Investigating Neural Circuit Mechanisms of Generalization Using a Virtual Reality Paradigm

Johanna Overbeck, Liam Kerner, Shin Kira

Florida State University, Programs in Neuroscience

Abstract

The ability to use past experiences to guide behavior in new situations, known as generalization, is a fundamental brain function, guiding decision-making and adaptation to changing environments. Understanding these neural mechanisms can help support the development of treatments for neurological and psychiatric conditions where generalization is often impaired and improve the flexibility of artificial intelligence systems. To study these processes, a virtual reality (VR) navigation paradigm was developed to examine navigation based decision-making processes and the underlying neural activity while in the virtual environment. Movement on the system is tracked by optical sensors and translated into real-time displacement within the VR environment where mice perform behavioral tasks. Further studies will also incorporate two-photon microscopy to measure neuronal activity during behavioral tasks, investigating how neural circuits support generalization across changing environments.

Background Information

- Decision-making research demonstrates that neural circuits accumulate and integrate information to guide behavior [1,4]
- Flexible Behavior depends on the ability to generalize learned knowledge across contexts [7]
- Neural representations become increasingly structured with experience, supporting generalization [2]
- Category learning in mice demonstrate that neural representations evolve with experience to encode both perceptual and semantic features, supporting generalization [2]
- Population dynamics provide a framework for understanding how neural circuits support flexible cognition [5]
- Virtual navigation offers a controlled platform to study these processes during learning [3]

Figure 1: Rendering of VR rig

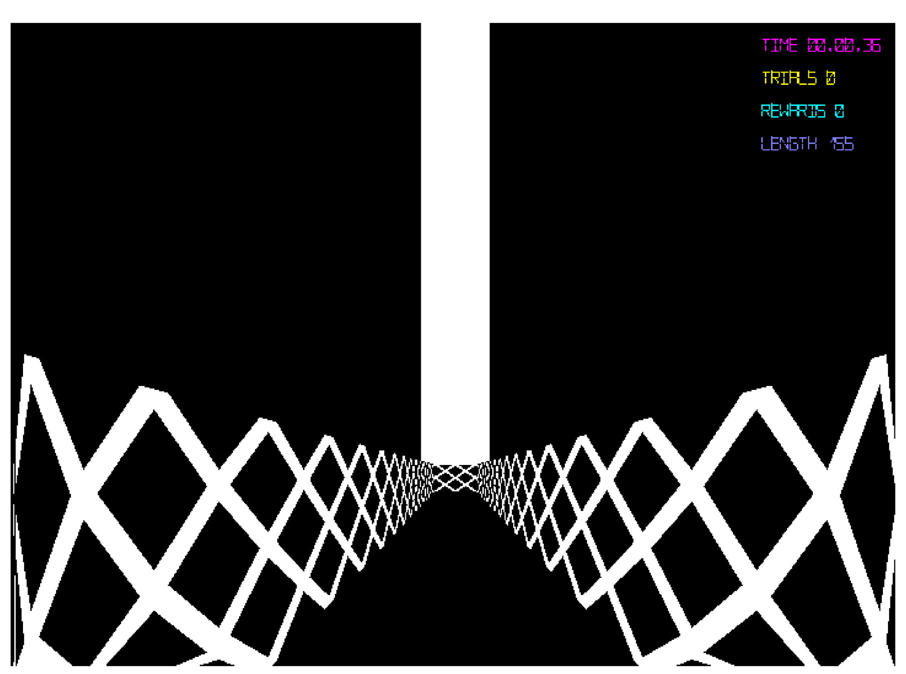

Figure 2: Linear Track environment

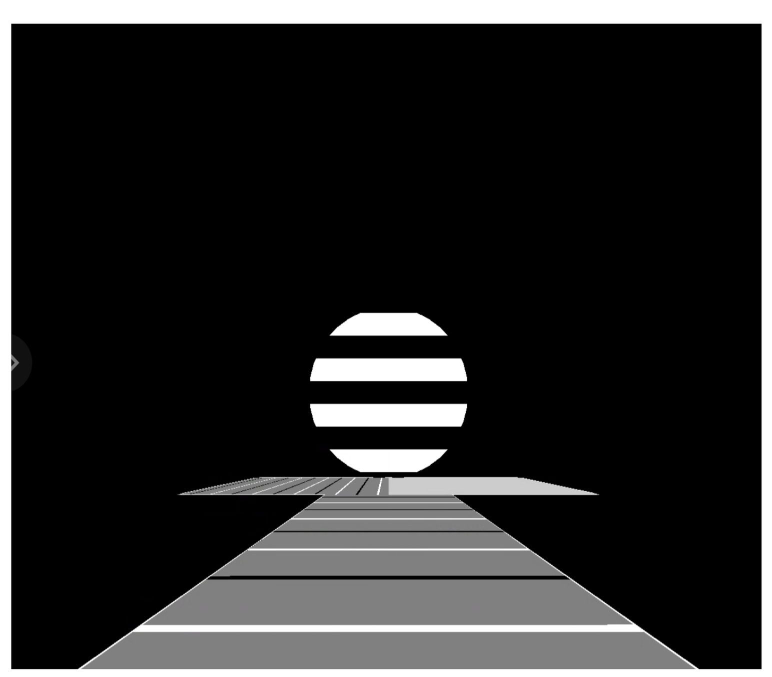

Figure 3: T-Maze environment.

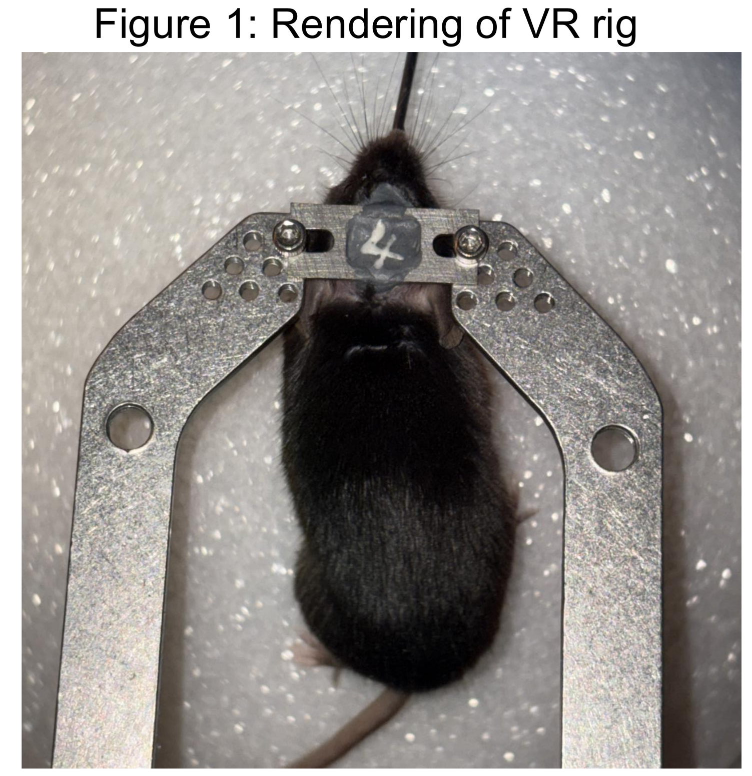

Figure 4: Mouse headplate fixation

Methodology

- Wildtype mice as animal model
- Water restriction to maintain motivation for reward-based tasks
- Reverse light cycle
- Surgery for headplates
- Head-fixed mice positioned on foam ball
- Virtual environment presented on screen
- Mice trained to navigate VR environments to obtain reward
- 1.5 mM Ace-K water solution
- VR Rig tacked with optical sensors that measure velocity, direction of movement, angular rotation, distance travelled
- Linear Track threshold of 100 trials per 50 minutes consistently before moving to T-Maze

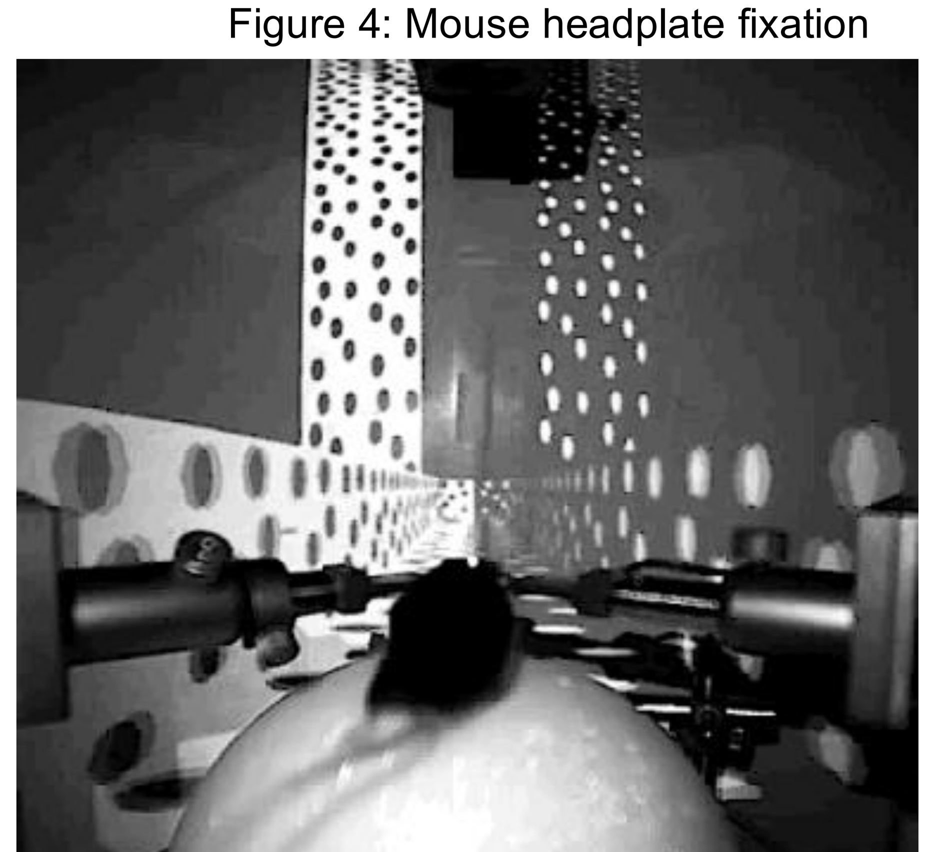

Figure 5: Virtual environment with mouse

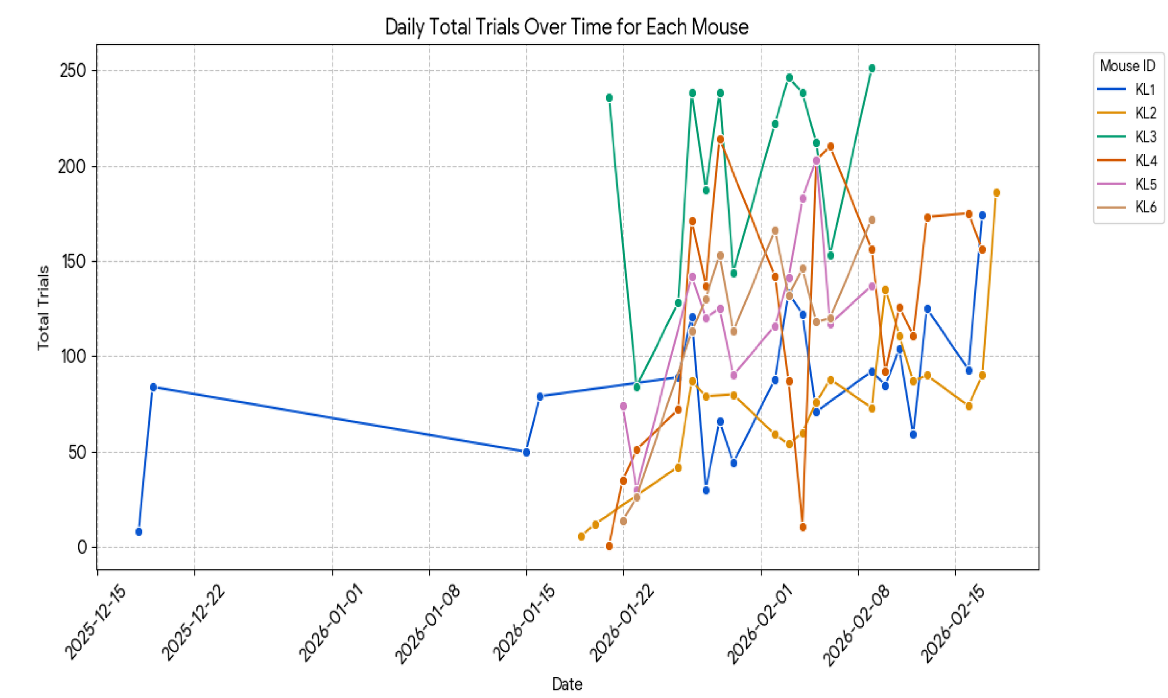

Figure 6: Total trials in Linear Track over time

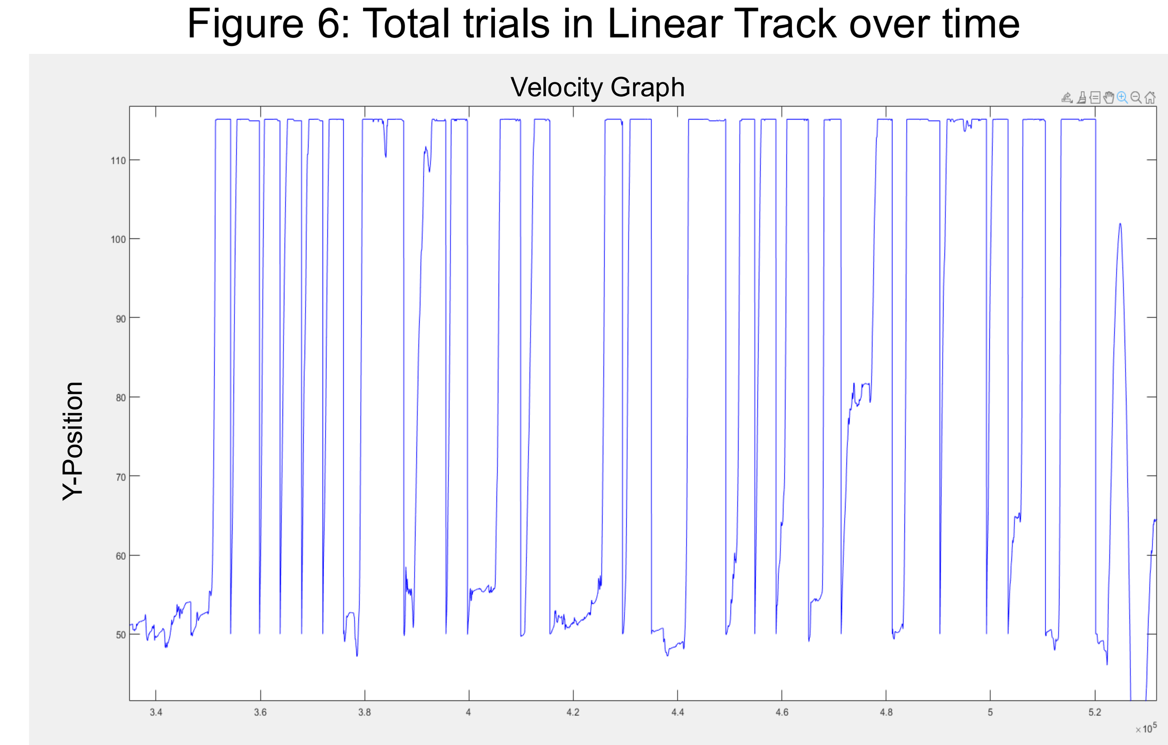

Figure 8: Position over time graph

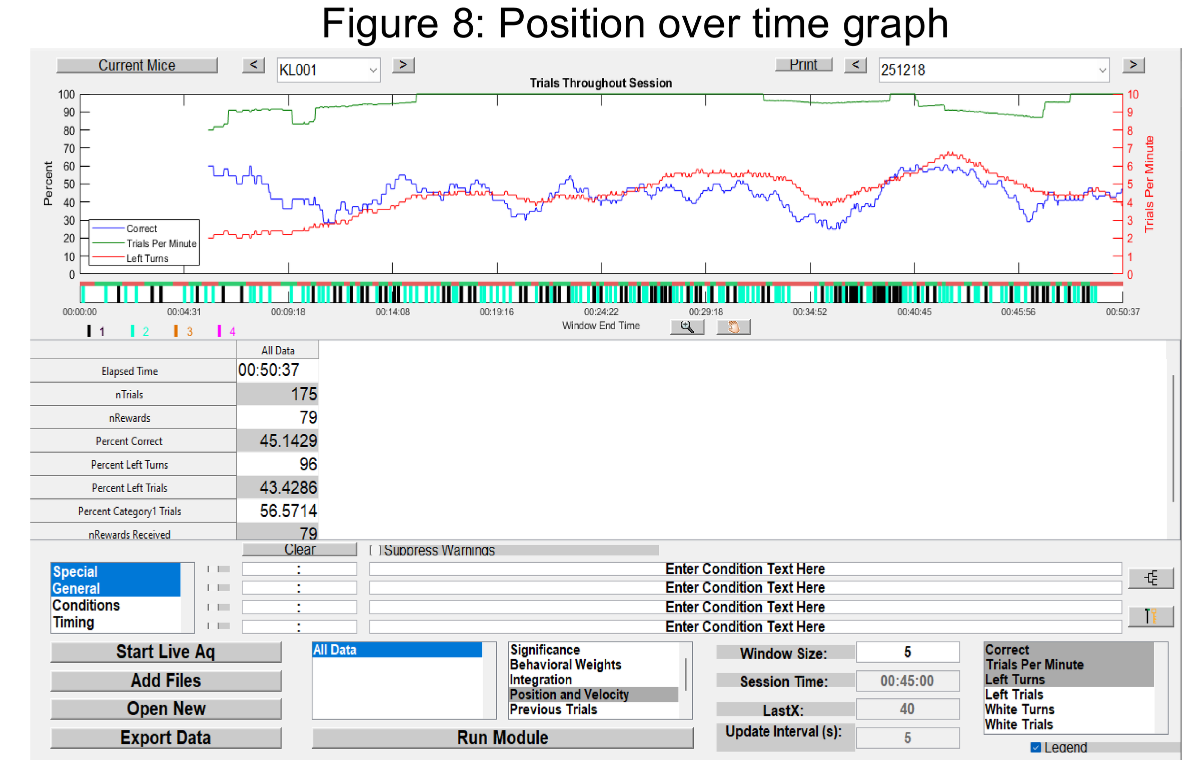

Figure 10: Behavior Acquisition Suite (BAS) interface

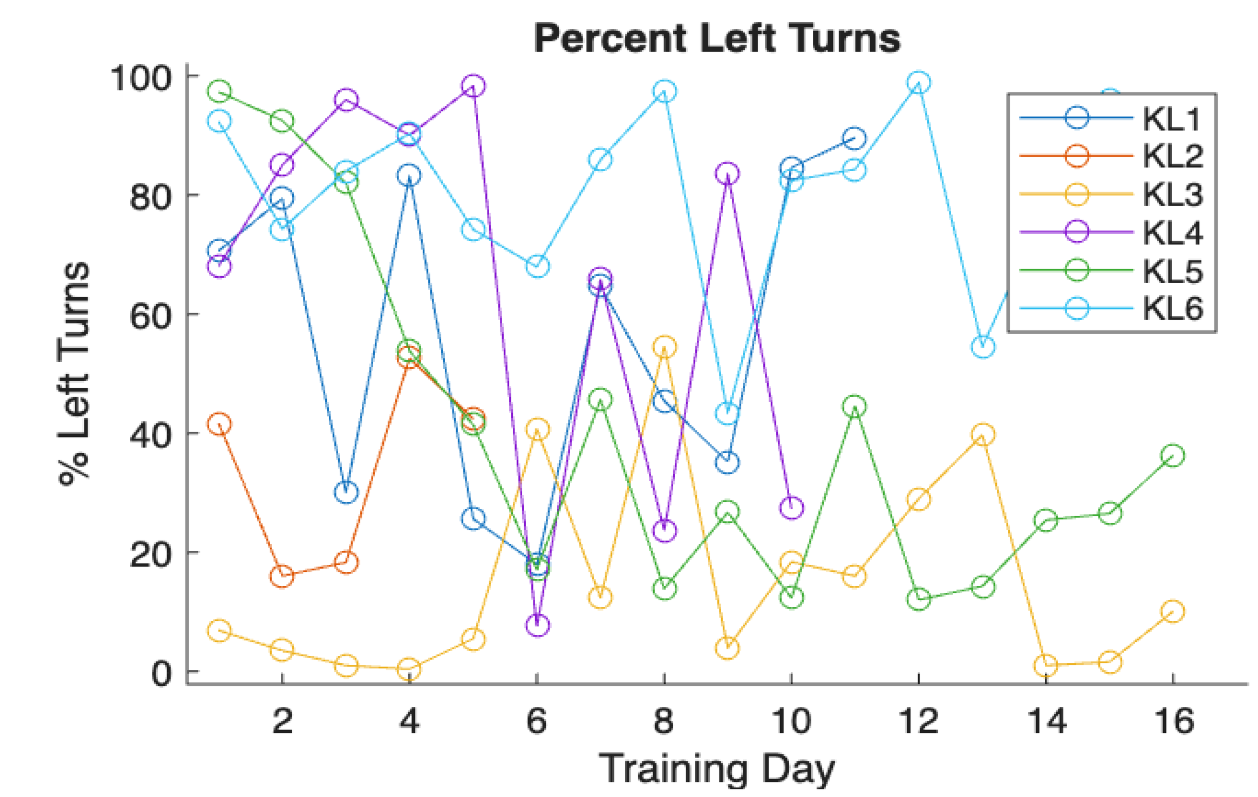

Figure 7: Left or right turn bias in T-Maze over time

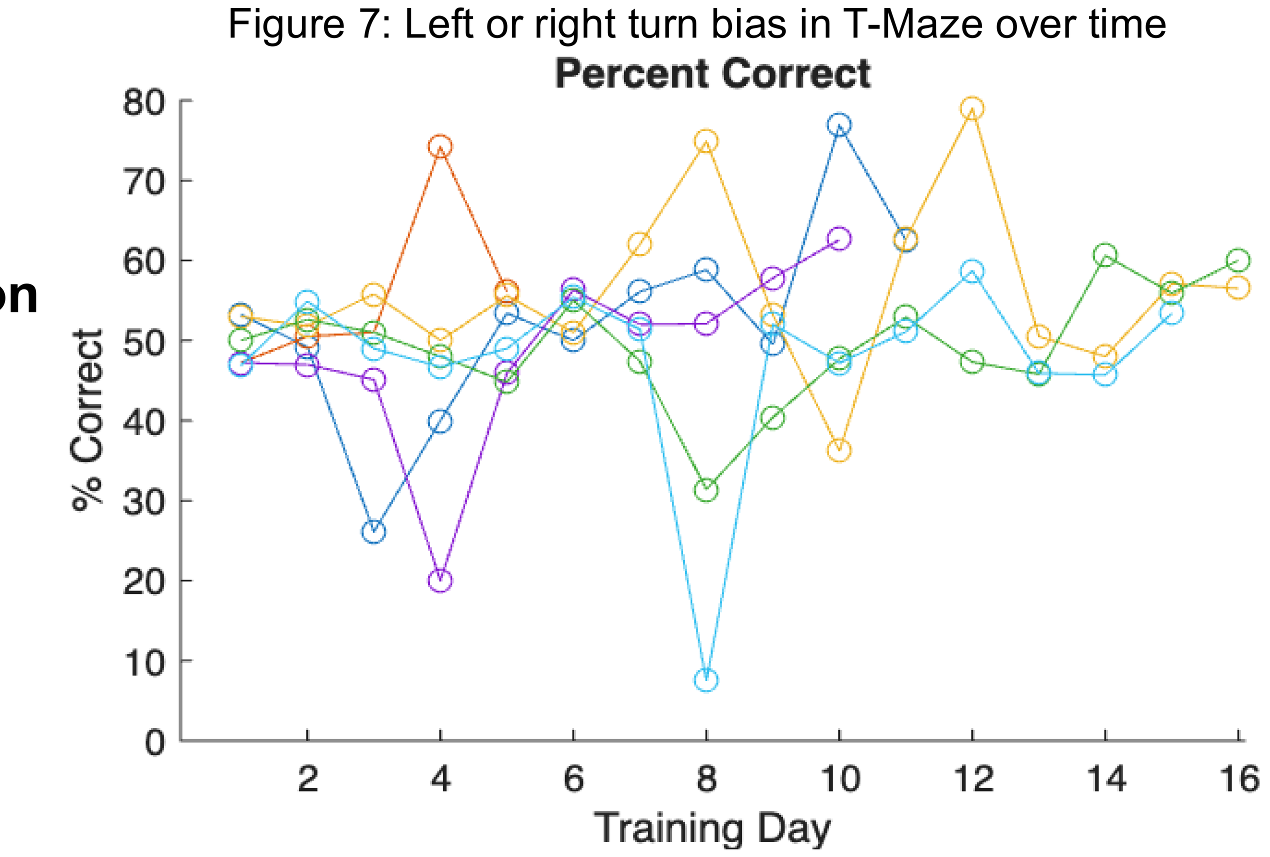

Figure 9: Percent correct turn in T-Maze over time

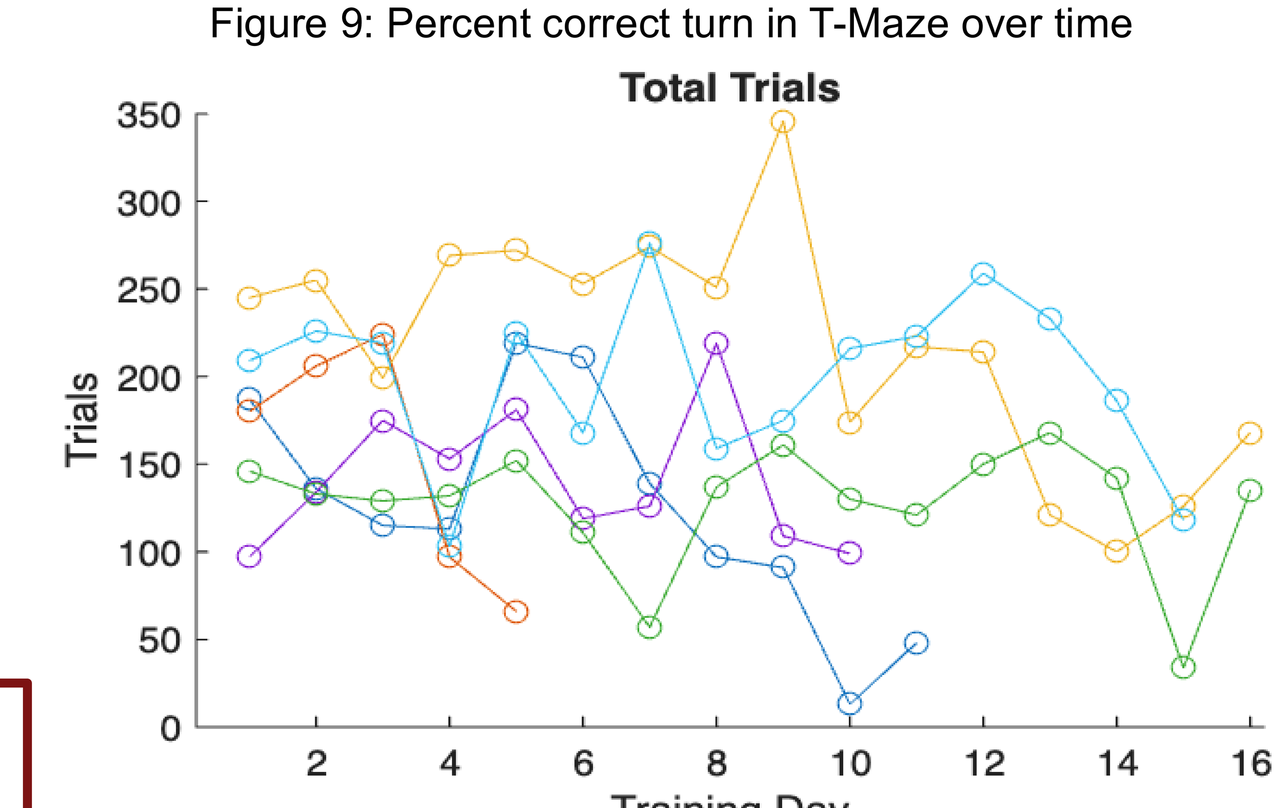

Figure 11: Total trials for each T-Maze training sessions

Discussion/Conclusion

- Figure 10 displays how mice behavior is tracked during and after tasks.
- Figure 8 exemplifies the data the optical sensor system can collect.
- Transitioning from the linear track to the T-Maze produced a marked decrease in performance.
- As Figure 9 shows after transitioning to T-Maze, mice developed strong turn biases, suggesting difficulty adapting to the new task.
- One possible explanation for the poor performance is the large visual and structural difference between the linear track and the T-maze environment.
- Future training will introduce a new linear track with greater similarity to the T-Maze, allowing mice to gradually generalize learned navigation strategies.
- Once mice are performing with high accuracy on behavioral takes, two-photon microscopy will be utilized to measure neuronal activity during tasks.

References