Video-based Quantitative Analysis of Orofacial Movements and Pupil Activity in a Parkinson's Disease Mouse Model

Samme Xie[1], Indeara Martinez[2], Li Su[2], Yunmiao Wang[2], Lisa Meyer-Baese[2,3], Dieter Jaeger[2]
Emory College of Arts and Science, Emory University; [2]Department of Biology, Emory University; [3]Department of Biomedical Engineering, Emory and Georgia Tech

INTRODUCTION

Background

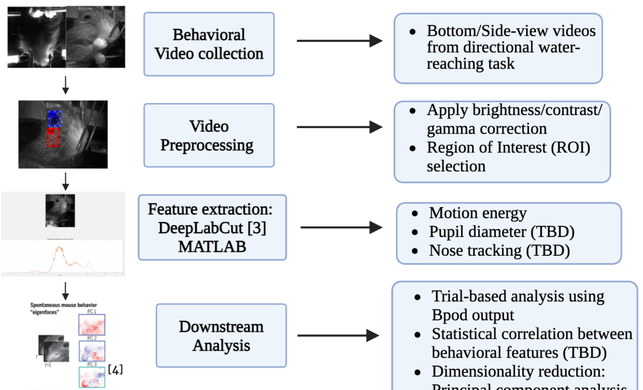
- Parkinson's Disease (PD): a neurodegenerative disorder characterized by progressive motor and nonmotor symptoms
- Hypomimia: reduced facial expression due to deterioration in facial muscle coordination, reflecting basal ganglia dysfunction [1].
- MitoPark mouse model: progressive parkinsonism due to mitochondrial impairment in dopamine neurons [2].

Objectives & Hypotheses

Objective: 1) Develop pipeline for analyzing orofacial movement. **2)** Extract orofacial behavioral features and quantify their change over PD developement;
Hypotheses: MitoPark mice will show **1)** decreased Orofacial movement evidenced by reduced motion energy **2)** reduced fluctuations in pupil diameter compared to their littermate control mice over time **3)** reduced nose twitching and movement.

MATERIALS & METHODS

Facial movement analysis pipeline



Facial motion energy (FME) calculation

Face ROI selection: 150 ×150 (pixels)

Frame-by-frame analysis on video recorded at 100 frames/second.

$FME_n = (Avg\ pixel\ intensity\ of\ ROI_{n+1} - Avg\ pixel\ intensity\ of\ ROI_n)^2$,
where n is the n-th frame [5].

Event alignment and statistics:
- Align motion energy vector for each trial with BPOD state output to obtain FME around a behavioral state.
- Average FME across success trials and obtain standard error to quantify face movement for each session.

Figure 1: Upper panel shows the proposed analysis pipeline for extracting orofacial movement from mouse behavioral recordings; Lower panel shows the FME calculation for facial ROI around the whisker pad to represent movement intensity and orofacial reaction toward the presence of water reward.

Results

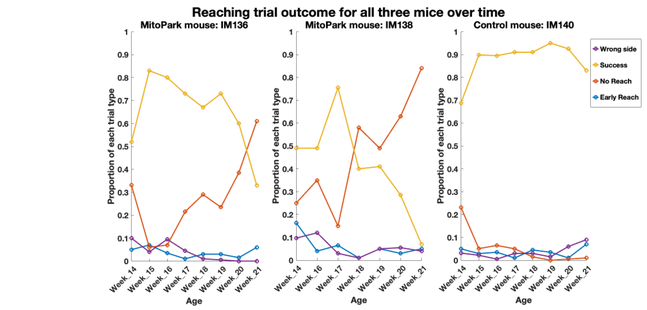


Figure 2: Reaching performance from weekly recordings (2 sessions per week) for one control (IM140) and two MitoPark mice (IM136/IM138) from week 14 to 21. The reaching performance was measured by the proportion of each type of trials divided by the total number of trials recorded each week. The reaching success rate of the two MitoPark mice starts to drop drastically around the age of week 19, while the success rate of the Control mouse stays consistently high. This result has been expected as the motor function of MitoPark mice drops as their PD symptoms advance.

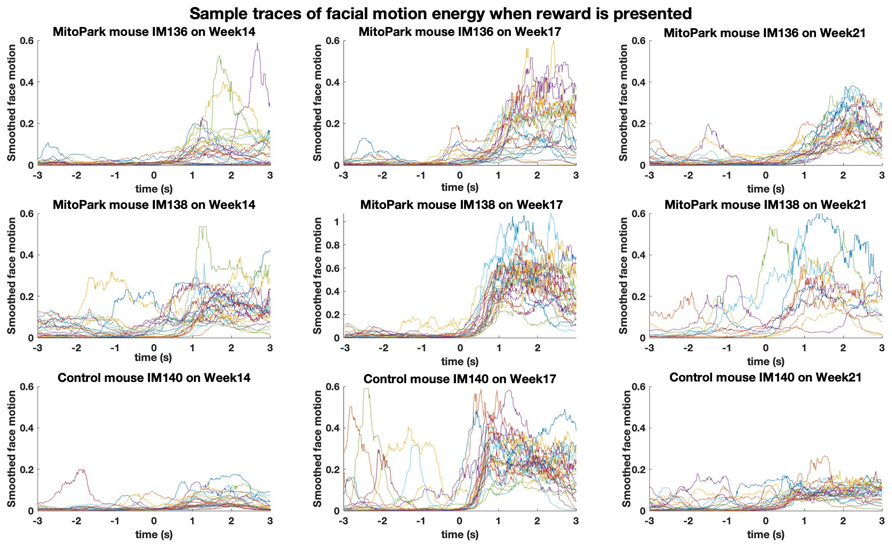


Figure 3: Smoothed motion energy traces of 25 trials from three example weeks for all three mice. Motion energy is calculated ±3 seconds around the time point when water reward is delivered. For all three mice, the motion energy increases after the reward is present. Upon inspection, IM136 (MitoPark) and IM140 (Control) show relatively similar pattern, while IM138 shows progressively higher and more variable motion energy from Week 14 to Week 21, suggesting potential decreased control over facial movement. Nevertheless, the traces for each mouse suggest distinct response pattern toward reward, requiring further statistical analysis to objectively identify trend as MitoPark mice age.

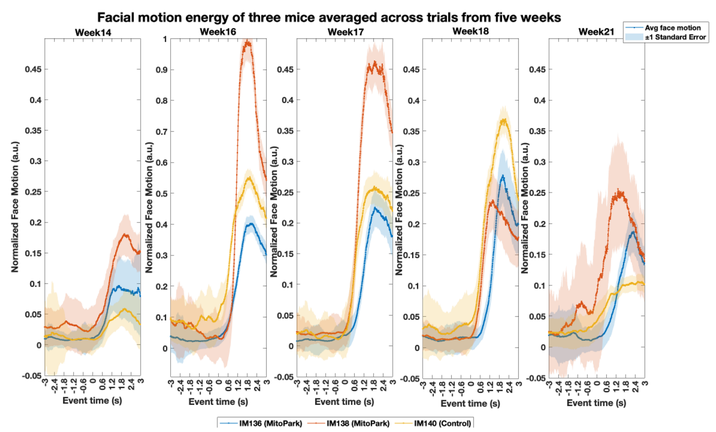


Figure 4: Motion energy averaged across success reaching trials around ±3 seconds when reward presents. Both IM136 (MitoPark) and IM140 (Control) demonstrate consistent motion energy pattern, especially before the presence of reward (baseline), as opposed to the high variability shown in IM138 (MitoPark).

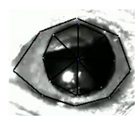


Figure 5: Example DeepLabCut labeling of key points on the pupil and eyelid to estimate pupil diameter and detect blinking from behavioral videos.

Summary

- The reaching performance of MitoPark mice decreases as they age compare to the control mouse.
- The facial motion energy of all mice increases after the reward is present during success trials, indicating increased facial movement.
- Though no clear trends identified as the MitoPark mice age, IM138 shows progressively more noisy motion traces as oppose to the other two and decreased face control during baseline period.
- Facial motion energy traces can serve as an useful indicator for movement intensity and behavioral pattern.

Next Steps

- Continue recording reaching behaviors from these mice to observe late-stage PD developement and analyze data from more mice.
- Finish tracking pupil and nose position using pose estimation tool DeepLabCut.
- Statistical correlation test between behavioral variables: e.g., how does changes in face motion related to pupil diameter fluctuation.
- Incorporate Dimensionality Reduction methods such as PCA, t-SNE, UMAP, or k-means clustering on motion energy traces and keypoint position of the nose to identify behavioral patterns (e.g., sniffing, grooming) and subtle motor changes throughout PD development.

REFERENCES

[1] Bologna, M., Fabbrini, G., Marsili, L., Defazio, G., Thompson, P. D., & Berardelli, A. (2012). Facial bradykinesia. Journal of Neurology, Neurosurgery & Psychiatry.
[2] Ekstrand, M. I., & Galter, D. (2009). The MitoPark Mouse–An animal model of Parkinson's disease with impaired respiratory chain function in dopamine neurons. Parkinsonism & related disorders, 15, S185-S188.
[3] Mathis, A., Mamidanna, P., Cury, K. M., Abe, T., Murthy, V. N., Mathis, M. W., & Bethge, M. (2018). DeepLabCut: markerless pose estimation of user-defined body parts with deep learning. Nature neuroscience, 21(9), 1281-1289.
[4] Stringer, C., Pachitariu, M., Steinmetz, N., Reddy, C. B., Carandini, M., & Harris, K. D. (2019). Spontaneous behaviors drive multidimensional, brainwide activity. Science, 364(6437), eaav7893.
[5] Vincis, Roberto, et al. "Dynamic representation of taste-related decisions in the gustatory insular cortex of mice." *Current Biology* 30.10 (2020): 1834-1844.

ACKNOWLEDGEMENTS

Thanks to Dr. Dieter Jaeger for his mentoring and support for this project, Indeara Martinez, and Dr. Li Su for helping with behavioral training and setup, Dr. Yunmiao Wang, Lisa Meyer-Baese, and Dr. Aurélie Pala for their suggestions on data analysis. Thanks to the generous support from the Emory SURE program, the Parkinson's Foundation PF-SSF-1298292 This work was funded by NINDS Udall Center Grant 1P50NS123103.