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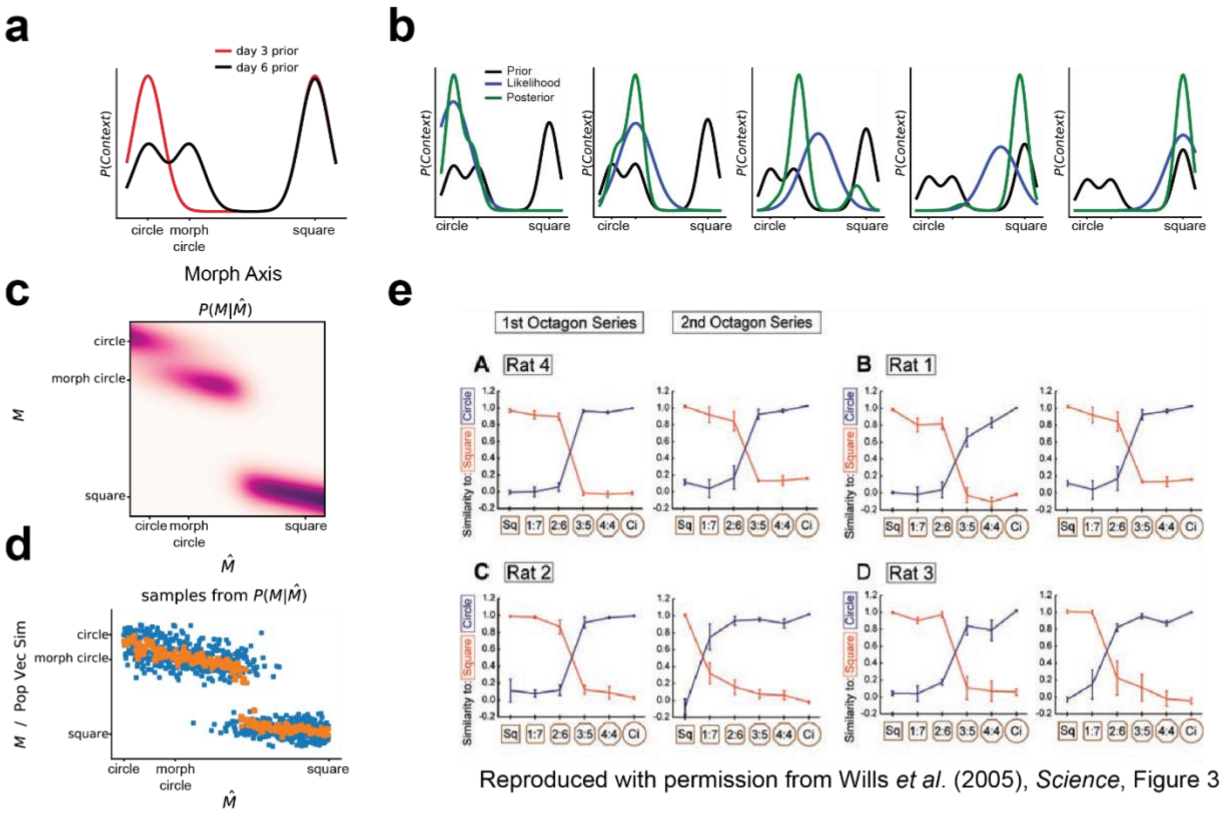
Supplementary information

Experience-dependent contextual codes in the hippocampus

Supplemental Data:

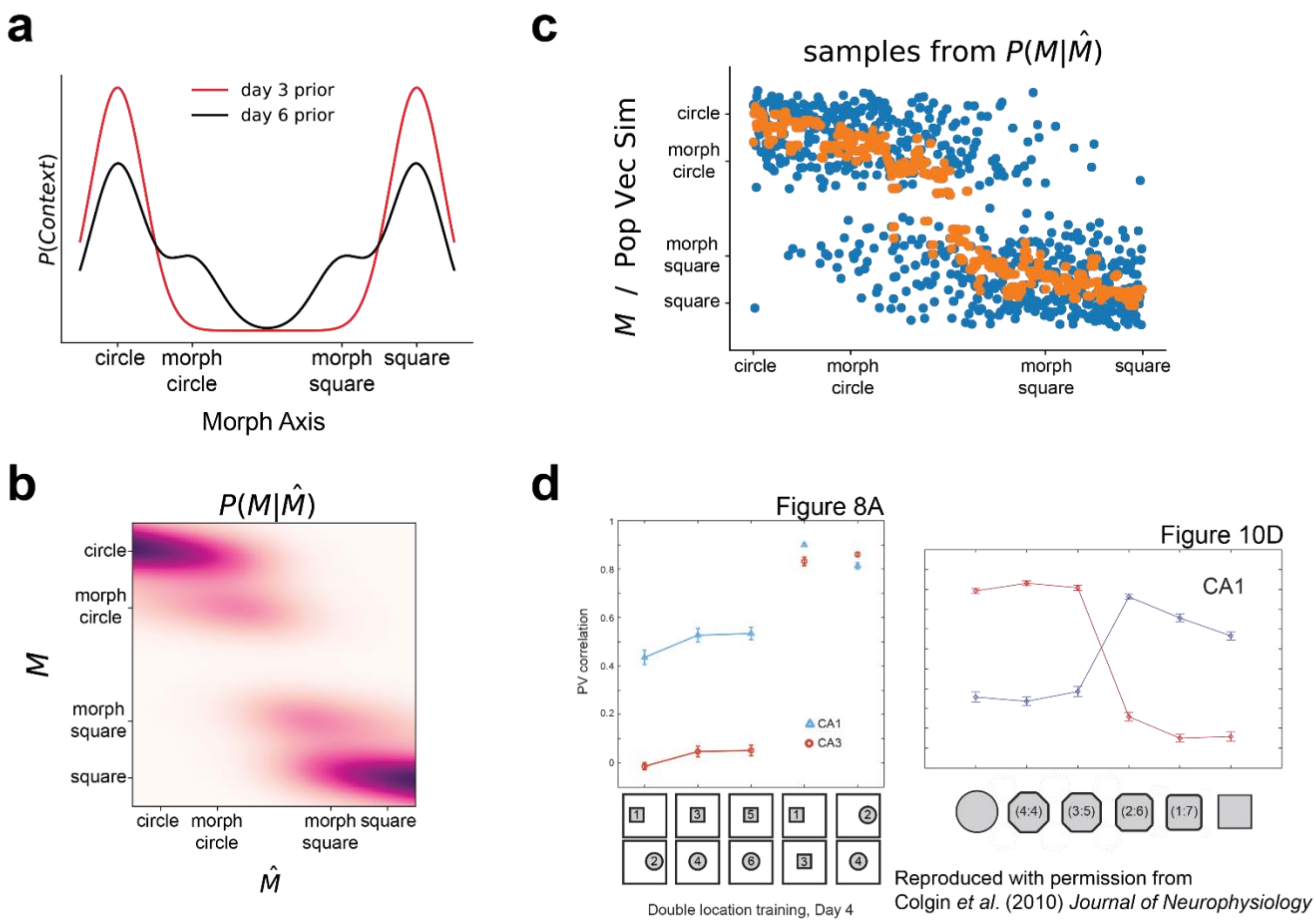
Replicating previous “morphed environment” remapping studies using probabilistic inference



Reproduced with permission from Wills *et al*. (2005), *Science*, Figure 3

Supplemental Figure 1 Replication of Wills *et al* (2005) *Science* results with probabilistic inference framework.

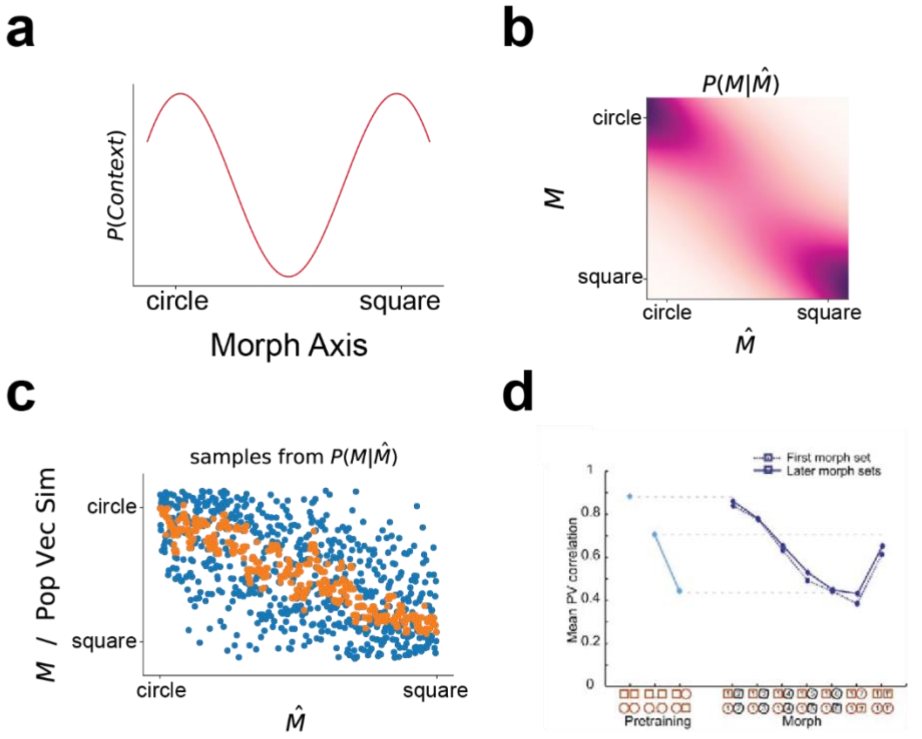
a, Proposed prior distribution for the animals trained in Wills *et al.* (2005) *Science* (main text reference 10). In the previous study, the experimenters first exposed the animals to square and circular environments that differed in color, texture and shape. After 3 days, the circular environment was replaced with a "morph circle" that was the same color and texture as the square. After three more days of training, animals underwent a morph sequence in which they were placed in deformed environments that gradually changed from a circle into a square and back. The place cells they recorded showed discrete remapping as we see in the rare morph condition (**e**). We imagine a morph axis which captures the variance in sensory information as the environment is deformed. After day 3, the animals have a bimodal prior, $P(M)$, with the modes centered at the circle and square on the morph axis (red curve). After day 6, the animals have not received any more experience in the circle but gain experience in the "morph circle", which is closer to the square on the morph axis, and continue to get experience in the square environment, resulting in a new prior (black curve). **b,** Simulation of probabilistic inference during the morph sequence. Akin to the procedures performed in our manuscript, for every value on the morph axis, we multiply a likelihood function (blue curve, $P(\widehat{M}|M)$) centered on the true value of the stimulus by the prior distribution (black curve, $P(M)$) to get a posterior distribution (green curve, $P(M|\widehat{M})$). **c,** Posterior distributions for every value on the morph axis as in Figure 1f. **d,** Simulation of samples drawn from the posterior distribution in (**c**) (blue dots). A median filter applied to these samples across morph values, $\widehat{M}$, is also shown (orange dots). This plot is intended to serve as a stand-in for single trial measures of neural population dynamics such as SF in our manuscript. **e,** Replication with permission of Figure 3 from the Will *et al* (2005) manuscript. Our simulation replicates three major aspects of these findings: 1) There is little remapping from the circle to the morph circle (Wills *et al*. (2005), Figure 1B). 2) Population representations change abruptly about halfway between the morph circle and the square (Wills *et al*. (2005) Figure 2-3). 3) There is some variance in exactly where on the morph axis, the population switches from one representation to the other (Wills *et al*. (2005) Figure 3A-D).



Reproduced with permission from
Colgin *et al*. (2010) *Journal of Neurophysiology*

Supplemental Figure 2 Replication of Colgin *et al* (2010) *Journal of Neurophysiology* "double location training" condition results using probabilistic inference framework.

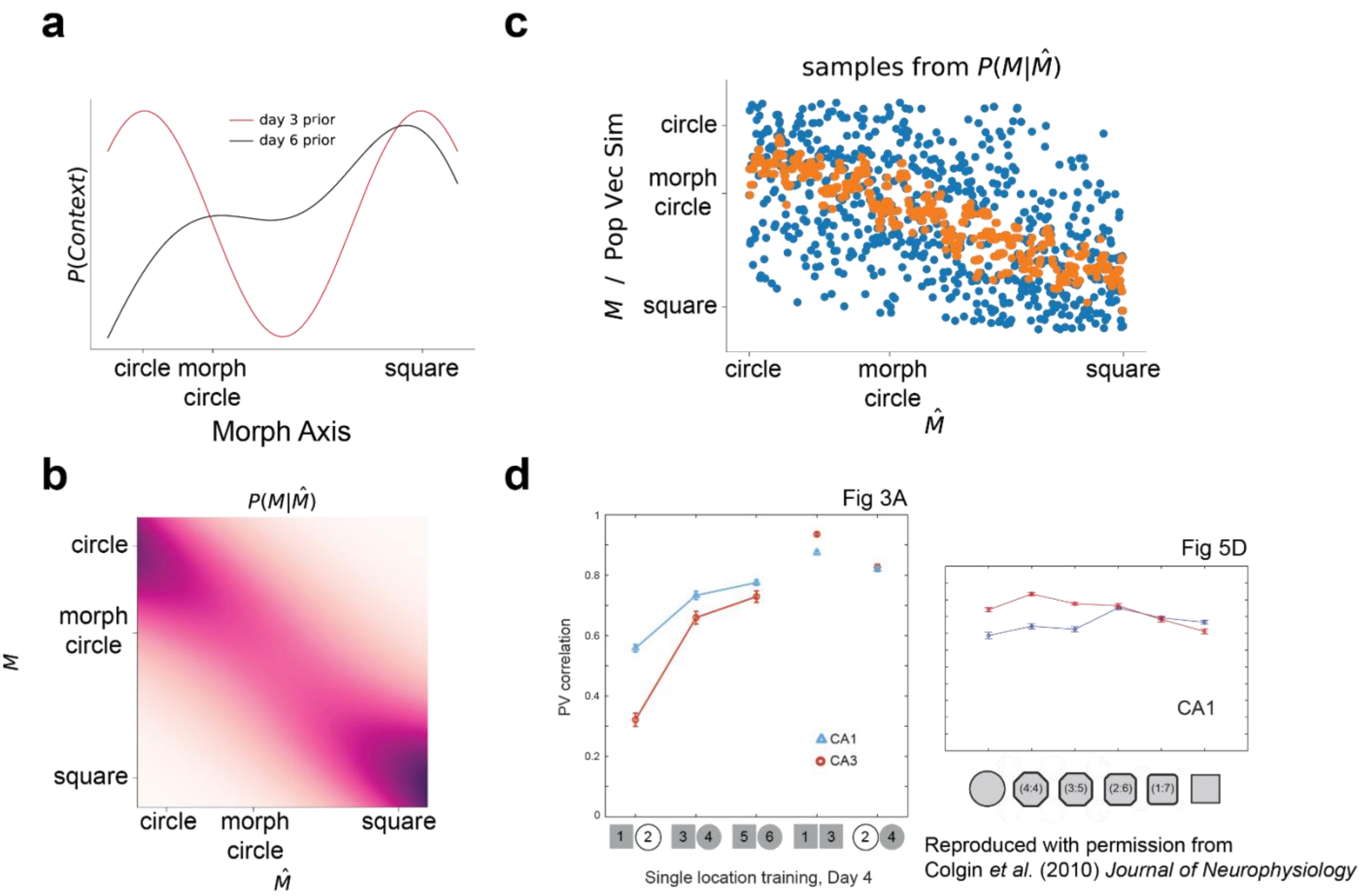
a, Proposed prior distribution for the animals trained in the "double location training" condition from Colgin *et al.* (2010) *Journal of Neurophysiology* (main text reference 3). In these experiments, animals were allowed to move between circular and square environments through a corridor for three days (proposed prior shown as red curve). The corridor was then blocked, and over the course of several sessions, the square and circle were moved to the same location (morph circle and morph square). We propose that this procedure resulted in more overlapping cues between the two environments (proposed prior shown as black curve). We weighted the modes of the two stages of training by the approximate number of sessions gleaned from the methods. The experimenters then recorded place cells during a similar morph sequence as was performed in Wills *et al*. (2005). **b**, Posterior distributions for every value on the morph axis as in Figure 1f. **c**, Simulation of samples drawn from the posterior distribution as in Supplemental Figure 1d. **d**, Reproduction with permission of Figures 8a and 10d from Colgin *et al*. (2010). In panel 8a, the authors show modest remapping when moving the circular and square environments to a common location. In panel 10d, the authors show similar remapping to the Wills *et al* (2005) paper during the morph sequence. Our simulations accurately predict both findings. The authors state that the reason for this result was anchoring of initial experience in an environment to different path integrator coordinates caused by locomoting between the different environments. In the probabilistic framework, we interpret the act of walking from one enclosure to the other as sufficiently changing the sensory input to allow for the formation of more distinct modes of the prior distribution (**a**, red curve). We do not wish to discount the importance of sequence formation and the temporal ordering of events for the formation of hippocampal representations, but we cannot directly account for those aspects of the animal's experience in the very simple model that we are using here.



Reproduced with permission from Leutgeb *et al*. (2005) *Neuron*, Figure 6E

Supplemental Figure 3 Replication of Leutgeb *et al* (2005) *Neuron* results using probabilistic inference framework.

a, Proposed prior distribution for the animals trained in Leutgeb *et al*. (2005) *Neuron* (main text reference 5). In these experiments, animals were trained extensively in morph circle and square environments before going through the morph sequence. These animals never experienced a circle enclosure with distinct texture and colors as in the other two studies. The authors found more modest levels of remapping between the circular and square environments. During the morph sequence, the authors found roughly equal proportions of discrete remapping cells and gradually remapping cells (Leutgeb *et al*. (2005) Figure 5), but the population seemed to gradually remap through the morph sequence (Leutgeb *et al*. (2005) Figure 6E). We model this result as the animal having a prior with two less distinct modes. **b,** Posterior distributions for every value on the morph axis as in Figure 1f. **c,** Simulation of samples drawn from the posterior distribution as in Supplemental Figure 1d. **d,** Replication, with permission, of Figure 6e from Leutgeb *et al*. (2005). Note that the authors see a shallow sigmoidal remapping across the morph axis. Our simulation (**c**) gives the same result.



Reproduced with permission from Colgin *et al.* (2010) *Journal of Neurophysiology*

Supplemental Figure 4 Replication of Colgin *et al* (2010) *Journal of Neurophysiology* “single location training” condition results using probabilistic inference framework.
a, Proposed prior distribution for the animals trained in the “single location training” condition from Colgin *et al*. (2010) *Journal of Neurophysiology* (main text reference 3). In these experiments, animals were trained similarly to the Wills *et al*. (2005) study, but the animals never developed orthogonal representations of the square and circle environments. Furthermore, introducing a “morph circle” that was the same texture and color as the square environment dramatically increased the correlation between the square and circle population representations. This is perhaps due to the presence of overlapping salient distal cues outside of the morph boxes. Though the specific reasons for these different results are unclear, the lack of remapping from the morph circle to the square suggests that the animals perceived these two environments as quite similar. When the morphed boxes were introduced, the experimenters were unable to reproduce the Wills *et al*. (2005) effect. This lack of remapping can be modeled in the probabilistic framework by creating overlapping modes in the prior distribution (red curve, initial prior; black curve, prior after introduction of “morph circle”). **b,** Posterior distributions for every value on the morph axis as in Figure 1f. **c,** Simulation of samples drawn from the posterior distribution as in Supplemental Figure 1d. **d,** Replication, with permission, of Figure 3a and Figure 5d from Colgin *et al.* (2010). Panel 3a shows the increase in population vector correlation to the square environment after the introduction of the morph circle. Panel 5D shows the modest and gradual remapping through the morph sequence. We capture each of these effects in panel (**c**). The overlapping samples (blue points in [**c**]) between the morph circle and square suggest little remapping but a roughly linear change in population similarity during the transition from morph circle to square.