Cells in the primate hippocampus provide a timing signal for particular trial contexts

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Background:
Recent work from our lab has implicated the hippocampus in keeping track of time through incremental changes in neuronal firing rates during a temporal order memory task (Naya & Suzuki, Science 333 August 2011). This incremental timing signal is characterized by gradual increases or decreases in firing rate across a delay period between task-essential encoding events. Here we ask if incremental timing can be found during an object-place association task that is not contingent on temporal order memory. We find a large group of cells (N=56) that display a gradual increase or decrease in firing rate across the delay, indicating that incremental timing signal is present during this object-place task. Intriguingly, these can be divided into 3 distinct types of incremental timing cells dependent on the contextual information of the object-place task. Similar contextual control of a hippocampal timing signal was also reported in rodents during the performance of an object-odor association task (Macdonald et al., Neuron 71 August 2011).

Object-Place Task:

Early release trial: (~50% of trials)
- Place task
- New objects (300 ms)
- Delay (300 ms)

Late release trial: (~50% of trials)
- Place task
- New objects (300 ms)
- Delay (300 ms)

Cell Classification:

- *Wildmon test between early and late release PSTHs across delay (20 ms bins).
- 01: Early release
- 02: Late release

Example Cells:

Example time cells from previous work:
- Sample monkey hippocampus time cells from Naya & Suzuki, Science 333 August 2011 recorded during a temporal order task. Shown are probability density functions (PDF) of trial-averaged spiking data with ±20 ms. Incremental timing signal across the delay period—sandwiched between two cue encoding periods—is highlighted in red.

Agnostic incremental timing cells:
- Of 59 cells that fired significantly differently between early and late trials, 43 of these cells did not fire differently to each object-place combination correct for that release type (e.g. O1P1 and O2P2 PSTHs do not differ). Of these 43 cells, 17 incrementally changed their firing across the delay. This indicates that these cells selectively time to either early or late release trials.

Release incremental timing cells:
- 35 of 59 cells that fired differently between early and late trials also fired differently for each separate object-place combination correct for the respective release type (e.g. O1P1 and O2P2 PSTHs differ). Of these 35 cells, 19 showed incremental timing signal for at least one of the object-place combinations. This indicates that these cells selectively time across the delay only for one specific object-place combination (e.g. O2P2 only).

Non-timing cells:
- For each of the above cell types that incrementally change their firing across the delay a number of cells of that type do not show this signal. For the agnostic, release and object-place timing cells, there are 60, 26 and 16 cells, respectively, that did not show incremental timing signal. Examples of each of these cells are shown here for comparison to the above incremental timing cells.

Correct vs. Error:

- The t-scores of all agnostic incremental timing cells were averaged to create population PSTHs separate for correct and error trials (only cells with ≥10 trials for each). As shown, the correct and error PSTHs are both fit significantly better by a 1st order polynomial, indicating that these cells incrementally time across the delay regardless of upcoming monkey choice.

Conclusions:
- Incremental timing signal is present in monkey hippocampal cells during a task not contingent on temporal order memory.
- Some cells incrementally time absolutely to all trial types while many incrementally time selectively to specific trial contexts. These include the trial type (early or late release) and the specific object-place combination.
- Incremental timing signal is more robust for trials when the monkey anticipates a correct response during the delay period before the decision is made.

References: