September 2n, 2017

Dear colleagues,

Attached please find a manuscript titled “Perceptual decisions can result from the continuous accumulation of memory and sensory evidence” by me, Mariam Aly, Samuel Feng, Nick Turk-Browne, Ken Norman and Jonathan Cohen, for consideration for publication in *Science*.

Here we present evidence in support of a formal model of how memory biases perception. Our lab has recently developed a novel extension of the canonical evidence accumulation framework, the drift-diffusion model (DDM), that allows for integrating multiple kinds of evidence, which may be available at different times and be of differing quality. Here, we use this to address the influence of memory on perceptual decision-making, and provide the first *in vivo* test of this model’s predictions, using behavioral and neuroimaging data. Specifically, in the first experiment, we show that choices and reaction times match the qualitative and quantitative predictions of a two-stage inference process: in the first stage, memory-based trial-specific expectations about the identity of an upcoming visual stimulus are established based on a contextual cue presented prior to the stimulus; then, when the visual stimulus becomes available, the integration process continues uninterrupted, now incorporating the (noisy) sensory evidence. In a second experiment, we replicate the behavioral findings of the first, and further show that the degree to which patterns of neural activity reflect the anticipation of a given stimulus — *before* the availability of sensory evidence — biases the speed and outcome of responses to sensory evidence, to favor the anticipated stimulus.

In addition to providing a formally rigorous account of how memory biases decision making, corroborated by neural evidence, our results also directly address a more general question concerning the sources of trial-by-trial variability in perceptual decision making. The canonical theoretical account treats such variability as noise in critical parameters of the decision process (e.g., starting point and/or drift rate), and models them as random distributions. Here, we show that these can be explained in mechanistic terms, as trial-specific expectations, resulting from a cue-driven integration of memory signals prior to stimulus onset. This finding implies that such memory-guided expectation-formation could occur even absent a specific cue, and when present should meaningfully influence behavior in any situation where expectations can be established before the availability of choice options. The model thus allows further studies to formalize the integration of expectations with externally-provided information, showing that — where possible — explicitly modeling priors as a preceding, memory-driven integration process can provide a more precise way of accounting for the effects of expectations (and thus trial-to-trial variability) in behavior.

The results also promise to draw interest beyond the domain of perceptual decision making. Evidence accumulation models have been among the most successful examples of providing detailed, quantitative accounts of both behavioral and neural evidence concerning many kinds of decision-making — sensory and memory decisions, but also lexical, social, value-based, and

collective choices — in human and non-human species. However, as in perceptual decisions, studies using these models have focused almost exclusively on the influence of the stimulus (such as visual input or external rewards) on the decision process, again treating other factors (such as expectations based on prior experience or contextual cues) as either static assumptions, or simply noise. Several studies by our lab and others have recently shown that memory retrievals preceding a decision play a critical role in influencing multiple kinds of choice behavior. Those studies, however, have lacked the accompanying theory to make precise, quantitative predictions about trial-to-trial fluctuations in the dynamics of performance. Here, we exploit the precision of accumulation models, and pair them with experimental methods that allow us to probe the neural activity that precede, as well as that accompanying the integration process itself, with broad impact for any modality in which these models apply.

For the reasons outlined above, we feel that the connection between memory sampling and decision making has the potential to be of significant interest to researchers in many disciplines, and consequently that our results are valuable to communicate to the broad audience of researchers who read *Science*. We appreciate your consideration for publication in your journal.

Sincerely yours,

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