Perceptual decision making of nonequilibrium fluctuations

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A pedestrian deciding when to cross a busy street must consider not only the average traffic flow but also the fluctuations in the movement of individual cars. Similarly, the perceptual system must handle both local fluctuations in individual elements and the global patterns that emerge from their interactions. To investigate how the brain makes efficient decisions in such nonequilibrium systems—where evidence changes over time—we conducted three experiments with sixty-seven human participants who judged the direction of a particle exhibiting drifted Brownian motion. The entropy production rate extracted from the particle's trajectory served as a measure of noise dynamics.

We found that mean decision time was inversely proportional to the entropy production rate, establishing an analytical approach to predict the amount of time required to extract the signal given stimulus parameters. Moreover, participants required more time than predicted, indicating suboptimal decision times. An evidence integration approach, equipped with a memory time constant, resulted in tighter fits, indicating that participants adjusted their integration time window to stimulus dissipation, favoring the global trajectory of the stimulus over local fluctuations when the stimuli exhibited higher entropy production.

Furthermore, comparisons between blocked and intermixed conditions revealed that environmental stability was directly linked with decision optimality as well as the flexibility in adjusting integration time window. Complementary approaches indicated that decision optimality was linked to (I) memory load, (II) the recency effect, and (III) the ability to detect meaningful statistical cues in the evidence.

Overall, our work shows that providing a detailed model of the physical properties of the stimuli allows for a better characterization of the variables influencing perceptual decision-making, and refines our understanding of the temporal dynamics of efficient evidence integration.

Keywords: perceptual decision making, nonequilibrium systems, decision optimality, evidence integration, stimulus statistics, integration time window