Closed-Loop Reinforcement Learning Based Deep Brain Stimulation Using SpikerNet: A Computational Model

WI Ne
Wisconsin Institute for Translational Neuroengineering

Scan QR code for link to full paper

Brandon S Coventry[1,2] and Edward L. Bartlett[2,3]

1. Wisconsin Institute for Translational Neuroengineering and the Department of Biomedical Engineering, University of Wisconsin-Madison
2. Weldon School of Biomedical Engineering, Purdue University West Lafayette. 3. Department of Biological Sciences, Purdue University West Lafayette

Purdue Engineering

Introduction

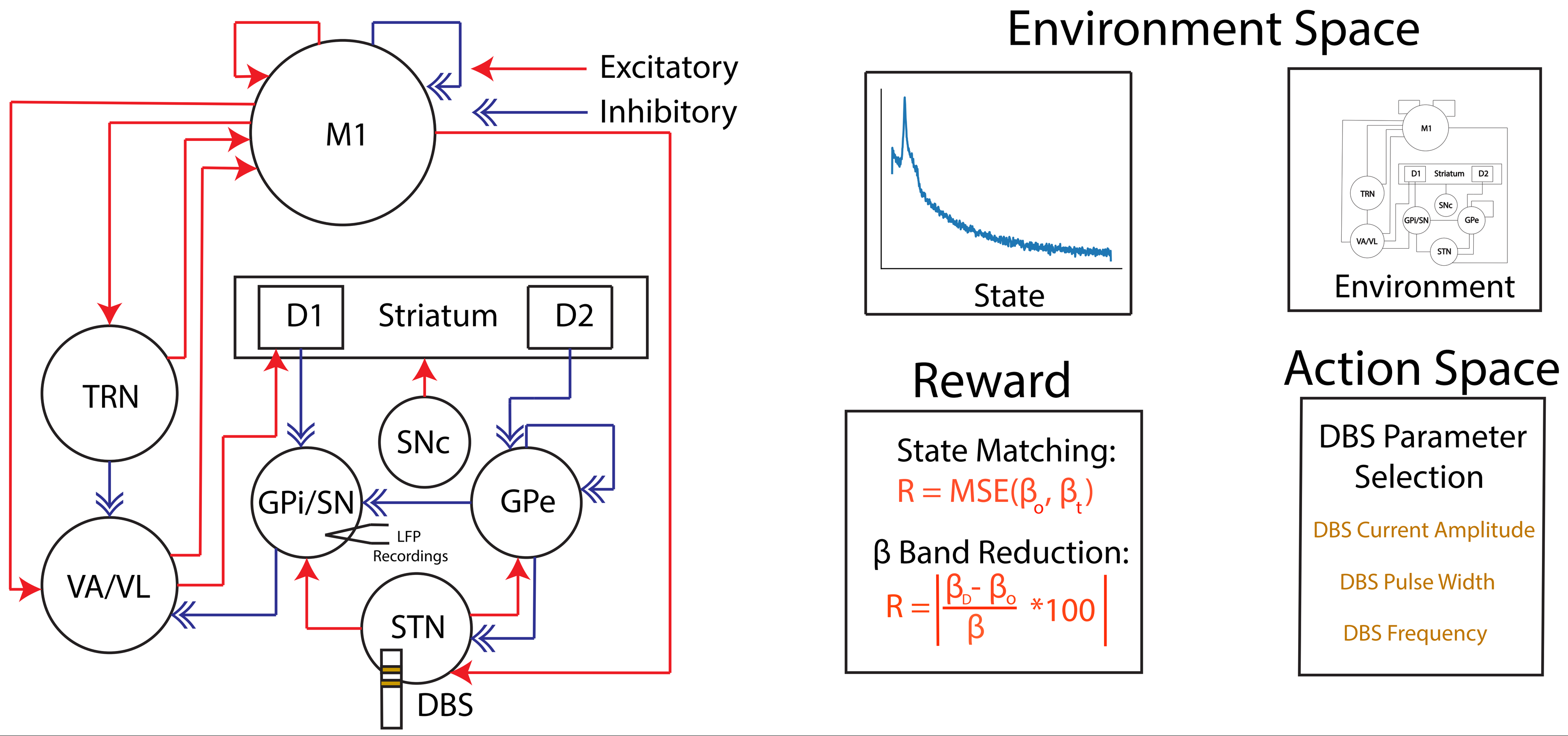
While DBS has proven to be an effective therapy for treatment of a wide variety of neurological and neuropsychiatric conditions, its application is limited by open-loop operation which does not account for short and long term changes in patient symptomology leading to off-target effects and repeat clinic visits for parameter tuning. Continuous DBS stimulation has also been found to modulate metabolic demands brain wide, potentially causing cell death and fundamental alterations to sensorimotor circuits[1].

Closed loop DBS has been introduced to mitigate deficits found in converntional DBS by introducing measurement of neurologic events correlated to patient symptomology. Closed loop DBS has been implemented in Parkinson's disease, where increases in β band dynamics related to symptomology has been used as a control signal to intiate DBS. However, these relatively simple control algorithms are prone to interfering with volitional movement and cannot adapt to the changing neural environment[2].

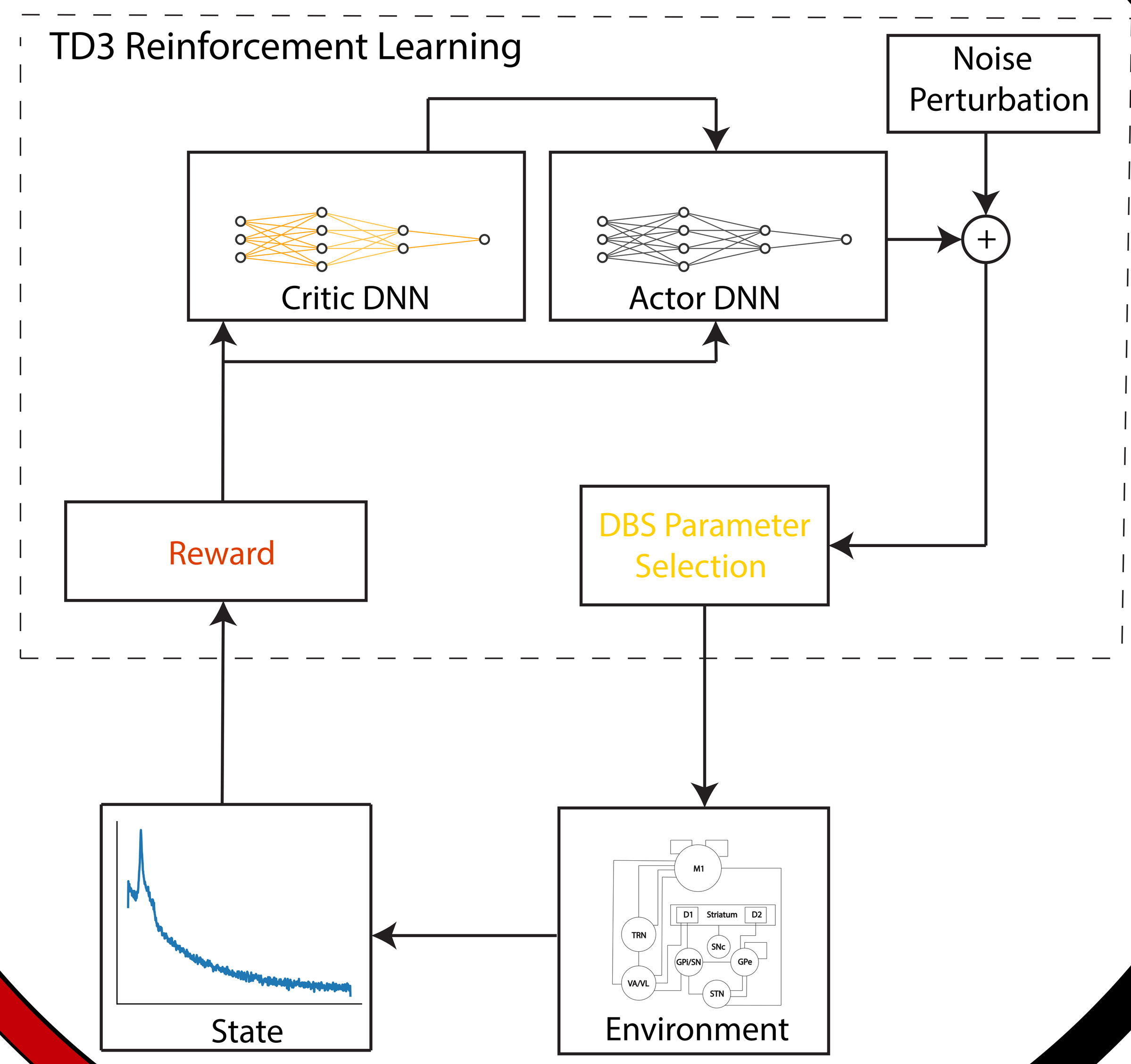
We recently introducted SpikerNet[3], a closed loop reinforcement learning based neuromodulation approach which actively tracks, learns, and adapts to patient specific neural dynamics using real time deep reinforcement learning. The goal of this work is to assess runtime costs, search efficiency, and the generation of DBS stimulation parameters in SpikerNet.

Methods

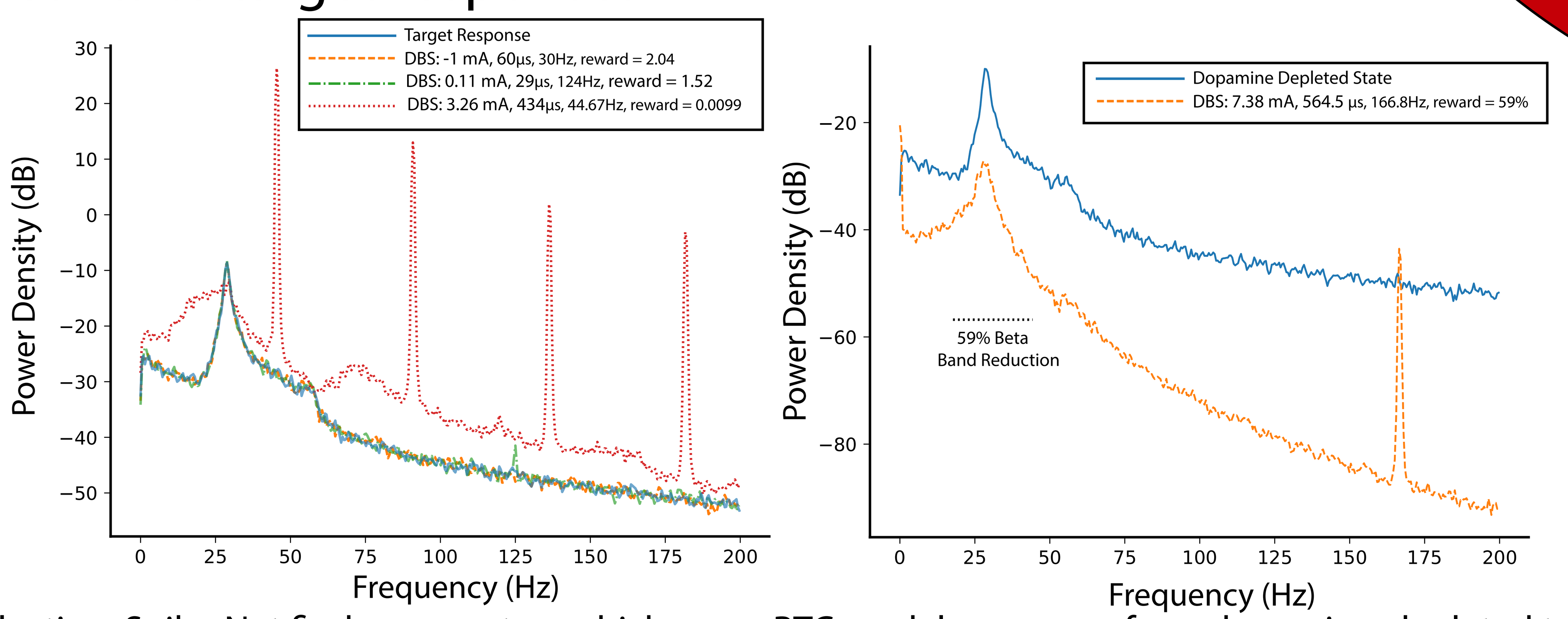
Mean-field computational models of network basal-ganglia thalamocortical(BTC) local field responses (LFP) to monophasic STN DBS[4] were implemented in a custom OpenAI gym environment. Models were then implemented into the SpikerNet framework.



SpikerNet Closed-loop Neuromodulation

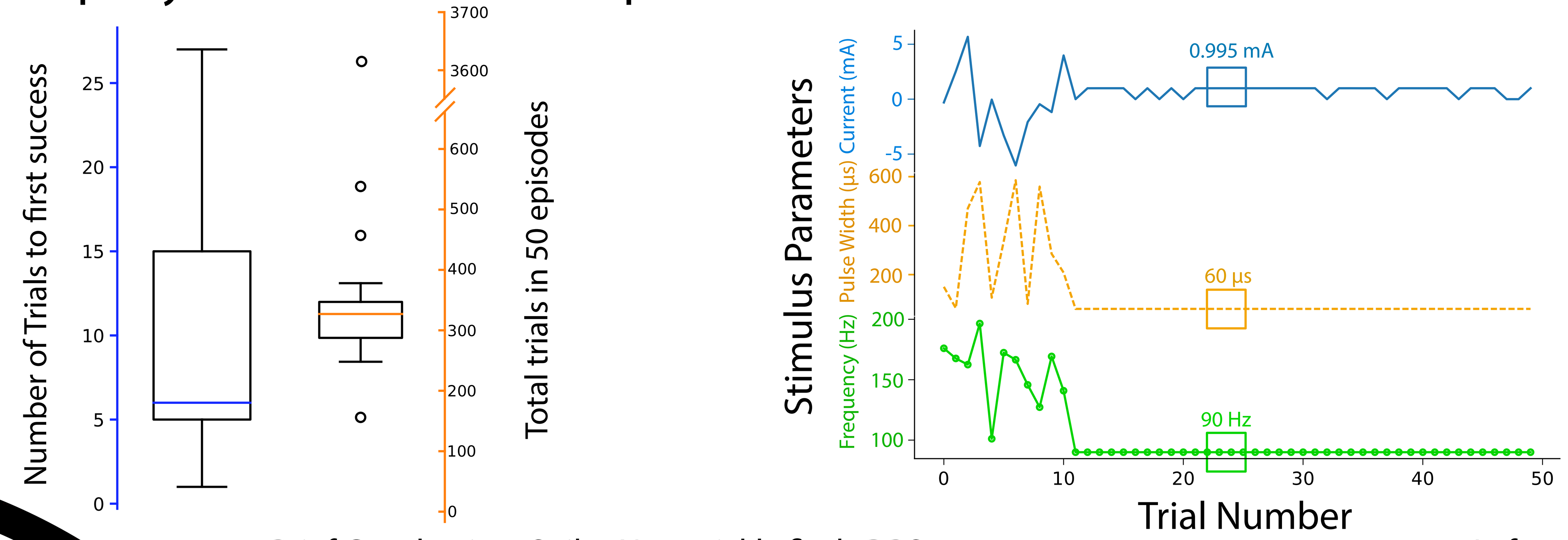


SpikerNet fits to target responses



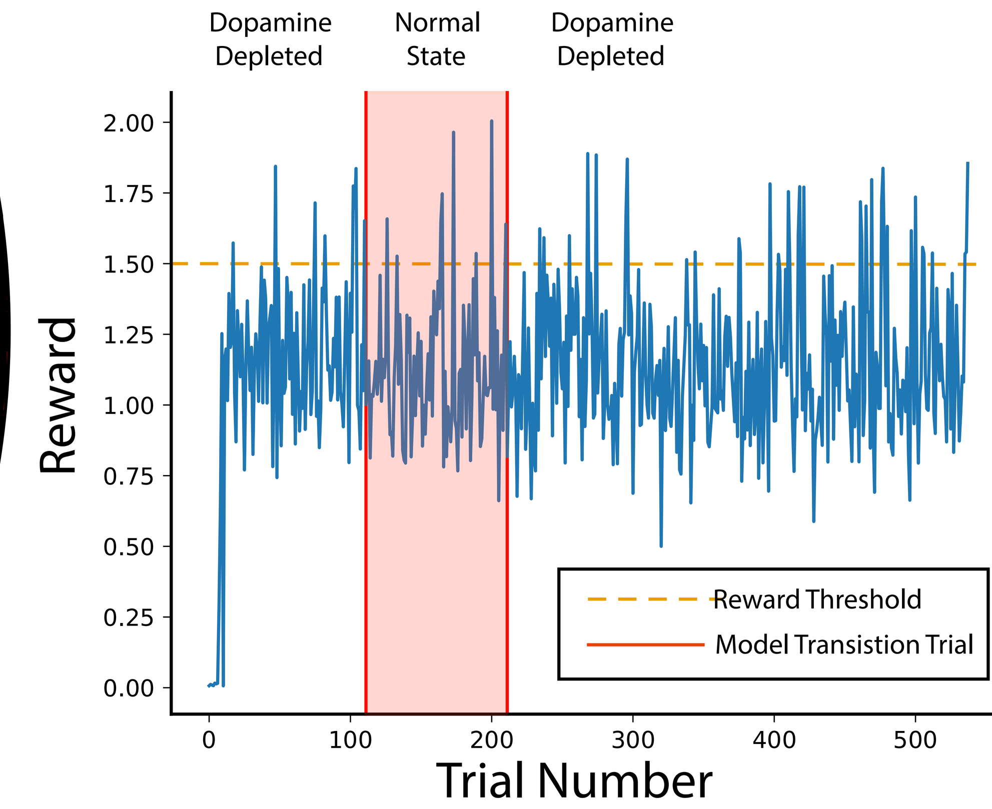
Brief Conclusion: SpikerNet finds parameters which move BTC model responses from dopamine-depleted to normal states. Left: Example fit responses and DBS parameters with one example of non-effective stimulation (red dotted line). Right: Reward function only observing reductions in β band power also results in reductions of off-target LFP frequency bands.

SpikerNet rapdily finds effective DBS parameters



Brief Conclusion: SpikerNet quickly finds DBS parameters to meet target responses. Left: Distribution of number of stimulus trials to first successful match (blue) and total number of search trials in 50 reinforcement learning epocs (orange). Right: Example of DBS parameter evolution during search.

SpikerNet rapidly tracks changes in brain state



Brief Conclusion: BTC models were randomly (10% probability per trial) switched between dopamine depleted and normal states. SpikerNet is able to track and derive viable DBS stimulation parameters across widely variable brain states.

SpikerNet as a closed-loop neuromodulation system

The present study uses computational BTC models to assess SpikerNet in Parkinsonian DBS applications, finding that SpikerNet obtains viable stimulation parameters in few iterations and is stable against drastic state changes. SpikerNet was developed to rapidly find a target brain state and learn stimulus trajectories to continuously titrate stimulation to maintain a target neural state. Training can be reinitialized online when stimulation is no longer achieving efficacy, adapting to patient needs and reducing return visits to the clinic. This study shows that training is rapid, stable and is able to generate a diversity of effective stimulus parameters. Our finding that simpler β band reduction reward functions may produce compromised neural responses generalize to any closed-loop DBS systems and potentially describes maladaptive closed-loop interactions with volitional movement[2]. Our findings then suggest that even slightly more informative control functions provide better neural control. While normal patient brain state cannot be obtained after disease onset, general reward functions can be obtained through models of BTC function through clinical and basic science collaborative studies.

Disclosures, Funding, and References

B.S.C. and E.L.B. hold a provisional patent on SpikerNet CL-reinforcement learning based neuromodulation system presented. USPTO: 18/083490
Funding: ELB - National Institutes of Health NIDCD #R01DC011580. BSC- Purdue Institute for Integrative Neuroscience collaborative training grant

[1]. T. J. van Hartevelt et al., "Neural Plasticity in Human Brain Connectivity: The Effects of Long Term Deep Brain Stimulation of the Subthalamic Nucleus in Parkinson's Disease," PLoS One, vol. 9, no. 1, p. e86496, Jan. 2014, doi: 10.1371/journal.pone.0086496.
[2].S. Little and P. Brown, "Debugging Adaptive Deep Brain Stimulation for Parkinson's Disease," Movement Disorders, vol. 35, no. 4, pp. 555–561, Apr. 2020, doi: 10.1002/mds.27996.
[3]. B. S. Coventry, "Closed-loop optical neuromodulation of the auditory thalamocortical pathway," Doctor of Philosophy, Purdue University,2021. doi: 10.25394/PGS.14831052.v1.
[4]. Grado L., et al "Bayesian adaptive dual control of deep brain stimulation in a computational model of Parkinson's disease," PLoS Comput Biol, vol. 14, no. 12, pp. 1–23, Oct. 2018