# Landmark stability needed for formation but not expression of spatial maps in retrosplenial cortex

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Our laboratory recently found spatial tuning in superficial retrosplenial cortex (RSC) neurons, which appears to be inherited from the hippocampus (Mao et al., 2018). We set out to determine how this spatial tuning develops in a novel environment. Hippocampal place cells are known to form fields rapidly based on path integration, and use landmarks mainly to reset position when path integration errors or disorientation occurs. **We hypothesized that if spatial information in the RSC is inherited from the hippocampus, then 1.) place fields would be formed rapidly in RSC and 2.) landmarks would play a role only in the initial formation of place fields, but not after a sequence is well learned.** Conversely, if hippocampus only plays a partial role in RSC spatial activity, RSC fields might require more learning trials to form and stabilize, and remain tied to landmarks after learning.

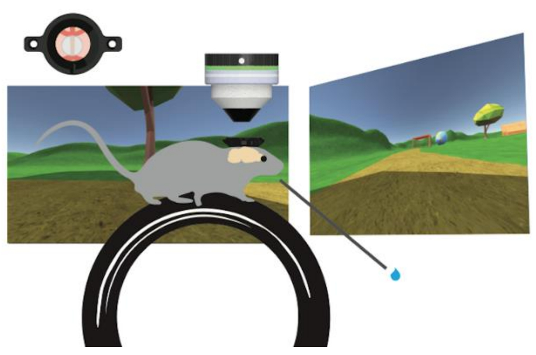
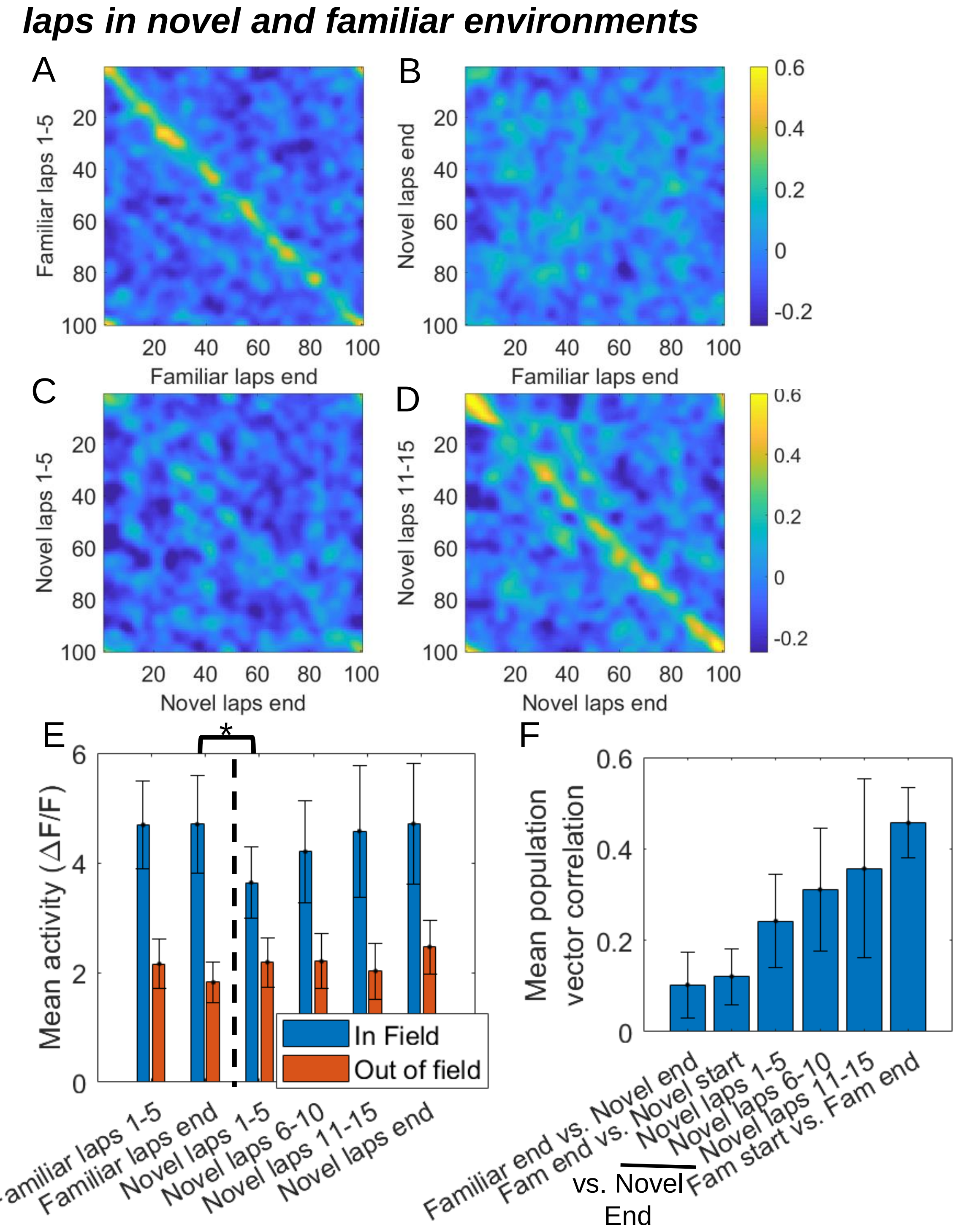


***Fig 1**: Mice were trained to run on a wheel surrounded by 3 tablets for water reward. As they ran, they moved in virtual space around a circular track (~350cm in diameter) in a visually complex environment.*

To determine how rapidly a new spatial map is formed in RSC, we used 2-photon calcium imaging to record superficial RSC pyramidal cell activity while mice ran along a familiar track, and then switched them to a novel track, with new backgrounds, landmarks, and water reward locations. We determined that RSC cells changed their firing locations on the very first traversal through the novel environment, and new spatial firing was established within the first 10-15 min. During the first few laps in the novel environment, more cells were silent, and they showed a low spatial correlation with future laps, but by laps 11-15, firing rates (Fig 2E) and spatial correlations were comparable to the familiar environment (Fig 2F).

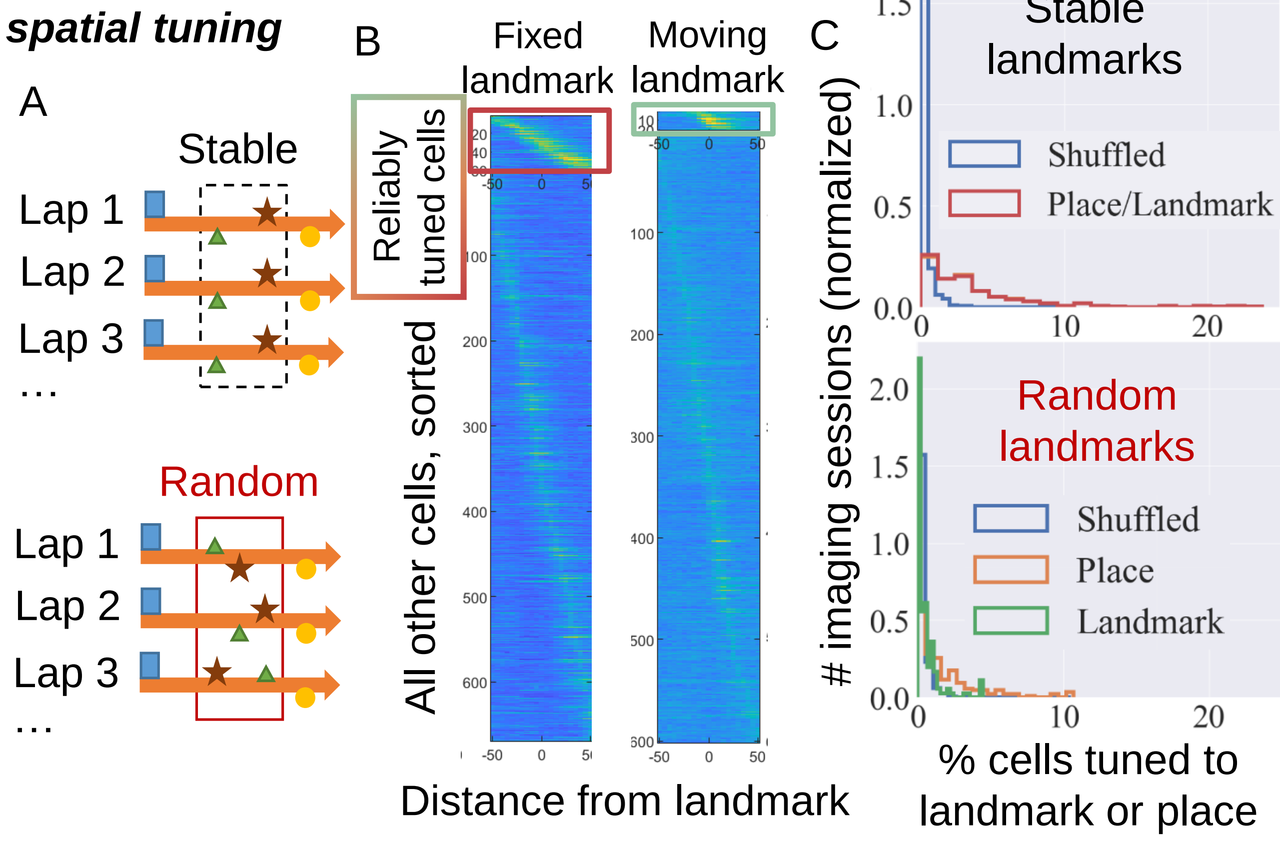
***Figure 2: Population vector correlations between laps in novel and familiar environments***




Reference: Mao D. et al. (2018). PNAS 115, 8015-8.

Next, we created environments that contained a patterned background, four fixed landmarks, and four landmarks that were moved in position after every lap. Some mice were trained in this "randomized" environment, and some were trained in a stable version of the same environment (Fig 3A). Mice that were trained in the stable environment had RSC place fields near to all landmarks, while mice that were trained in the unstable environment had place fields only in the zone with the fixed landmarks. This was the case when considering both the fixed reference frame, as well as referenced to each landmark. Thus, RSC cells were neither spatially-tuned, nor landmark-tuned, when the landmarks were shuffled from the start of experience in that environment (Fig 3C).

***Figure 3: Moving landmarks reduces spatial tuning***




However, when a mouse trained with fixed landmarks experienced the same environment with the landmarks later moved, RSC cells remained spatially-tuned (Fig 4). **We conclude that RSC cells form their spatial tuning in 1D virtual environments through rapid association between path integration cues and landmarks, and maintain it via sequential association of place cells, irrespective of landmark relocation.**

***Figure 4: Initial experience with fixed landmarks causes place fields to persist even after landmarks are moved***