilja, V., Nuyujukian, P., Ryu, S. I., Shenoy, et al
IEEE.2008: 125-128
- **Wireless neural signal acquisition with single low-power integrated circuit** *IEEE International Symposium on Circuits and Systems*
Harrison, R. R., Kier, R. J., Greger, B., Solzbacher, F., Chestek, C. A., Gija, V., Nuyujukian, P., Ryu, S. I., Shenoy, K. V.
IEEE.2008: 1748-1751
- **Bi-Fi: An embedded sensor/system architecture for remote biological monitoring** *IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE*
Farshchi, S., Pesterev, A., Nuyujukian, P. H., Mody, I., Judy, J. W.
2007; 11 (6): 611-618
- **A TinyOS-enabled MICA2-based wireless neural interface** *IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING*
Farshchi, S., Nuyujukian, P. H., Pesterev, A., Mody, I., Judy, J. W.
2006; 53 (7): 1416-1424
- **A TinyOS-based wireless neural sensing, archiving, and hosting system** *2nd International IEEE/EMBS Conference on Neural Engineering*

Farshchi, S., Nuyujukian, P. H., Pesterev, A., Mody, I., Judy, J. W.
IEEE.2005: 671–674