

March Madness: Behavioral, physiological, and neural effects of surprise during naturalistic sports viewing

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Agents use sophisticated event models to predict characteristics of their environments¹. As events unfold over time, agents implicitly and rapidly adjust their **predictions** based on these models, which can produce feelings of surprise².

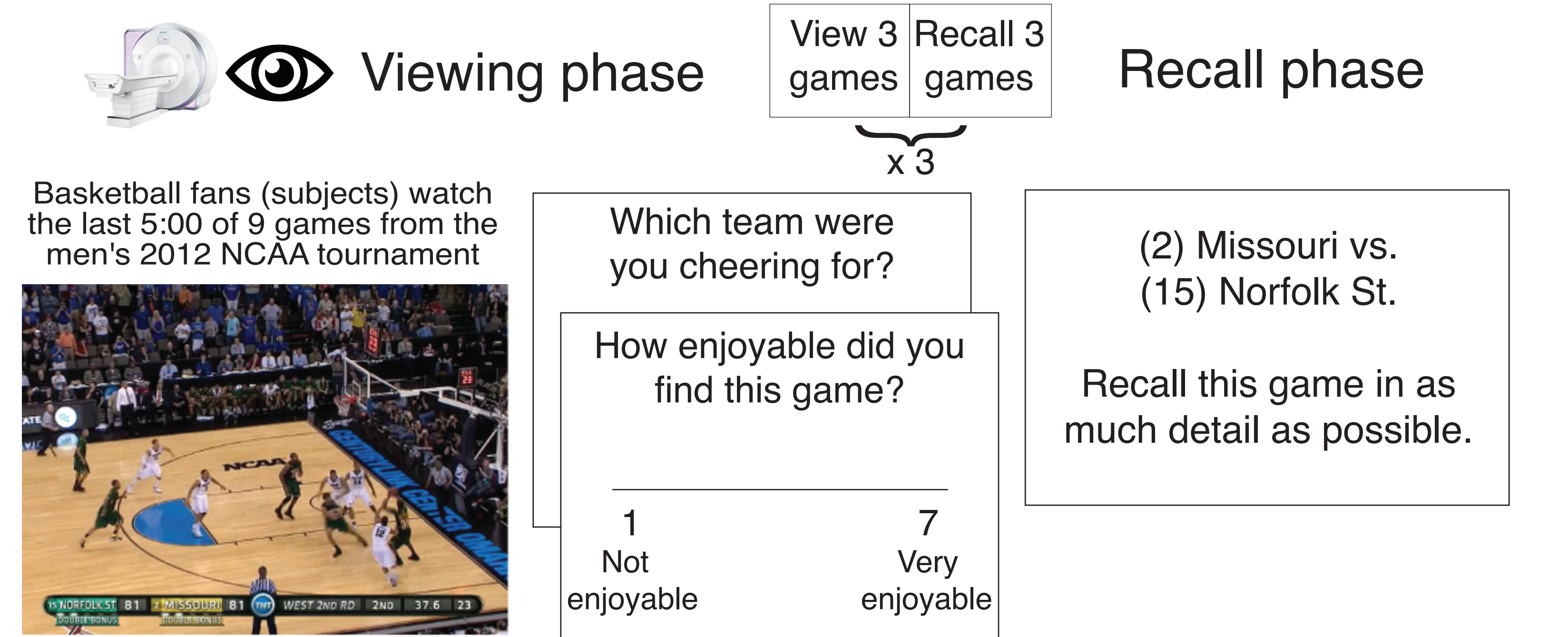
Surprise, or unsigned prediction error, tracks the difference between previous and current predictions²⁻⁵. According to Event Segmentation Theory (**EST**), surprise can drive the segmentation of ongoing experience into distinct events⁶⁻⁷. Surprise can also trigger learning that updates subsequent predictions about the structure of the world^{3,8}, and it can benefit memory for immediately preceding events⁴.

We used sports games to understand how surprise influences perceived event segmentation, memory, eye physiology, and neural activation patterns in humans.

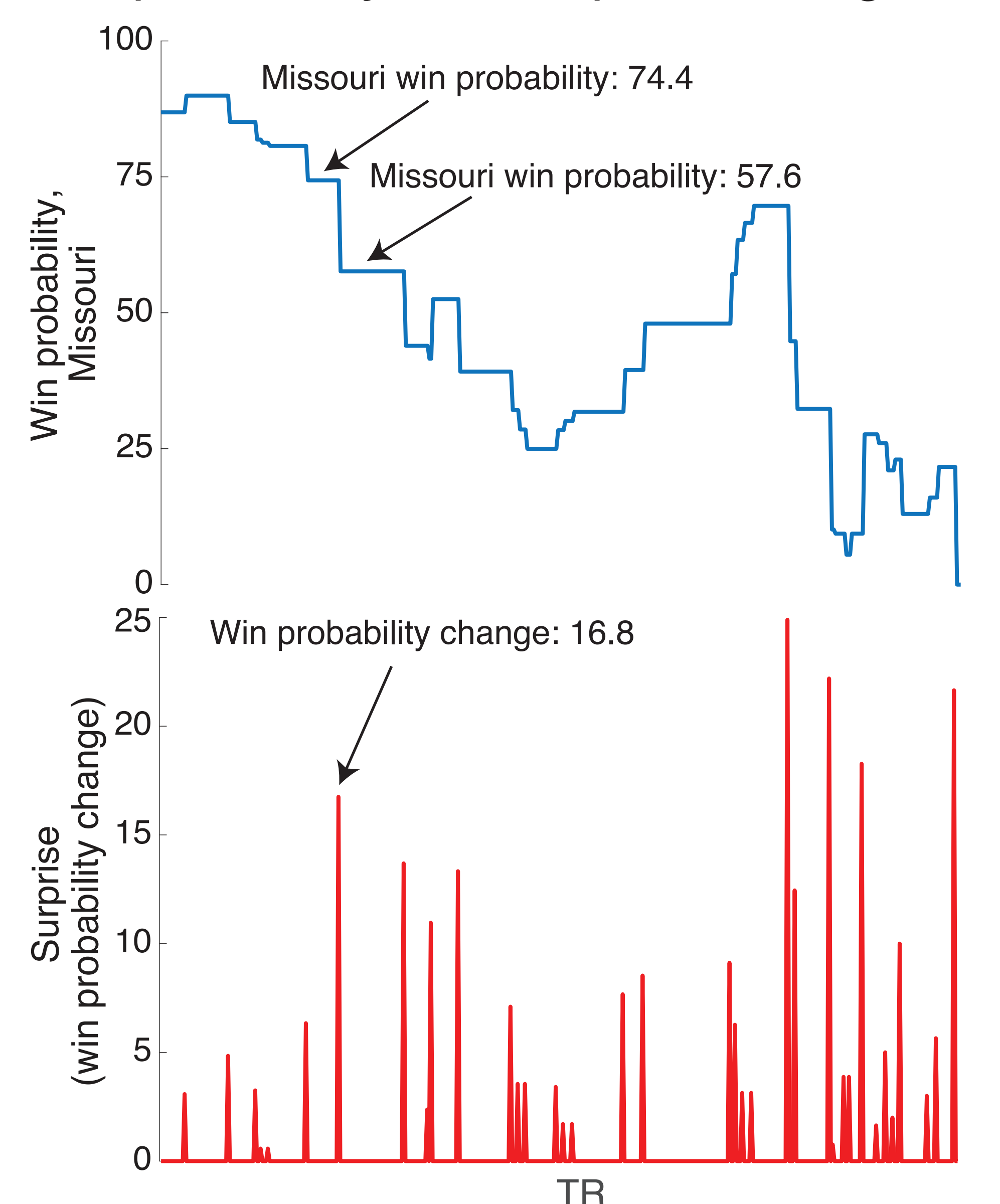
Operationalizations:

Predictions: "win probability" metrics from an expert basketball analyst (<https://kenpom.com/>) updated after each change in possession

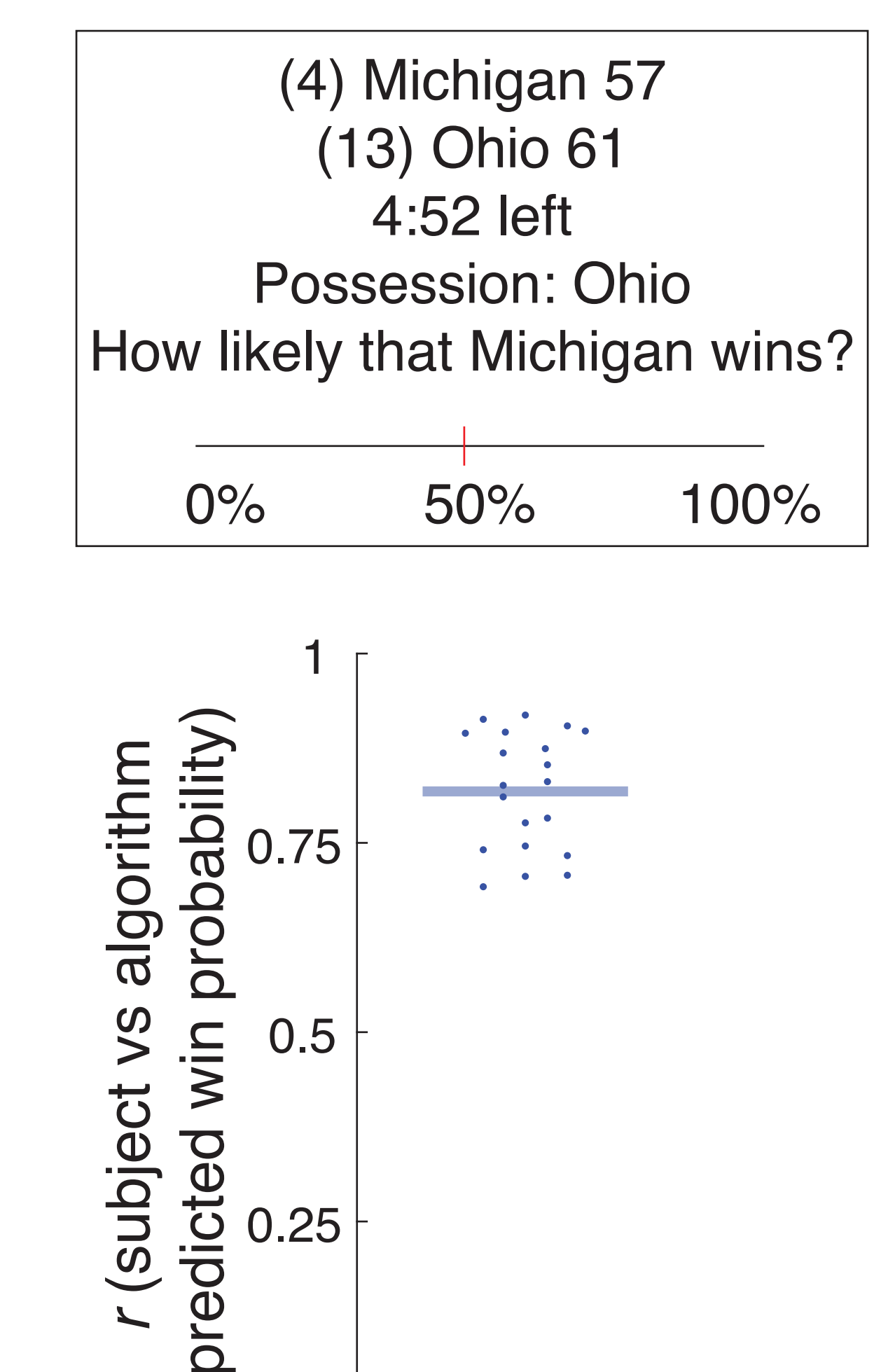
Surprise: absolute value of the derivative of the win probability time course. We also compute "signed" prediction error if the subject prefers which team wins.



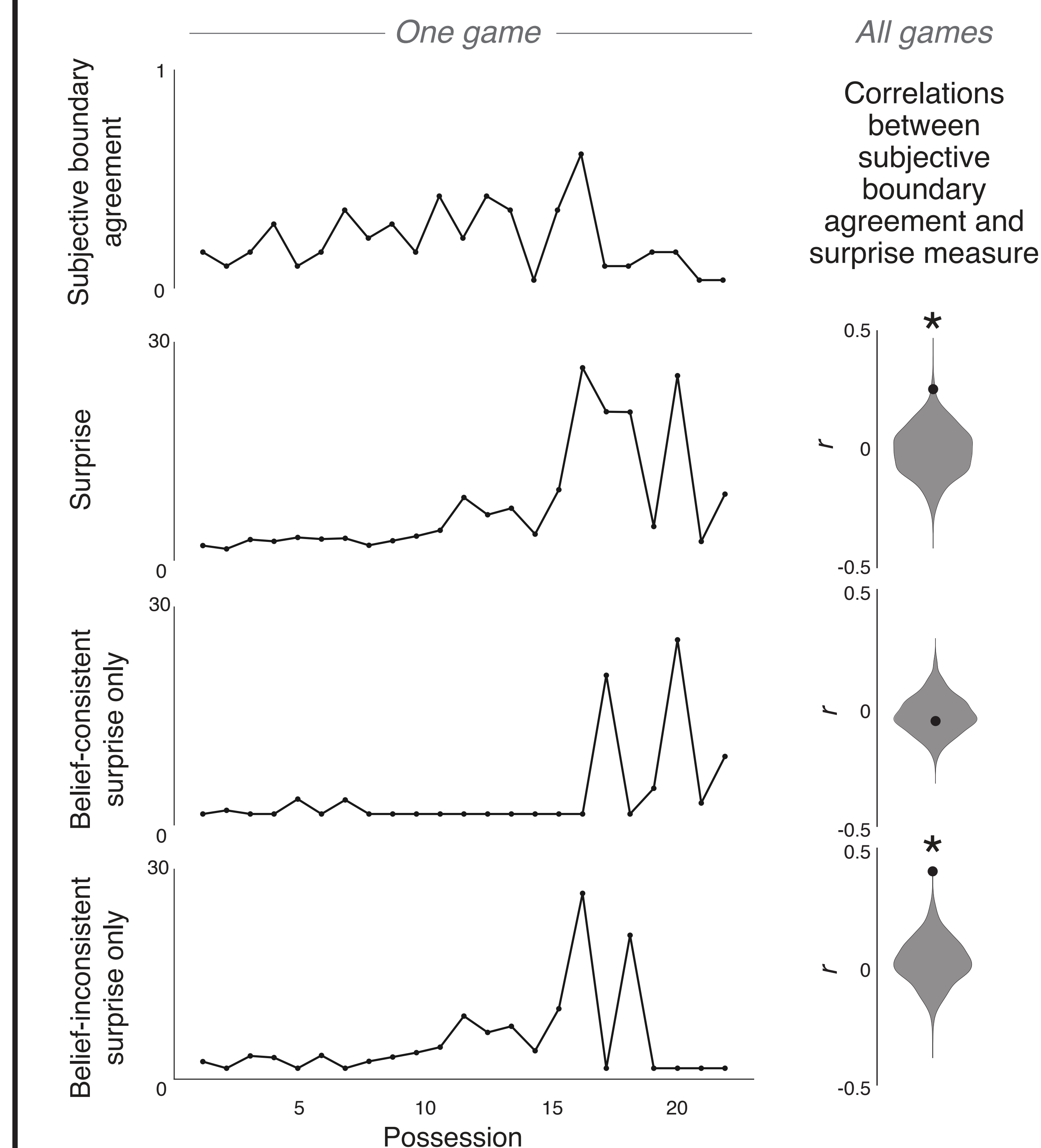
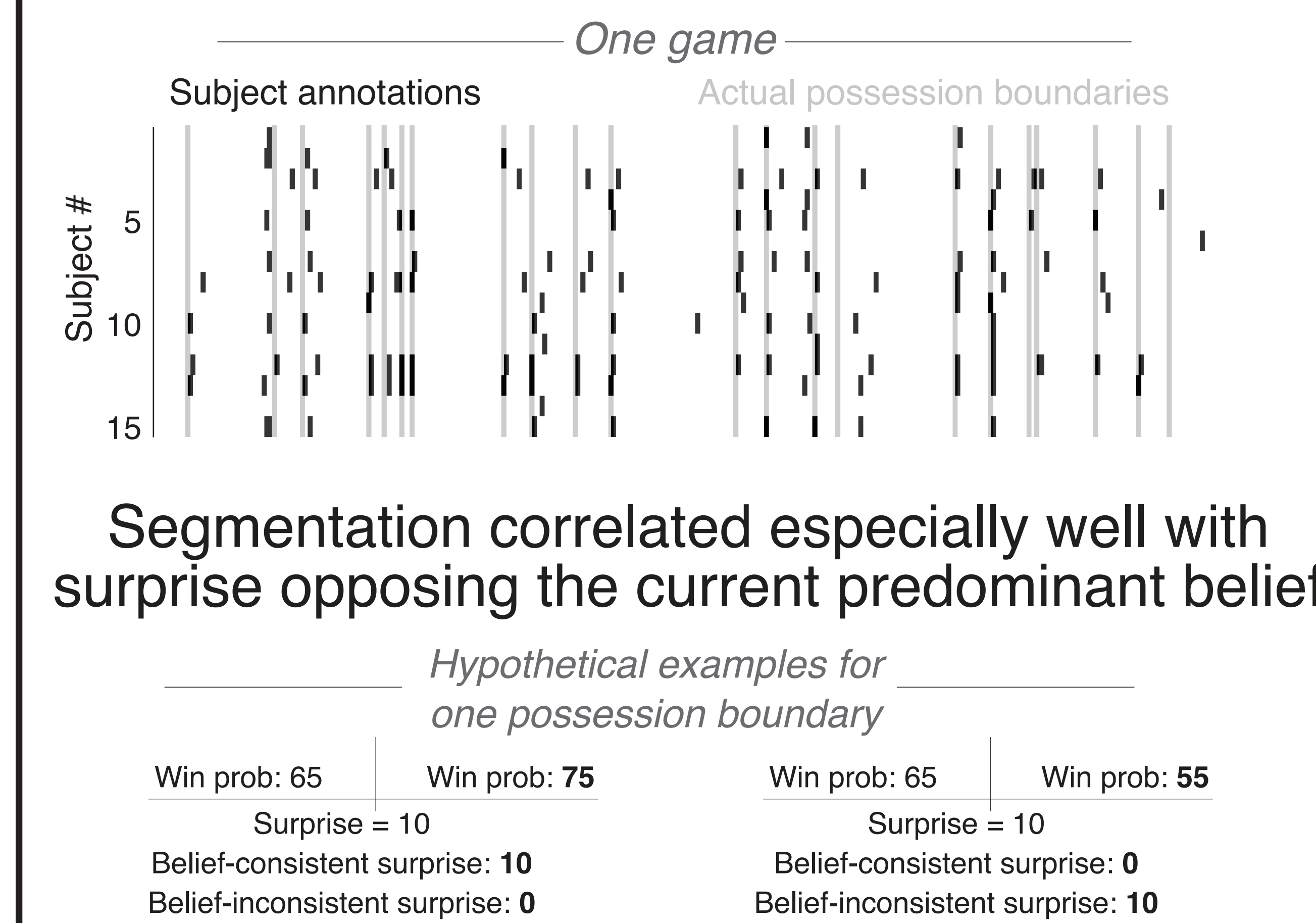
Win probability and surprise, one game



Subjects can accurately predict win probabilities



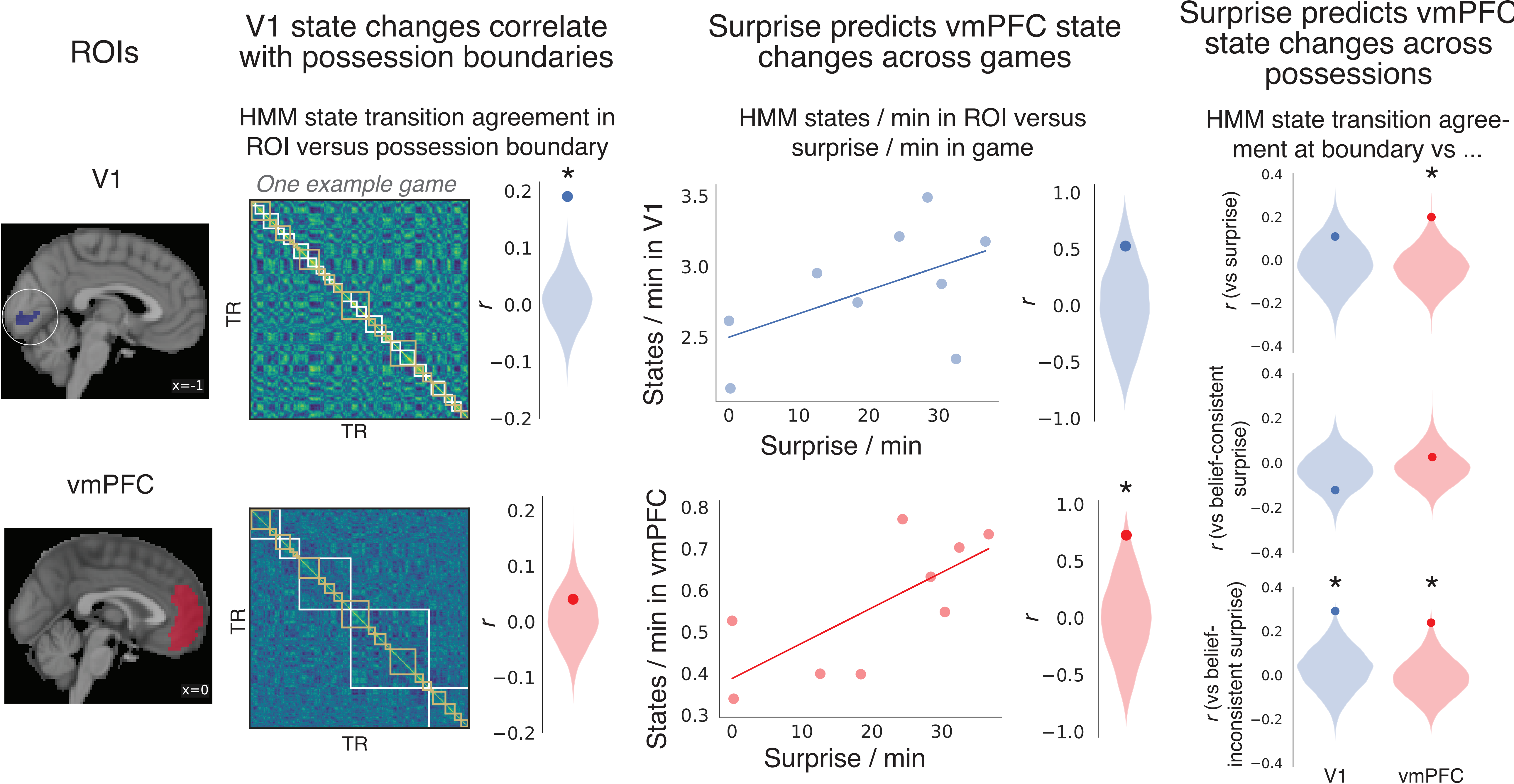
↑ Surprise, ↑ event segmentation



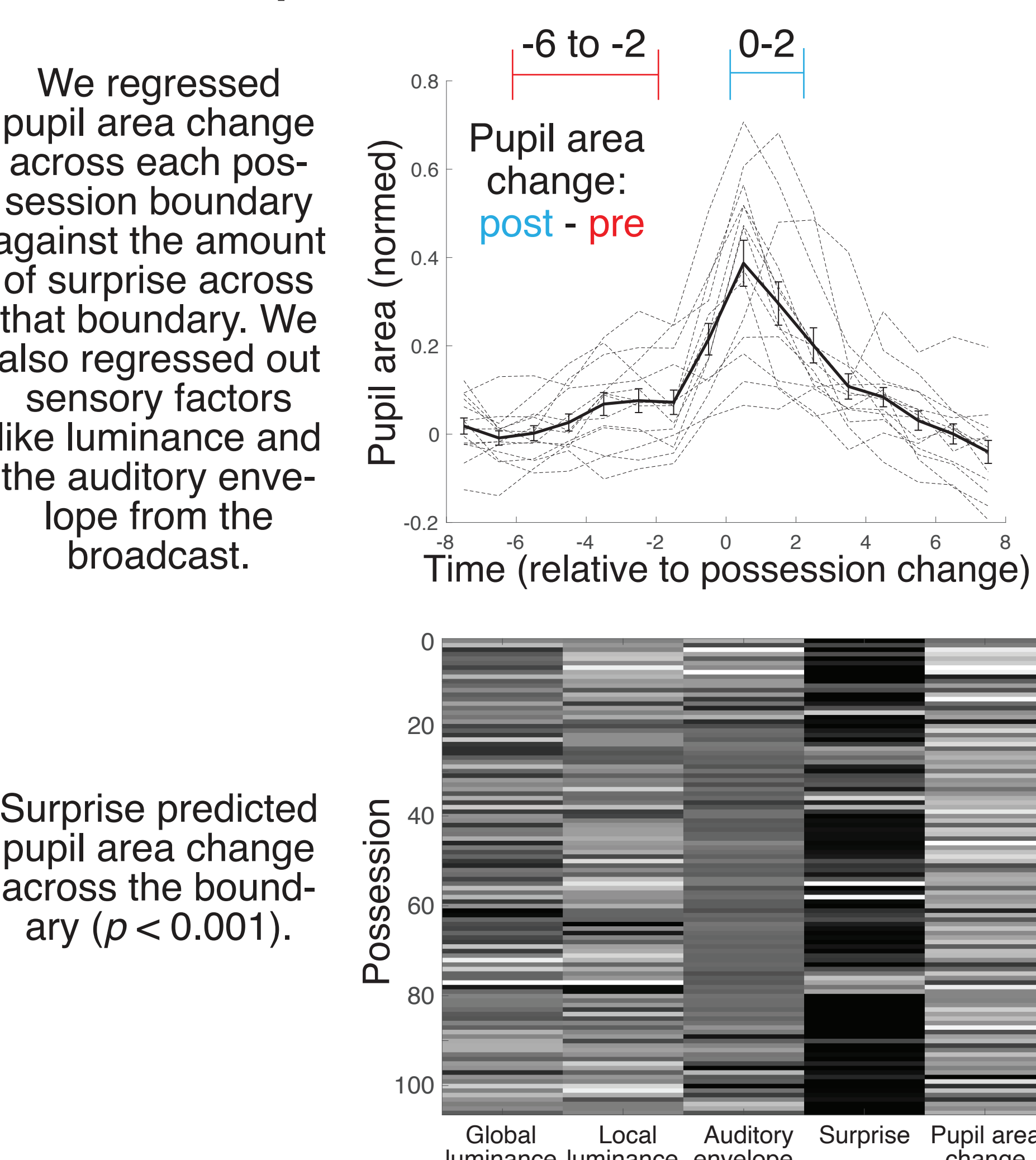
References • DuBrow, S., Rouhani, N., Niv, Y., & Norman, K. A. (2017). Does mental context drift or shift? *Current Opinion in Behavioral Sciences*, 17, 141–6. • Ely, J., Frankel, A., & Kamenica, E. (2015). Suspense and surprise. *Journal of Political Economy*, 123, 215–260. • O'Reilly, J. X., Schuffelgen, U., Cueli, S. F., Behrens, T. E. J., Mars, R. B., & Rushworth, M. F. S. (2013). Dissociable effects of surprise and model update in parietal and anterior cingulate cortex. *Proceedings of the National Academy of Sciences*, 110(38), E3660–9. • Rouhani, N., Norman, K. A., Niv, Y., & Bornstein, A. M. (2019). Reward prediction errors create event boundaries in memory. *bioRxiv*. • Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature*, 307, 161–163. • Franklin, N. T., Norman, K. A., Ranganath, C., Zacks, J. M., & Gershman, S. J. (2019). Structured event memory: a neuro-symbolic model of event cognition. *Psychological Review* 127(3), 327–361. • Zacks, J. M., Braver, T. S., Sheridan, M. A., Donaldson, D. I., Snyder, A. Z., Ollinger, J. M., ... Raichle, M. E. (2001). Human brain activity time-locked to perceptual event boundaries. *Nature Neuroscience*, 4(6), 651–655. • Sutton, R. S., & Barto, A. G. (1998). Introduction to reinforcement learning. (Vol 2, No. 4). Cambridge: MIT press. • Baldassano, C., Chen, J., Zadbood, A., Pillow, J. W., Hasson, U., & Norman, K. A. (2017). Discovering event structure in continuous narrative perception and memory. *Neuron*, 95(3), 709–721.e5. • Chang, L. J., Jolly, E., Cheong, J. H., Rapuano, K., Greenstein, N., Chen, P.-H. A., & Manning, J. R. (2018). Endogenous variation in ventromedial prefrontal cortex state dynamics during naturalistic viewing reflects affective experience. *bioRxiv*.

↑ Surprise, ↑ Hidden Markov Model (HMM) state changes

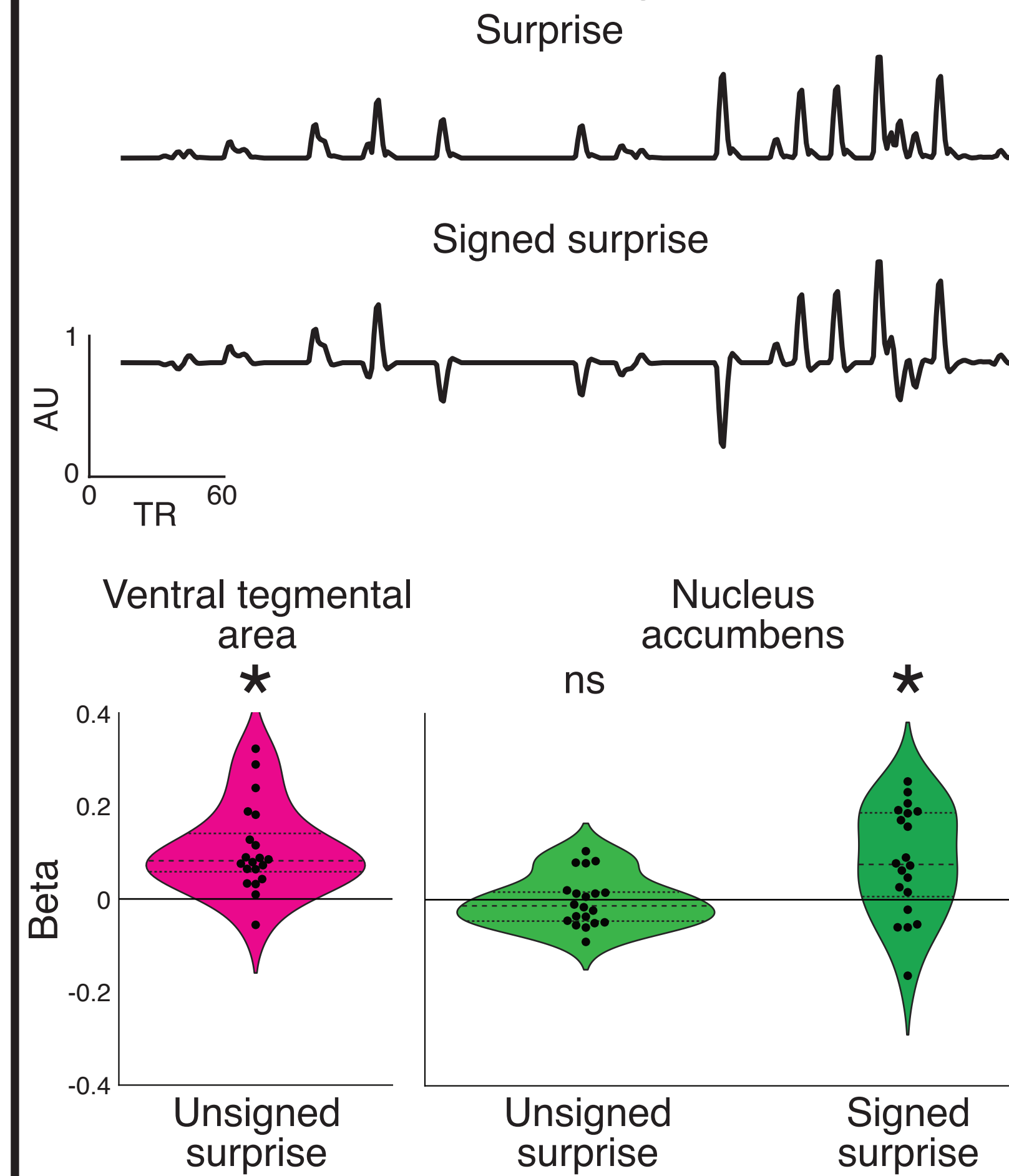
According to event segmentation theory (EST)⁷, surprise triggers segmentation⁹. HMMs offer a data-driven way of finding segments by identifying moments when neural patterns shift. We predict surprise leads to state changes in vmPFC¹⁰.



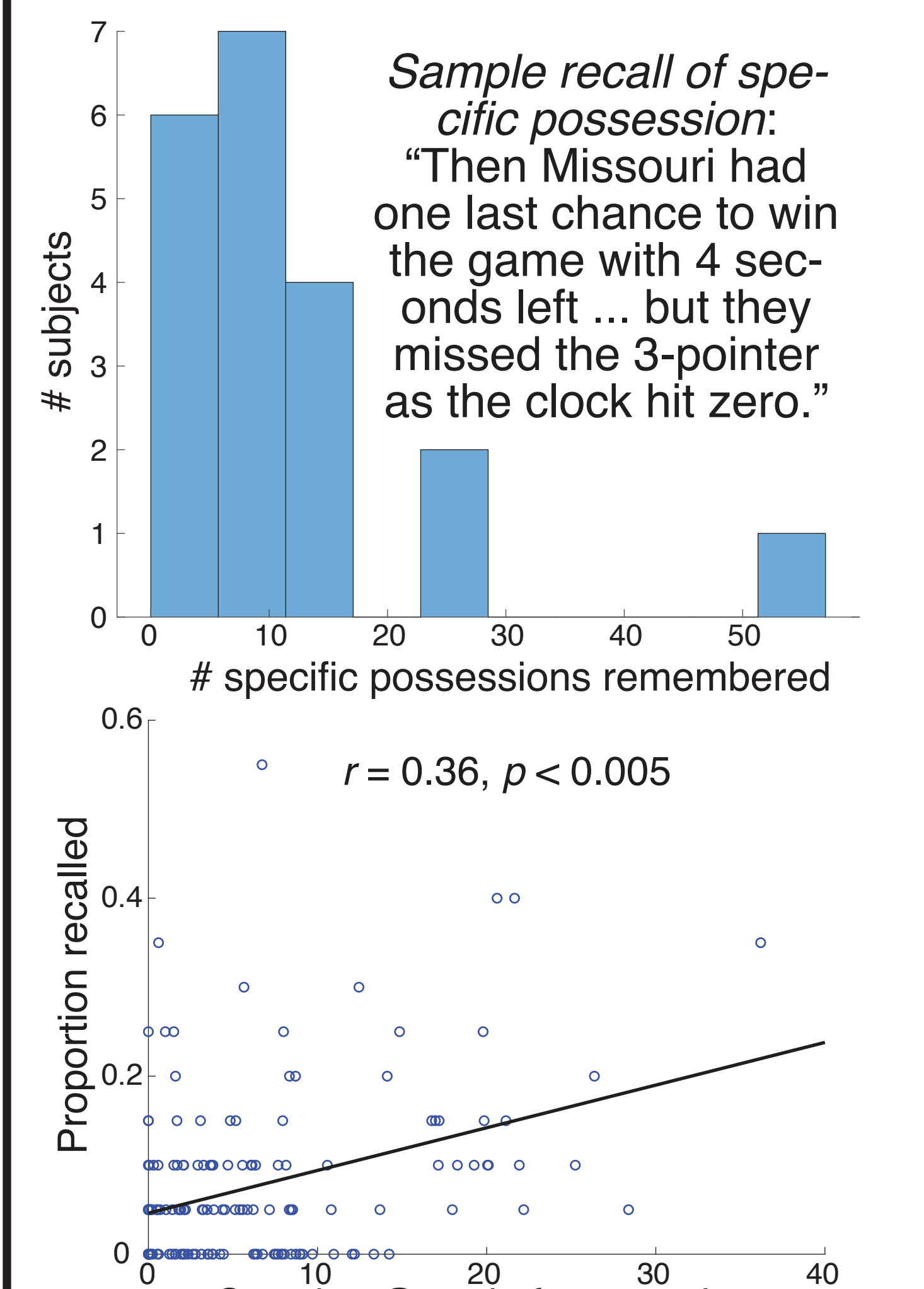
↑ Surprise, ↑ pupil area changes across possession boundaries



↑ Surprise, ↑ VTA activity, ↑ signed surprise, ↑ NAcc activity



↑ Surprise, ↑ memory for possessions



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Take-home messages: • Surprise derived from sports games map onto behavioral, physiological, and neural measures. • Results confirm predictions of EST: Possession changes with greater surprise \Rightarrow greater probability of HMM-identified state transition^{1,4,9}, and this was especially strong for surprise opposing the predominant belief. • Surprise also predicted pupil dilation, VTA activity, and memory for possessions, and signed surprise predicted NAcc activity. [Preprint here: https://www.biorxiv.org/content/10.1101/2020.03.26.008714v1](https://www.biorxiv.org/content/10.1101/2020.03.26.008714v1).