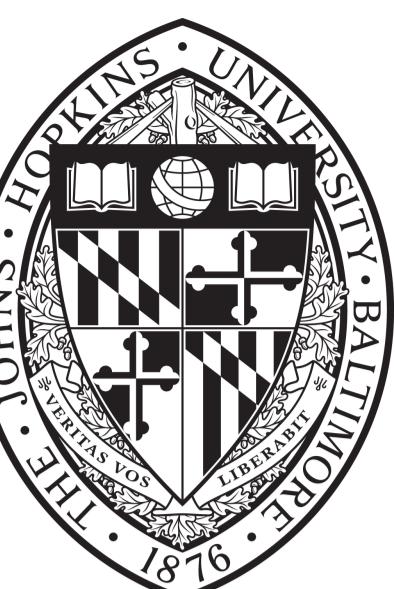


Effect of reward and effort on the opportunity cost of time and movement vigor



Shruthi Sukumar^{1*}, Reza Shadmehr⁴, Alaa A. Ahmed^{2,3}

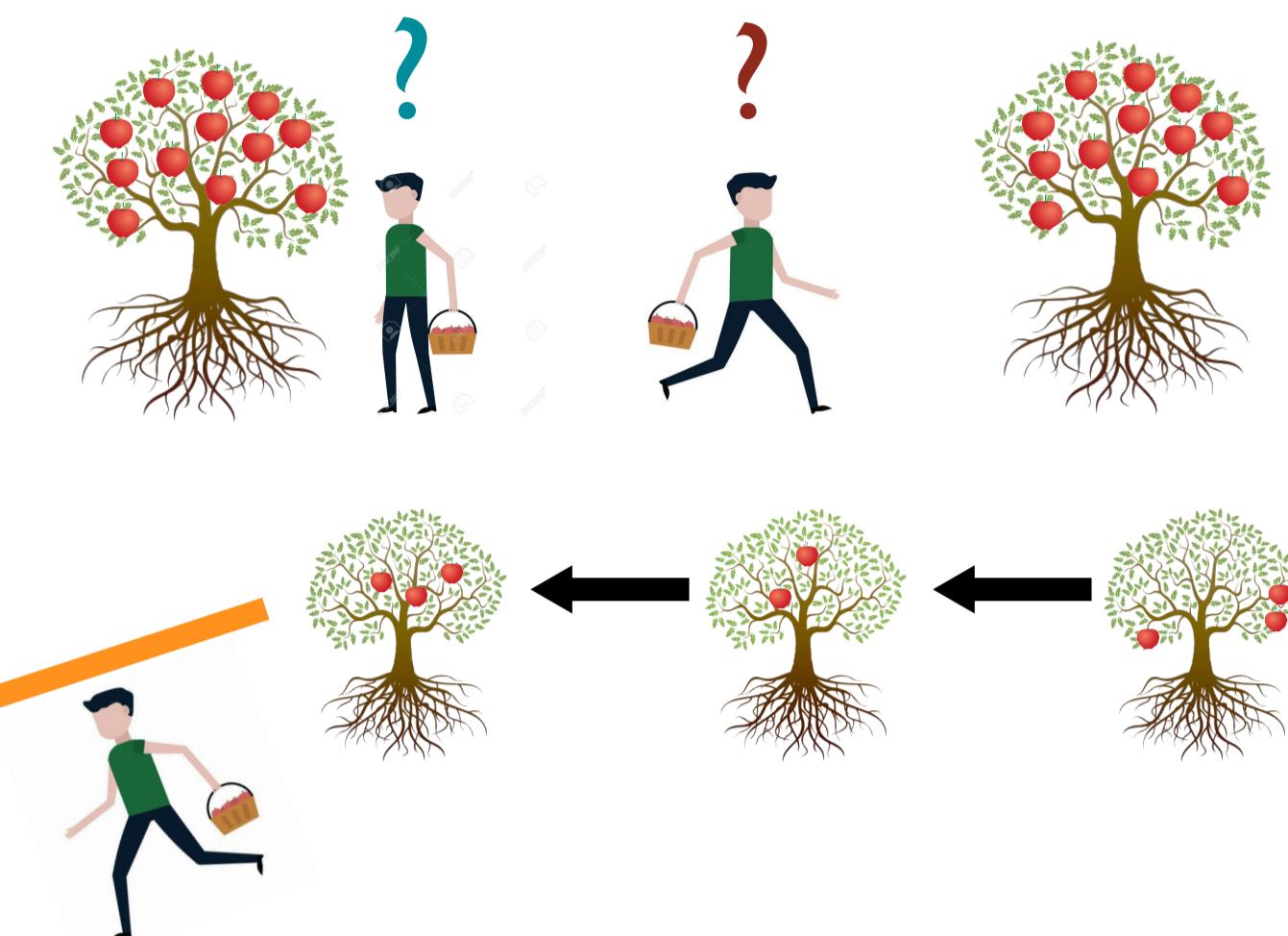
Department of Computer Science¹, Department of Mechanical Engineering², Department of Integrative Physiology³, University of Colorado at Boulder, U.S.A.

Department of Biomedical Engineering⁴, Johns Hopkins School of Medicine, U.S.A.

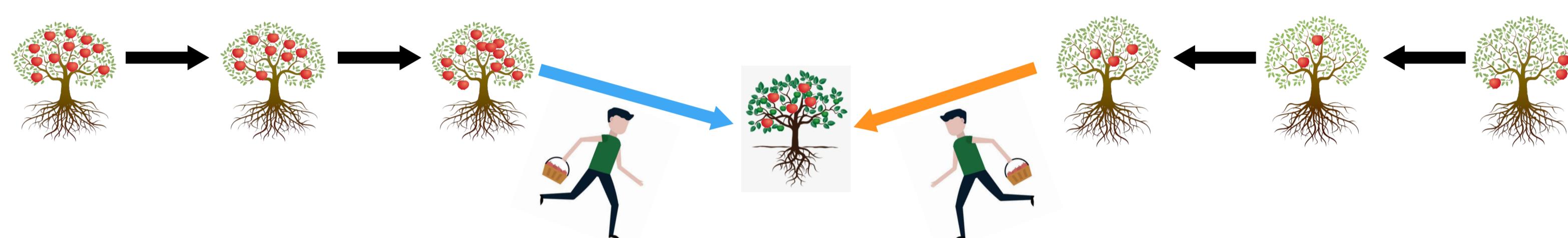
*Contact: shruthi.sukumar@colorado.edu

I. Introduction and Theory

When you're picking apples in an orchard,



- How long should you spend at one tree?
- How fast should you move to the next tree?



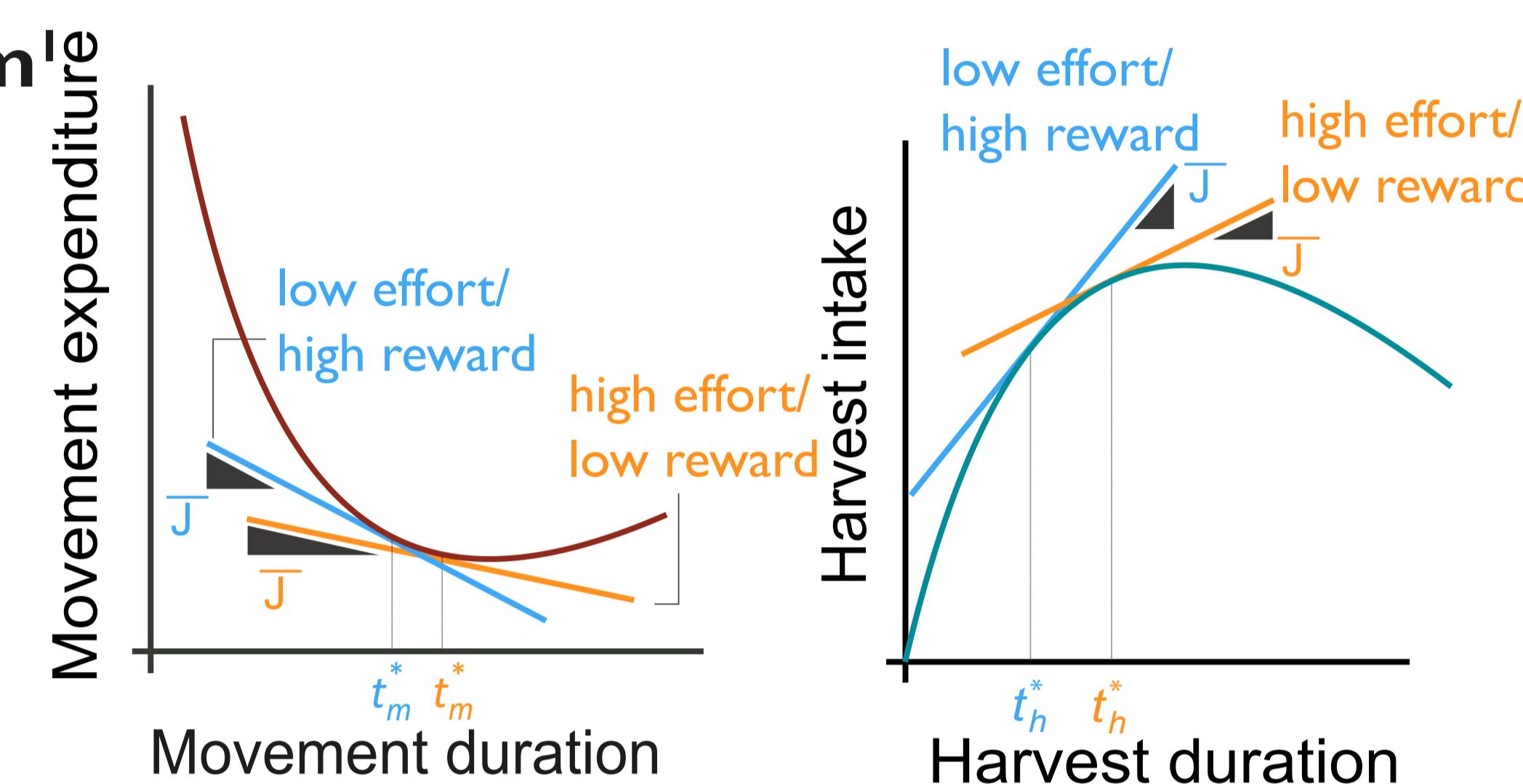
Does the history of apple trees change how fast you move to the next tree?

Marginal Value Theorem¹ and extension²:

Optimal harvest duration and movement duration, or vigor, are dependent on environment capture rate.

HYPOTHESES:

H1: After a history of (a) low reward or (b) high effort, **movement vigor decreases** for equivalent immediate outcomes.



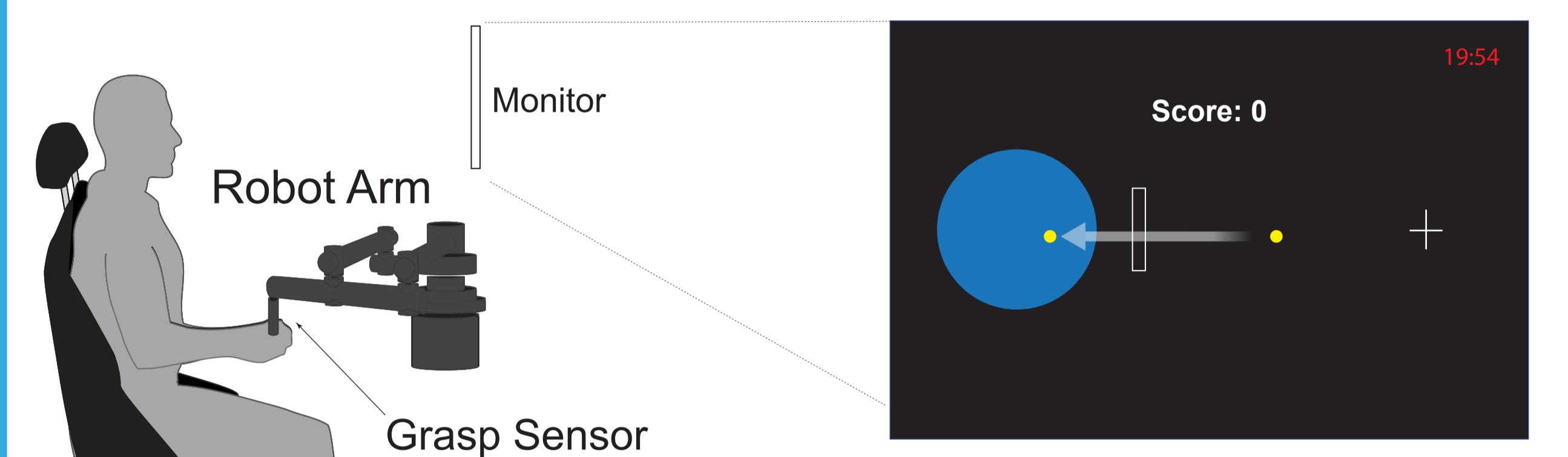
H2: After a history of (a) low reward or (b) high effort, **harvest duration increases** for equivalent immediate outcomes.

Durations of actions such as movement vigor is modulated by our internal state as determined by the history of reward and effort experienced.

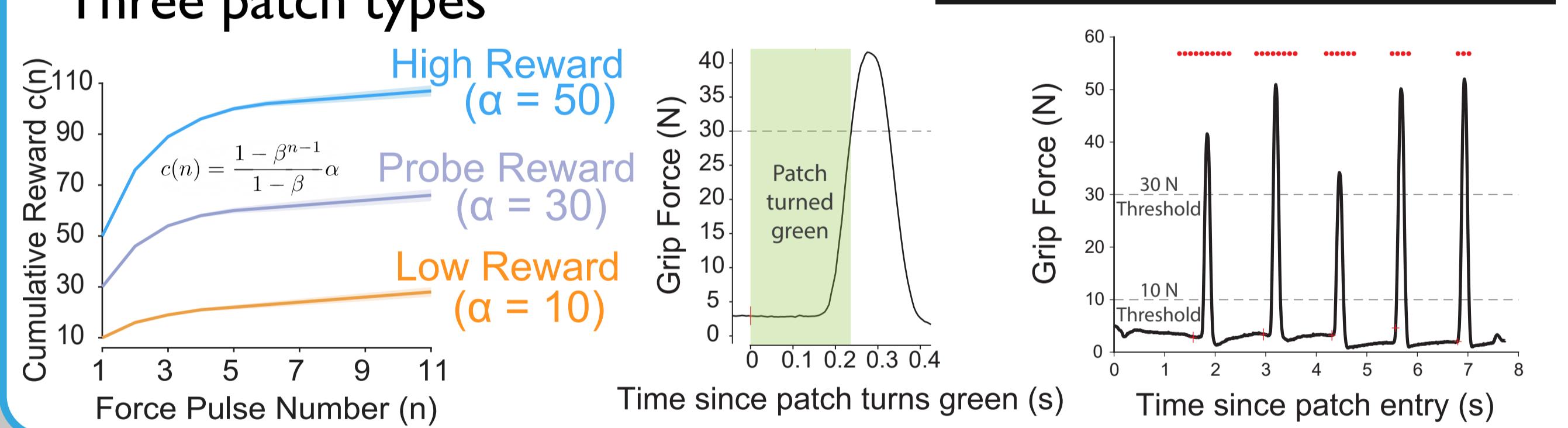
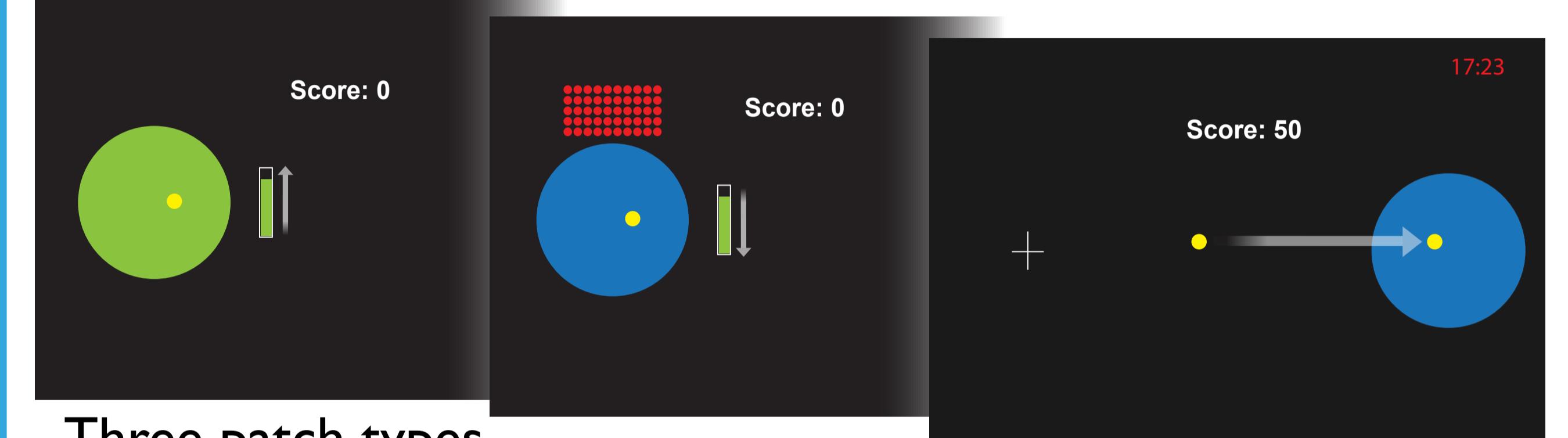
2. Emulating patch-foraging in a reaching protocol

Experiment 1: Changing history of reward

Subjects (n=14) performed a foraging experiment in two environments with changing reward amounts.



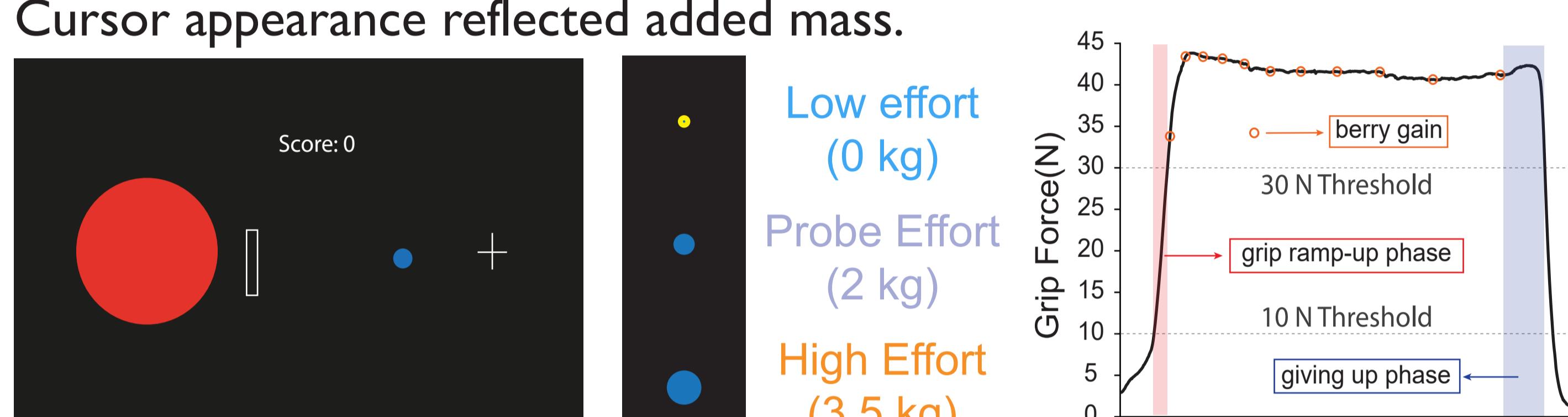
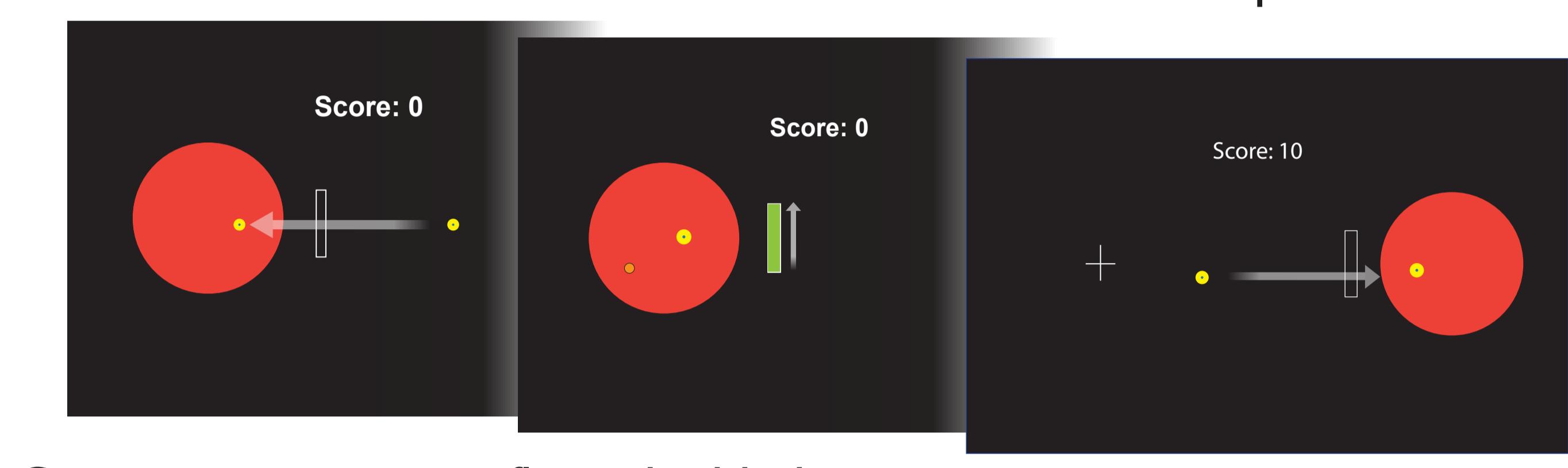
Once inside patch, subjects applied grip force pulses to collect berries. They choose when to move on to the next patch.



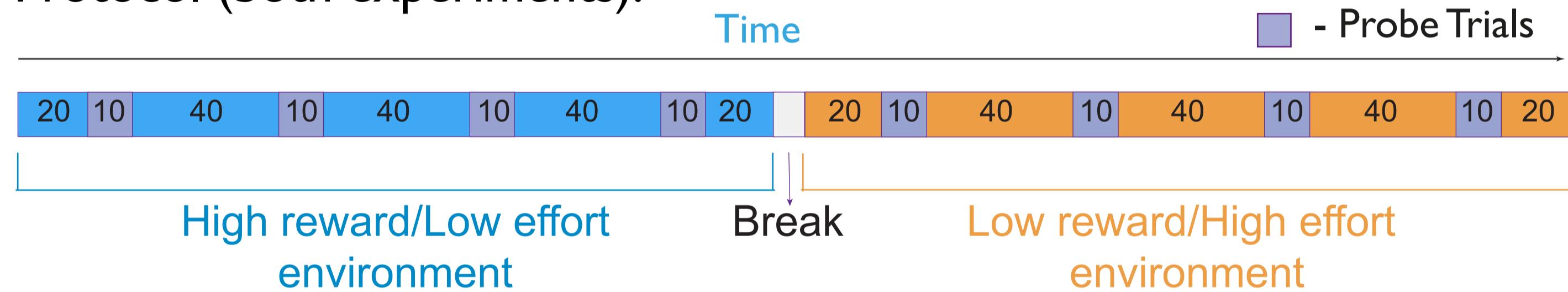
Experiment 2: Changing history of effort

Subjects (n=18) performed a foraging experiment in two environments with changing effort (added mass values)

Subjects harvested berries by increasing force and holding at 30 N. They choose when to reduce force and move on to the next patch.

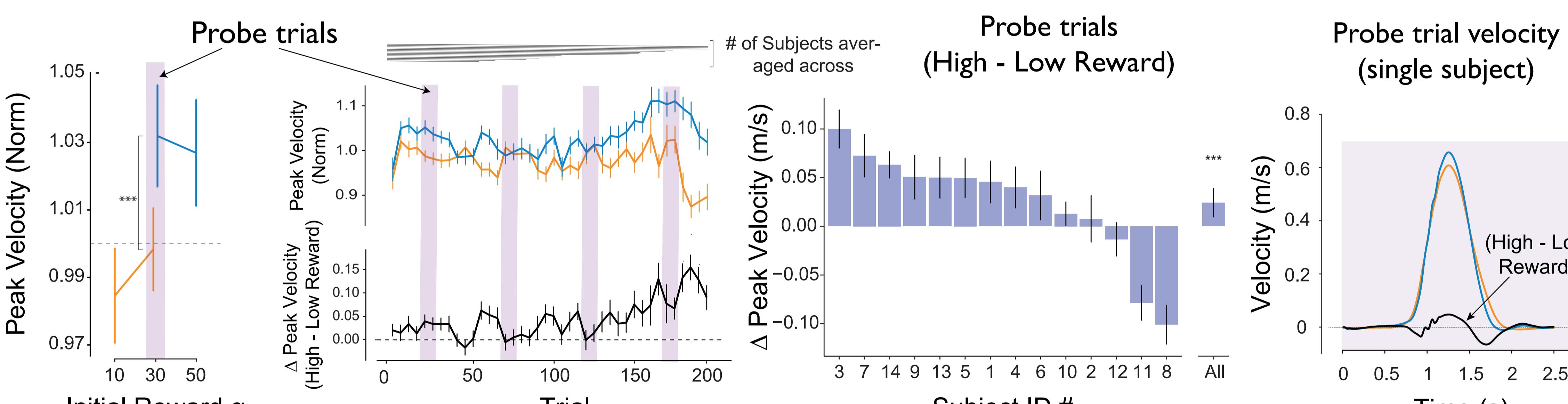


Protocol (both experiments):

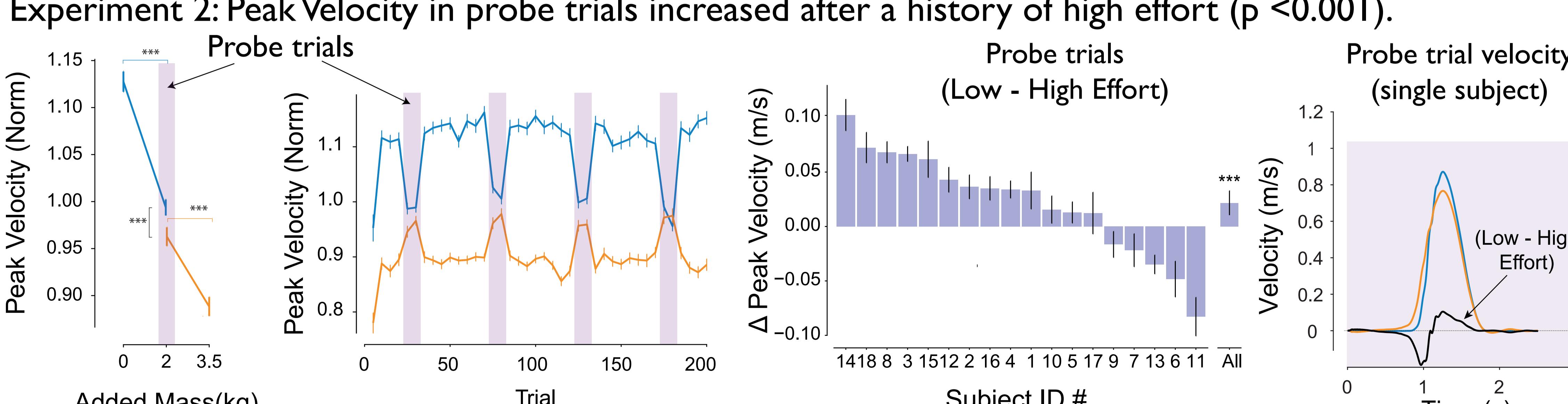


3. Movement vigor is modulated by reward and effort history (H1)

Experiment 1: Peak Velocity in probe trials increased after a history of low reward ($p < 0.001$).

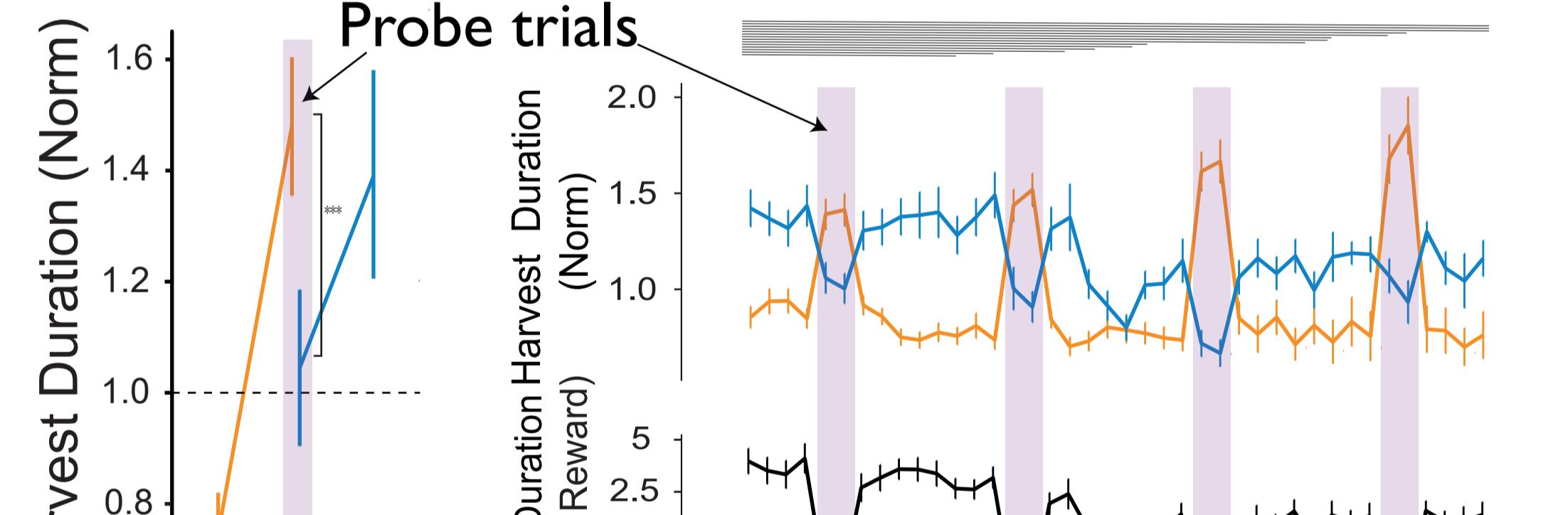


Experiment 2: Peak Velocity in probe trials increased after a history of high effort ($p < 0.001$).

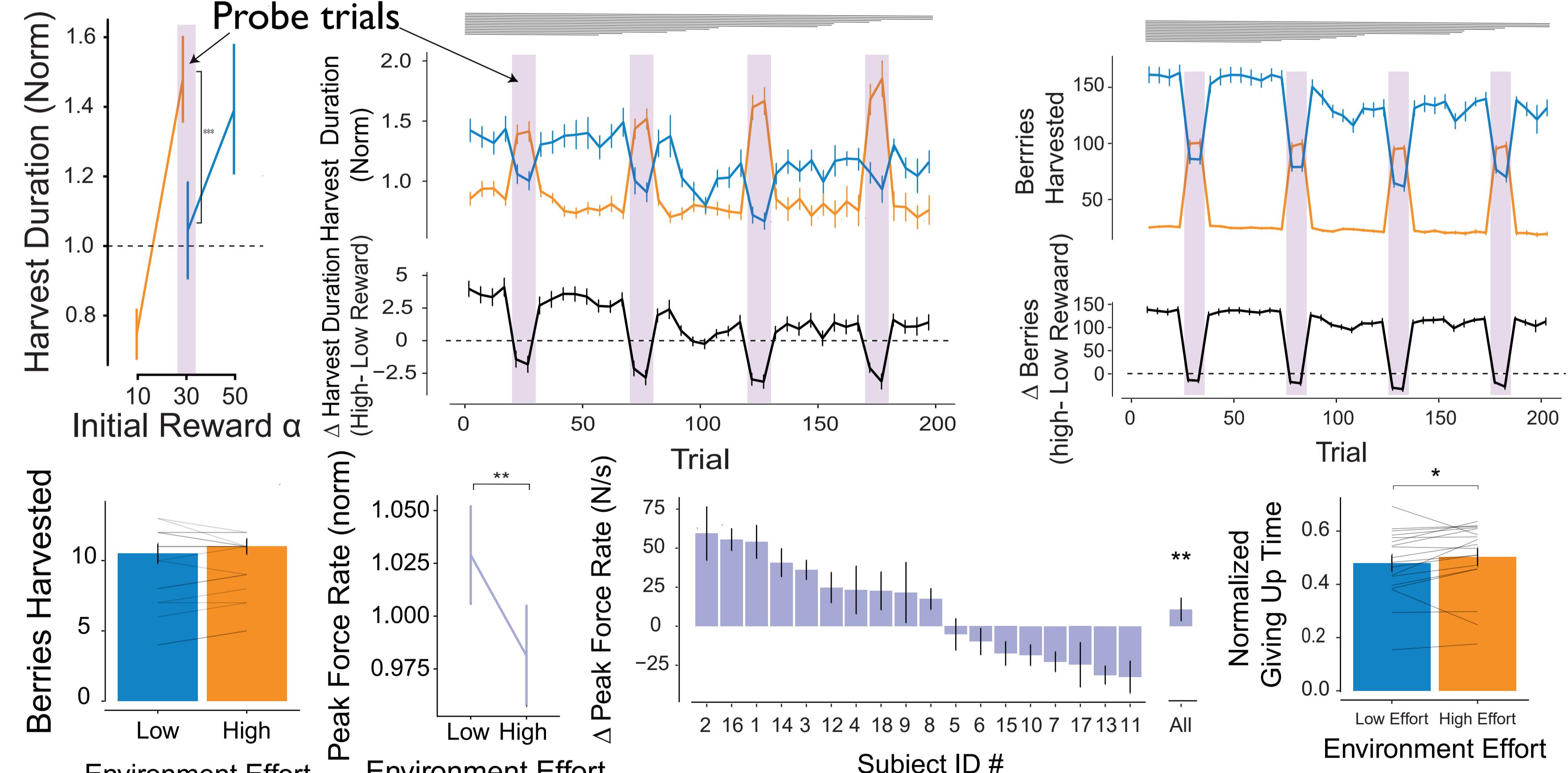


4. Harvest duration is modulated by reward and effort history (H2)

Experiment 1: Harvest duration and berry count increases after history of low reward.



Experiment 2: Subjects began harvesting faster and giving up on a patch sooner after a history of low effort.



5. Conclusions

1. Movement vigor increases after a history of high reward or low effort for equivalent immediate outcomes. **H1 ✓**

2. Harvest duration increases after history of low reward and harvest behavior are modulated by history of effort. **H2 ✓**

Movement vigor and decision-making are modulated by internal state as determined by the history of reward and effort.

References:

1. Charnov, E. L. (1976) in Theoretical Population Biology, 9, 129-136. E20476-E104

2. Yoon, T., et al (2018) in Proceedings of the National Academy of Sciences, 115(44),

Funding:

Supported by NIH grant (NINDS R01NS096083) and NSF grant (Award 1461535).