Intracranial Signatures of Effort Based Decision Making

Vivek Anand[1], Dongyeun Kim[1], Camilla May[1], Zeke Gleichgerrcht[2], Neal Laxpati[2], Michael Treadway[2], Chris Rozell[1] & Sankar Alagapan[1]

[1]Georgia Institute of Technology [2]Emory University

Motivation

Effort-based decision-making (EBDM) paradigms provide an objective measure of motivation by quantifying how individuals weigh effort costs against potential rewards, capturing processes often disrupted in conditions such as anhedonia, apathy, and amotivation . However, most EBDM tasks use button presses or other minimal-effort actions [2–3], which are metabolically trivial and do not reflect the sustained, whole-body efforts typical of daily behavior. To address this limitation, our work introduces the PEDaL (Physiologically-demanding Effort Decision and Learning Task) task, an under-the-desk biking paradigm that engages participants in naturalistic, energetically demanding activity while recording high-resolution SEEG data. Preliminary results show differential activations during decision making and effortful activity in the insula, suggesting this approach can reveal neural mechanisms of motivation under ecologically valid conditions.

Task Design

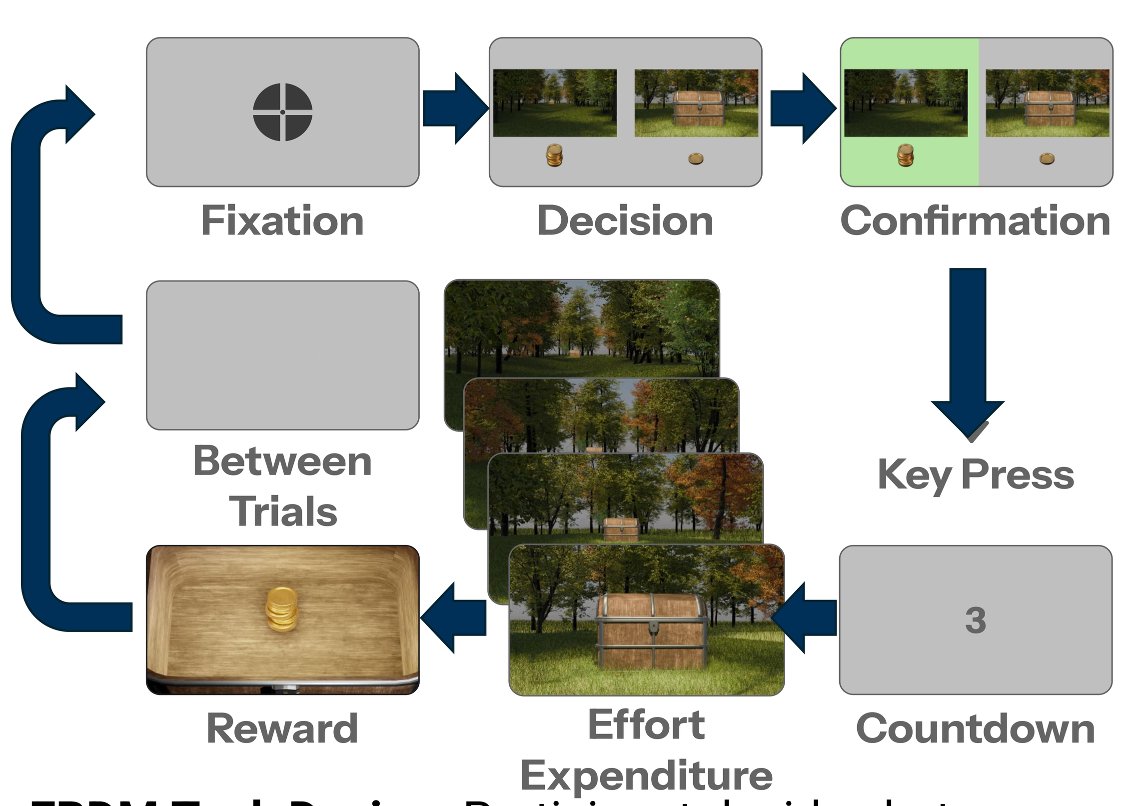


Fig 1. EBDM Task Design. Participant decides between a reference and variable effort reward pair and performs effortful task (button pressing if Control or biking if PEDaL) to receive reward if successful. (24 trials each modality)

Instrumentation

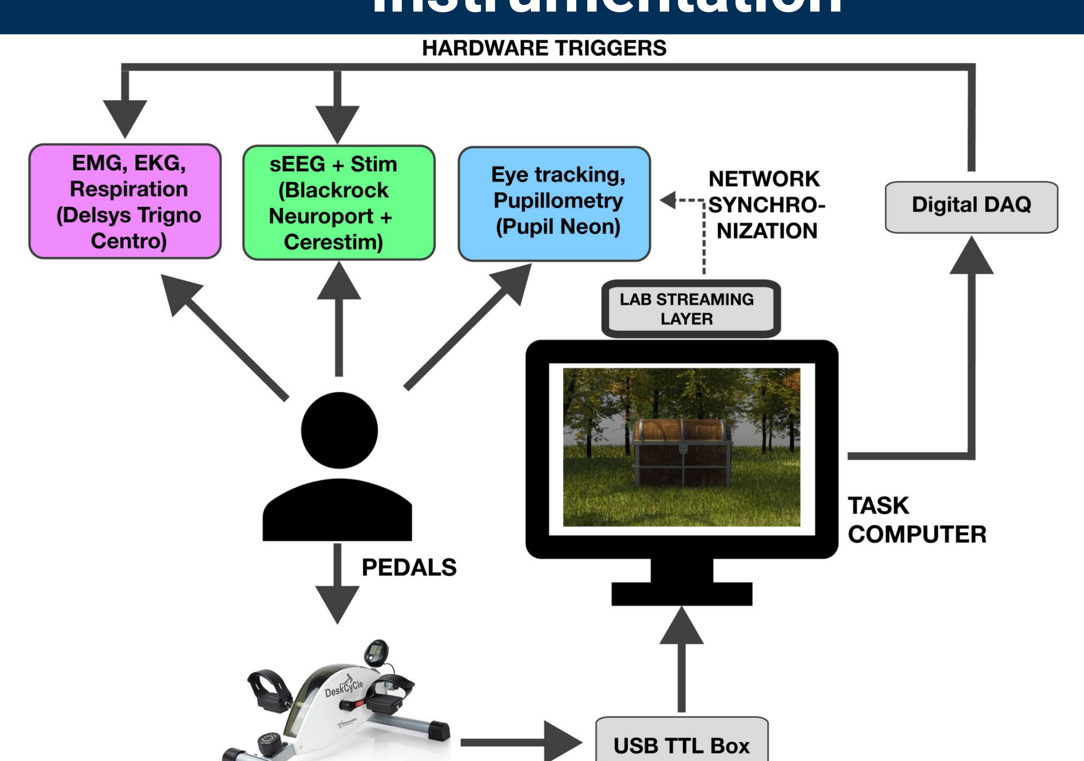
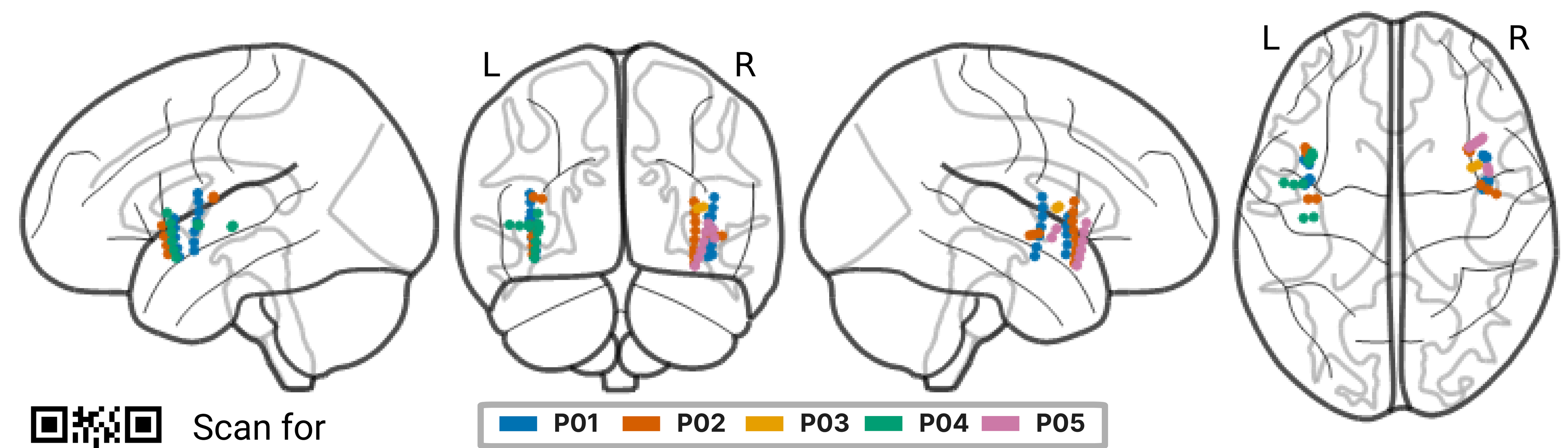


Fig 2. Data collection setup. **E**yetracking, pupillometry, EMG, SEEG, EKG) are all collected synchronously with the task.

Insula Lead Locations



Scan for interactive 3D visualization

Fig 3. Lead Locations (46 channels) in Insula for (N=5) patients.

Behavioral Results Capture Differences between Control and PEDaL

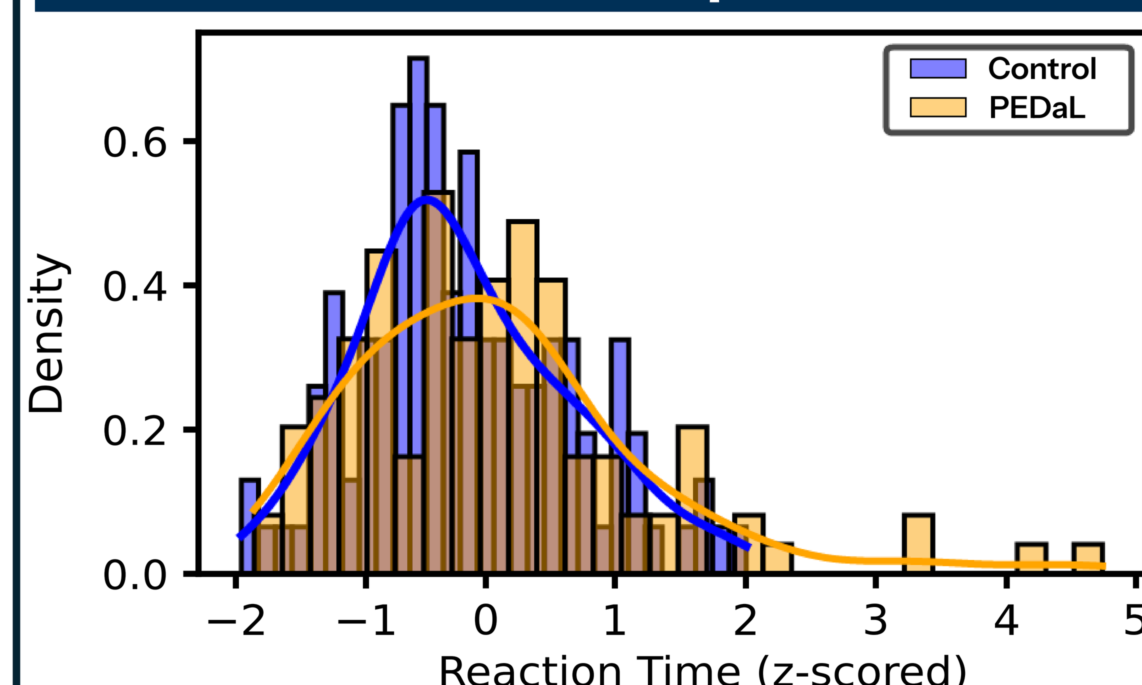


Fig 4. Normalized Reaction Time Distributions for PEDaL and Control across (N=5) patients. Variance is distinct between PEDaL and Control (Levene's test for equal variance p=0.0308)

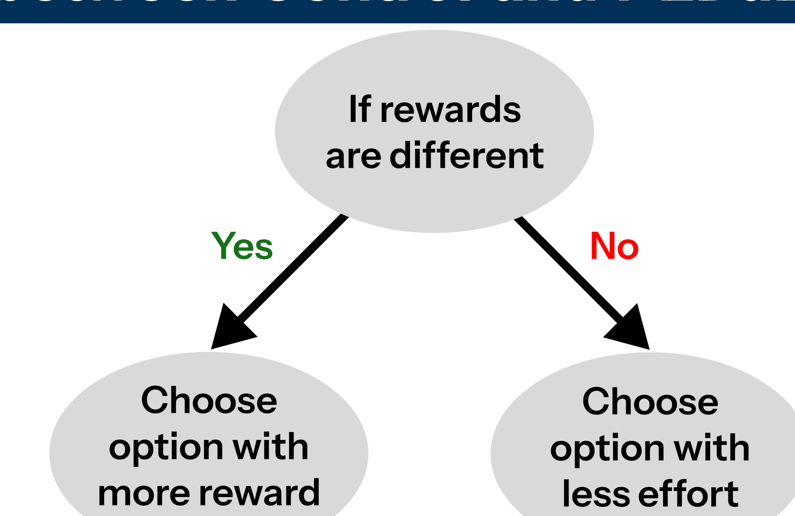


Fig 5. Predicted Heuristic Decision Tree on how patients make decisions

Control (%)	PEDaL (%)
84.87	89.38

Fig 6. Accuracy of Decision Tree on patient behavior (N=5, 24 trials each)

Spectral Bandpowers Capture Differences between Control and PEDaL

- Linear Mixed Effects Model to measure effects of Action, Phase and Band
- Power ~ Action * Phase * Band + (1 | patient / trial) + (1 | channel)
- **All interaction terms significant** to p<0.01
- Pairwise post-hoc tests (Tukey-adjusted) show significant difference between button and pedal for **delta, theta and high beta bands** (p<0.001) in decision and effortful phases

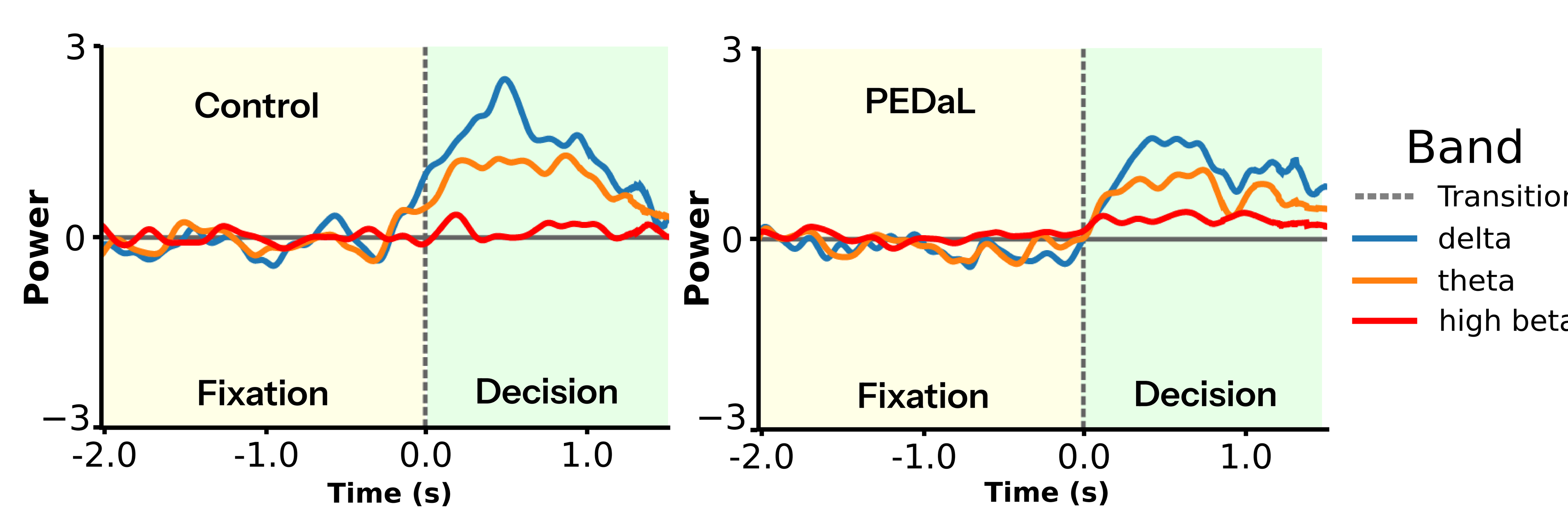


Fig 7. Averaged Bandpower Spectrograms for Fixation and Decision Phase: (N=5)

Directed Shifts Based On Effortful Modality

Principal Component 1 (Delta + Theta) modulates effortful phase for Control vs PEDaL

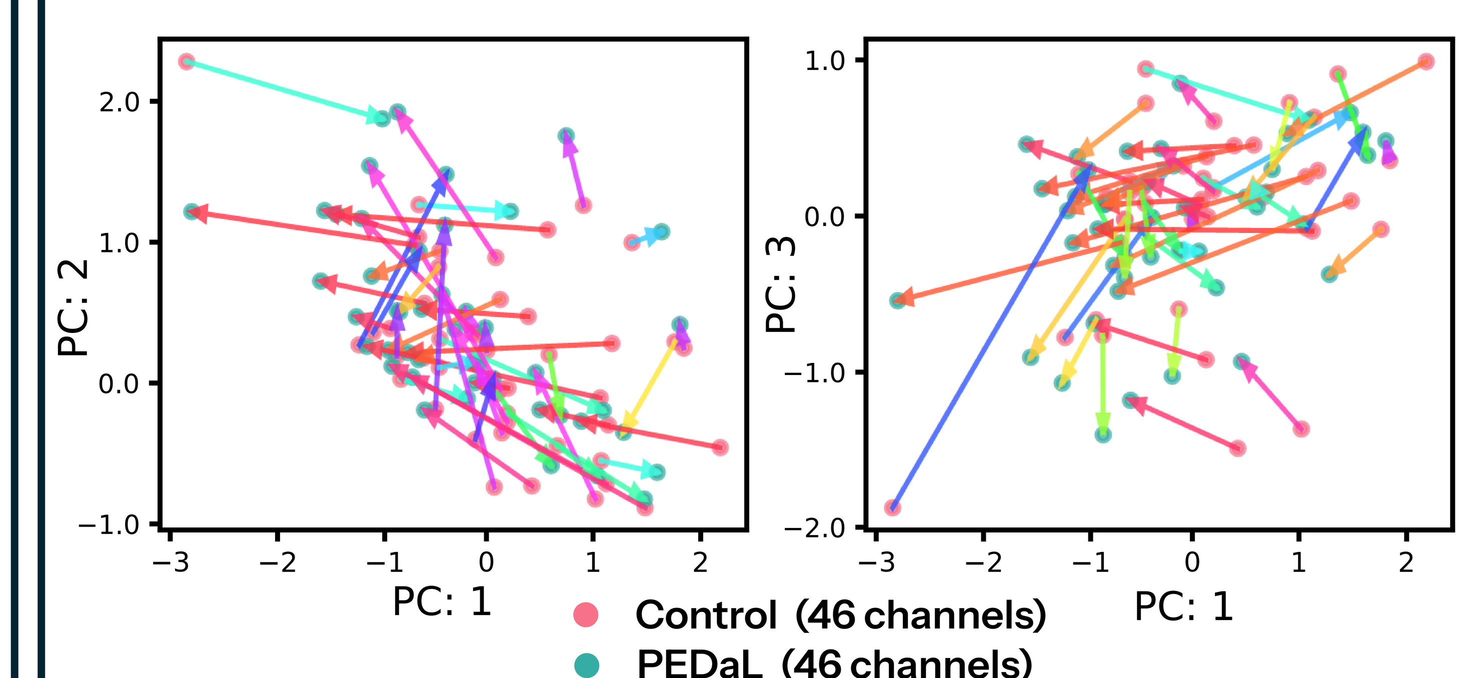


Fig 8. All Insula Channel Shifts for Effortful phase Spectra for PEDaL and Control in Principal Component Space: (N=46 total channels)

Conclusion

Task specific differences for effortful tasks can significantly bias decisions chosen [4], a result we see too. Therefore, there is a need to employ *naturalistic tasks* which better approximate real-life situations to avoid task biases. Specifically, we find that

1. **The Insula differentially modulates for Control versus PEDaL** during decision making and effort expenditure for delta, theta and high beta bands which has been previously implicated in playing a key role in physical and cognitive effort expenditure. [5-6]
2. **Behavioral Results show differential modulation** of normalized reaction times for Control and PEDaL.

Future work will explore:

- **Neural correlates of reward:** from data already collected.
- **Multimodal correlates of decision making:** we will analyze the signals from the body (Eyetracking, EKG, EMG) to predict differential modulation in the brain.

References

1. T.-J. Chong, V. Bonnelle, and M. Husain, “Quantifying motivation with effort-based decision making paradigms in health and disease,” Progress in brain research, vol. 229, pp. 71–100, 2016.
2. M. T. Treadway, N. A. Bossaller, R. C. Shelton, and D. H. Zald, “Effort-based decision-making in major depressive disorder: a translational model of motivational anhedonia.,” Journal of abnormal psychology, vol. 121, no. 3, p. 553, 2012.
3. I. T. Kurniawan, M. Guitart-Masip, P. Dayan, and R. J. Dolan, “Effort and valuation in the brain: the effects of anticipation and execution,” Journal of Neuroscience, vol. 33, no. 14, pp. 6160–6169, 2013.
4. M. F. Green, W. P. Horan, D. M. Barch, and J. M. Gold, “Effort-based decision making: a novel approach for assessing motivation in schizophrenia,” Schizophrenia bulletin, vol. 41, no. 5, pp. 1035–1044, 2015.
5. B. S. Porter, K. Li, and K. L. Hillman, “Regional activity in the rat anterior cingulate cortex and insula during persistence and quitting in a physical-effort task,” eneuro, vol. 7, no. 5, 2020.
6. P. S. Hogan, S. X. Chen, W. W. Teh, and V. S. Chib, “Neural mechanisms underlying the effects of physical fatigue on effort-based choice,” Nature communications, vol. 11, no. 1, p. 4026, 2020.

Acknowledgements

This research was funded in part by the following sources: NIH EB T32 EB025816, NIH NCATS KL2TR002381, NIH NCATS UL1TR002378, Julian T. Hightower Chair, and Georgia Institute of Technology