ENVIRONMENTAL NOVELTY PROMOTES RODENT HEAD-SCANNING BEHAVIOR LINKED TO ENHANCED ENTORHINAL ACTIVITY

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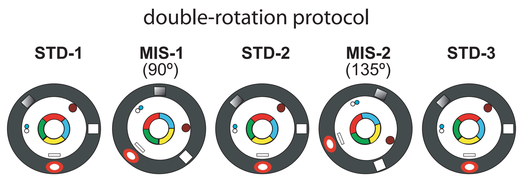
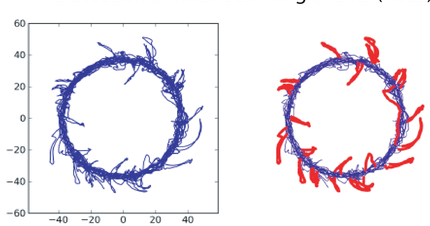
INTRODUCTION

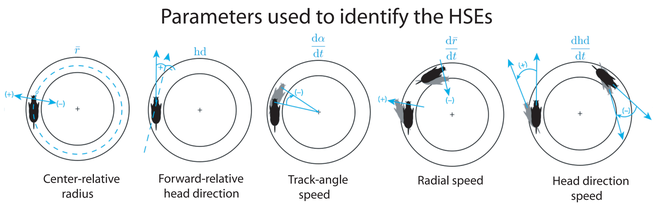
Rodent locomotion during exploration consists of forward running interspersed with brief pauses (Golani et. al, 1993; Sinnamon et. al, 1999). These stops are frequently accompanied by lateral head movements, or "scanning," presumably reflecting periods when the animal is gathering information about its environment (Drai and Golani, 2001). Perceptual and attentional processing during these pauses may allow integration of environmental information into the spatial representations maintained by the hippocampus and medial entorhinal cortex. Head-scanning events (HSEs) may be a behavior that provides the sensory input that drives the reorienting and updating of the animal's internal spatial representations as well as incorporating nonspatial input into these representations. If the behavior is related to acquiring information about the environment, we would expect that when the familiar landmarks in an environment are rearranged, head scanning behavior will increase. Furthermore, we hypothesize that neurons in the two major inputs to the hippocampus, the medial entorhinal cortex (MEC) and the lateral entorhinal cortex (LEC), will be differentially active during head scanning, based on the suggestion that MEC is involved in processing self-motion information for path-integration, whereas LEC is involved in processing sensory information from the external world (Deshmukh and Knierim, 2011).

METHODS



Rats were trained to run clockwise on a circular track in a curtained room with landmarks on the curtains. Local cues consisted of quadrants with different textures.





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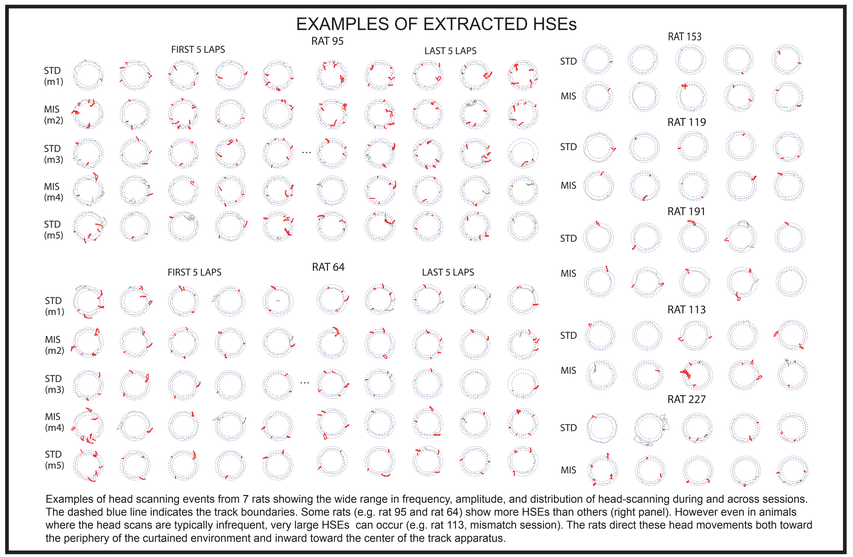
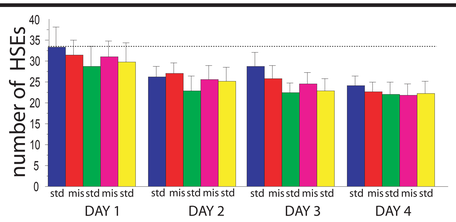
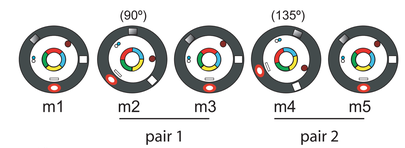
BEHAVIOR

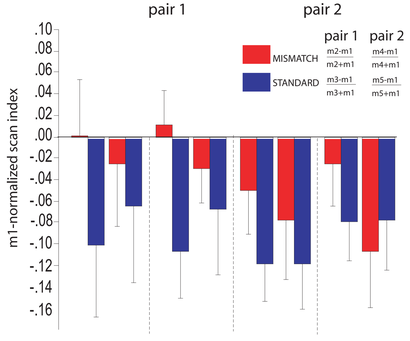


Examples of head scanning events from 7 rats showing the wide range in frequency, amplitude, and distribution of head-scanning during and across sessions. The dashed blue line indicates the track boundaries. Some rats (e.g. rat 95 and rat 64) show more HSEs than others (right panel). However even in animals where the head scans are typically infrequent, very large HSEs can occur (e.g. rat 113, mismatch session). The rats direct these head movements both toward the periphery of the curtained environment and inward toward the center of the track apparatus.

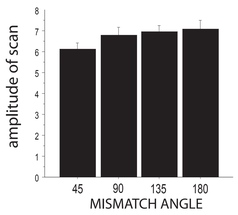


The number of detected HSEs is high on Day1 and decreases significantly over days (repeated measures ANOVA n =14 rats, effect of day F=5.65, p=.0026). HSEs were also significantly effected by maze session (F = 3.419, p=.0148). The animals may be habituating to repeated manipulations of the environment or other procedural aspects of the experiment.



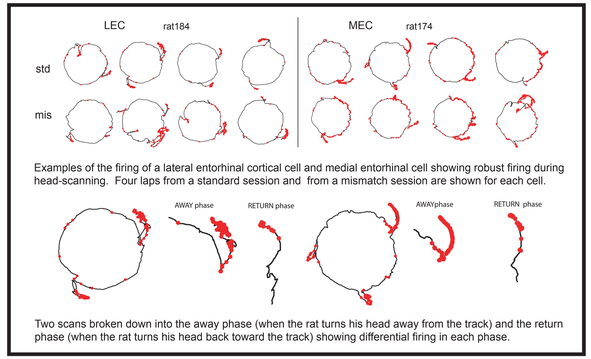


To examine the effect of maze type (standard or mismatch) we normalized the number of HSEs in the sessions m2 to m5 relative to the first standard session (m1) on a given day. This normalized scan index is negative for almost all sessions beyond m1 because the rat will typically scan the most when he first enters the room on a given day, despite it being a familiar environment. A significant effect of session type (p=.0348) indicates that the head-scanning behavior is affected by environmental novelty, with more scans occurring during mismatch than standard sessions after m1.



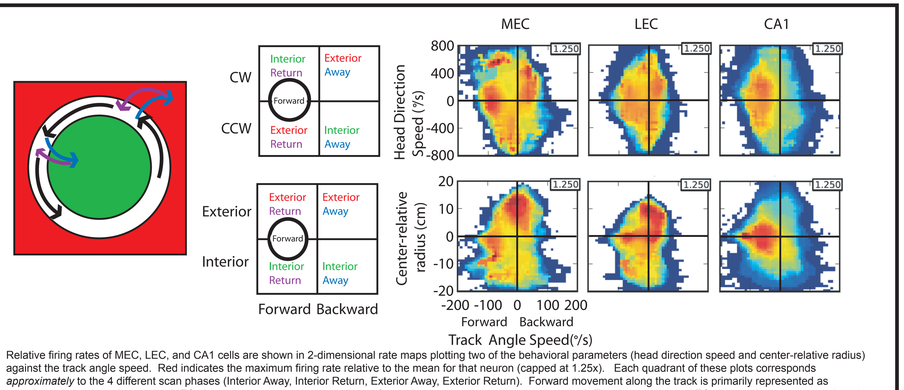
The protocol presents the rat with 4 different mismatch angles over the course of 2 days. The radius of the HSE was significantly correlated with the magnitude of the mismatch angle (repeated measures ANOVA, F=6.076, p=.0014). This result indicates that the size of the HSEs is correlated with the degree of cue-mismatch in the environment, consistent with the premise that one purpose of scanning is to investigate novel environmental features.

PHYSIOLOGY



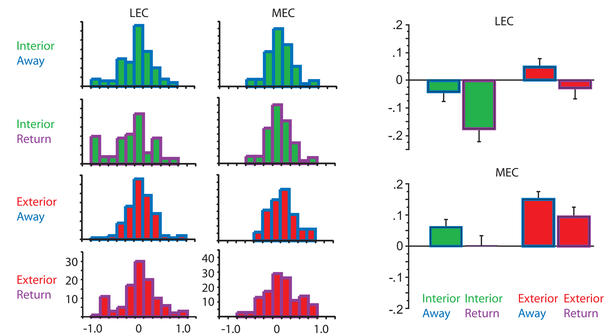
Examples of the firing of a lateral entorhinal cortical cell and medial entorhinal cell showing robust firing during head-scanning. Four laps from a standard session and from a mismatch session are shown for each cell.

Two scans broken down into the away phase (when the rat turns his head away from the track) and the return phase (when the rat turns his head back toward the track) showing differential firing in each phase.



Relative firing rates of MEC, LEC, and CA1 cells are shown in 2-dimensional rate maps plotting two of the behavioral parameters (head direction speed and center-relative radius) against the track angle speed. Red indicates the maximum firing rate relative to the mean for that neuron (capped at 1.25x). Each quadrant of these plots corresponds *approximately* to the 4 different scan phases (Interior Away, Interior Return, Exterior Away, Exterior Return). Forward movement along the track is primarily represented as negative values along the x-axis. MEC shows strong peaks coresponding to forward movement, as well as peaks in both Exterior quadrants. LEC shows a less pronounced peak corresponding to forward movement, with a bias toward Exterior scans. CA1 shows a strong peak corresponding to forward movement, with less scan-related firing.

Normalized Scan-Nonscan Indices for Different Scan Phases



Individual scans were segregated into Interior-Exterior, Away-Return segments. Firing rates of LEC and MEC neurons during each segment were normalized to the firing rate of the neuron during nonscanning periods with the index **(Scan-Nonscan)/(Scan+Nonscan)**. A value of 0 indicates that the firing during that segment was equal to the firing during Nonscan periods, whereas -1 and +1 indicate that the neuron's firing was restricted completely to the Nonscan or Scan segments, respectively. Histograms on left show that a fraction of LEC neurons fired very little during the return phase of a scan (values skewed towards negative). Repeated measures ANOVA revealed main effects for both LEC and MEC of Exterior vs. Interior scans ($p < 0.01$) and Away vs. Return phases ($p < 0.0001$), with no significant interaction. Positive values for MEC indicate that on average, MEC cells fired more strongly during scans than nonscans.

CONCLUSIONS

- Head scanning events in the rat appear to be significantly correlated with environmental novelty.
- MEC and LEC cells fire robustly during scanning behavior. Whether this firing subserves the same function between the two areas is an open question.
- MEC and LEC appear to be biased toward firing during exterior scans rather than interior scans, suggesting a role in incorporating the rich distal landmark information.