Population and Individual Firing Behaviors in Sparsely Synchronized Rhythms Appearing in The Hippocampal Dentate Gyrus

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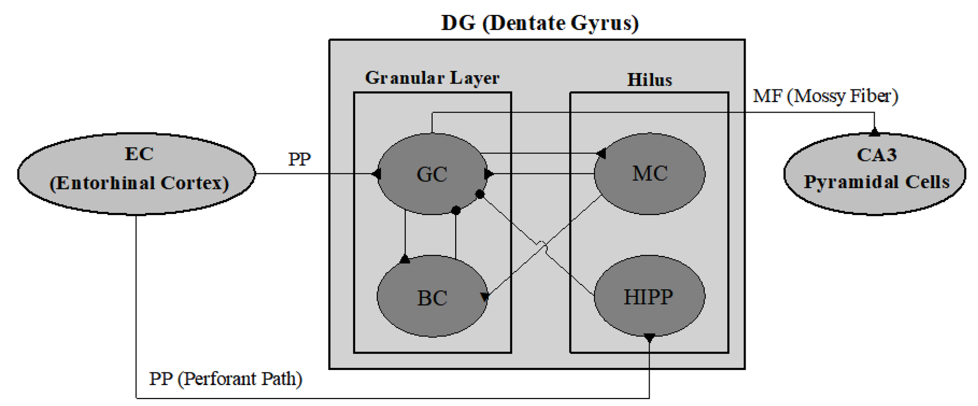
Introduction

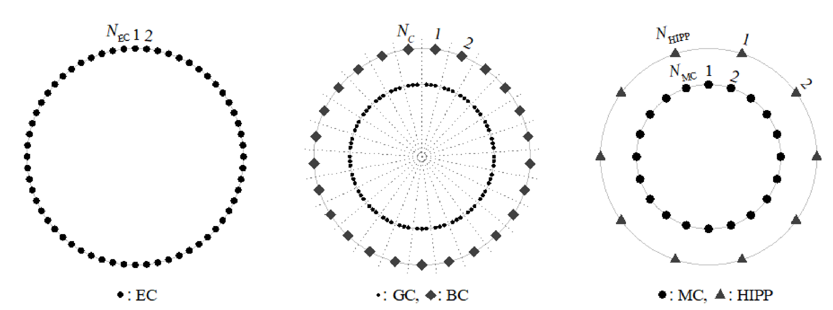
- **Hippocampus**
  - Consisting of the dentate gyrus (DG) and the areas CA3 and CA1
  - Play a key role in memory formation, storage, and retrieval
- **Pattern Separation**
  - Pattern Separation: Transforming input patterns into sparser and orthogonalized patterns
  - DG: Pre-processor for the CA3: Granule cells (GCs) in the DG performs pattern separation, facilitating pattern storage and retrieval in the CA3
  - Sparsity → Enhancing the pattern separation
- **Purpose of Our Study**
  Investigation of Emergence of Sparsely Synchronized Rhythms (SSR) in The Hippocampal Dentate Gyrus

Hippocampal DG Network

- **DG Network**
  - DG receives inputs from the entorhinal cortex (EC) via the perforant paths (PPs)
  - Granular Layer: Excitatory granule cells (GCs) providing the output to the CA3 via the mossy fibers (MFs) & Inhibitory basket cells (BCs)
  - Hilus: Excitatory mossy cells (MCs) & Inhibitory hilar perforant path-associated (HIPP) cells

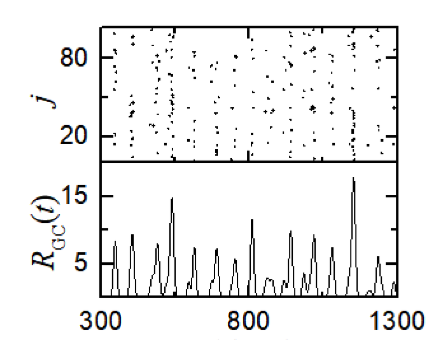


- **DG Ring Networks**
  - EC Ring Network: $N_{EC}(= 400)$ EC cells
  - Granular-layer Ring Network
    $N_C(= 100)$ GC clusters
    $N_{GC}(= 20)$ GCs & one BC in each GC cluster
    → Total No. of GCs = 2000
    No. of BCs N_{BC} = 100
  - Hilus Ring Network: $N_{MC}(= 80)$ MCs & $N_{HIPP}(= 40)$ HIPP cells

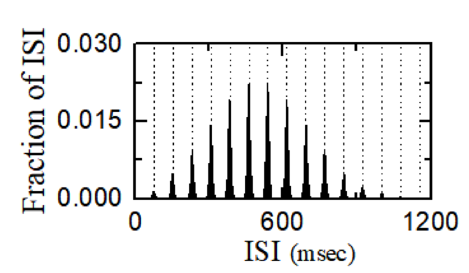


Emergence of SSR of the GCs

- **Population Behavior of GCs**
  - Raster plot of spikes: Appearance of sparsely synchronized stripes with the population frequency f_p (~ 13 Hz)
  - Emergence of sparsely synchronized rhythms in the GC-BC loop due to the feedback inhibition from the BCs

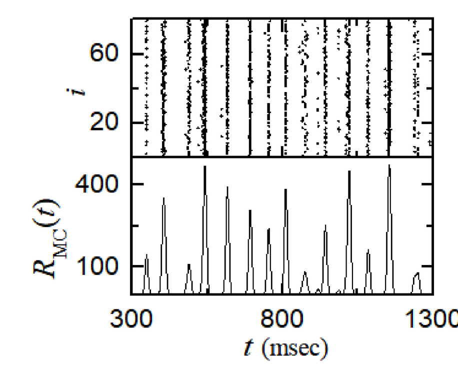


- **Multi-peaked Interspike Interval Histogram (ISIH)**
  - Stochastic spike skipping
    → Distinct multiple peaks at the integer multiples of global period T_G (≈ 77 msec) of the population rhythm in ISIH
    → Standard sparse synchronization

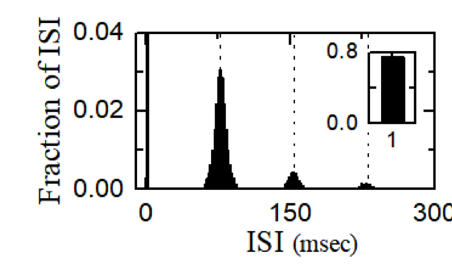


Emergence of SSR of the MCs

- **Population Behavior of MCs**
  - Emergence of sparsely-synchronized rhythm in MCs via interaction in the GC-MC loop

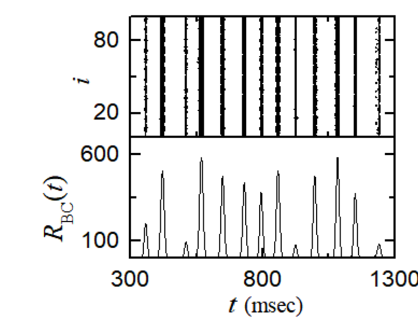


- **Multi-peaked ISIH**
  - Unlike the case of GCs, dominant intrastripe "bursting" peak and the interstripe multi-peaks in contrast to the standard sparse synchronization of GCs with only the interstripe multi-peaks

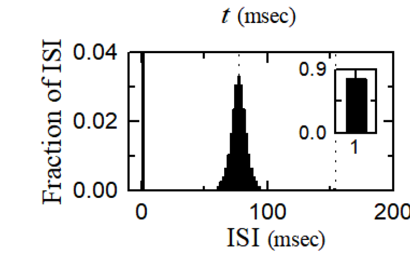


Emergence of SSR of the BCs

- **Population Behavior of BCs**
  - Emergence of sparsely-synchronized rhythm in BCs via interaction in the GC-BC loop



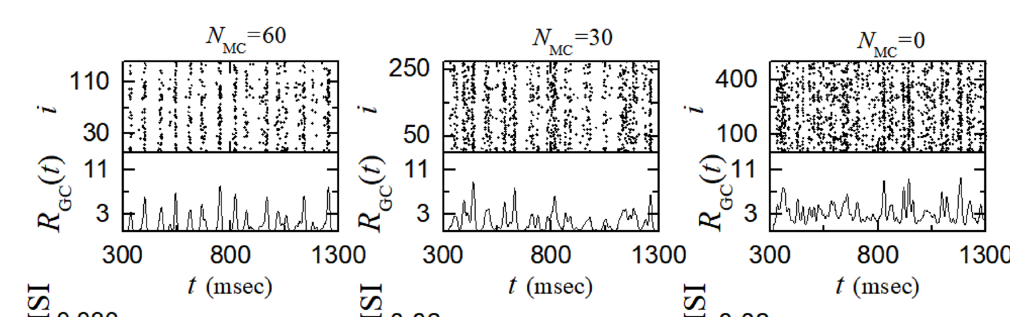
- **Multi-peaked ISIH**
  - Similar with the case of MCs, dominant intrastripe "bursting" peak and the interstripe multi-peaks

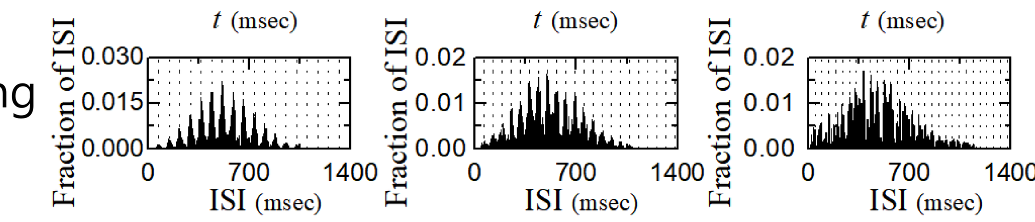


Effect of Hilar MCs on SSR of The Active GCs

- **Effect of Hilar MCs on The Population Behaviors of The Active GCs**
  - With decreasing F_{MC} $(= N_{MC}/80)$,
    Increase in population frequency $f_p^{(GC)}$ due to decrease in the feedback inhibition from BCs

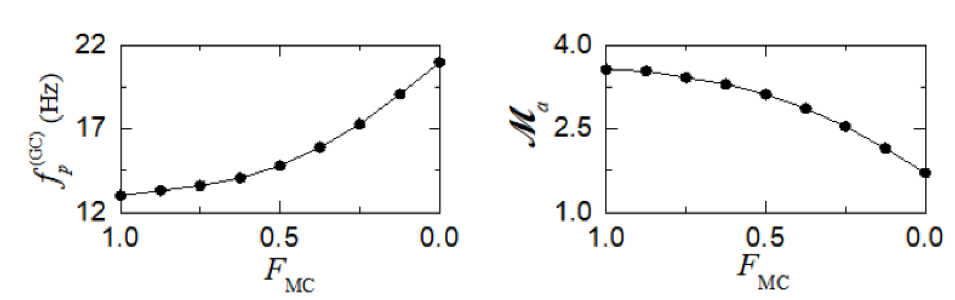
    Decrease in the thermodynamic amplitude measure $\mathcal{M}_a$ [representing time-averaged amplitude of IPSR $R_{GC}(t)$] → Decrease in overall synchronization degree

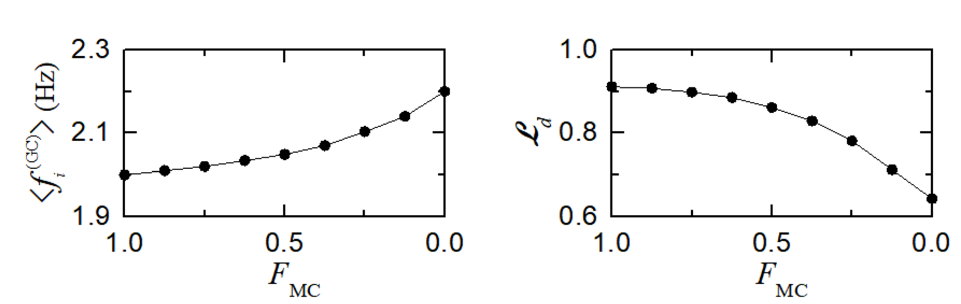




- **Effect of Hilar MCs on The Individual Behaviors of The Active GCs**
  - With decreasing F_{MC},
    Increase in population-averaged mean firing rate $\langle f_i^{(GC)} \rangle$

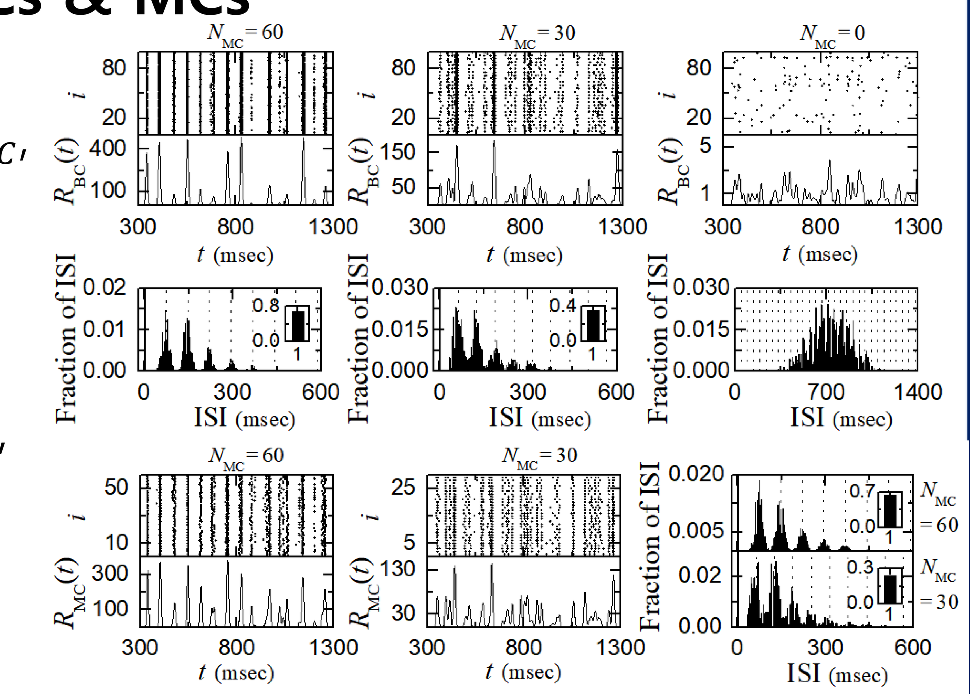
    Interstripe skipping peaks in ISIH become more and more smeared
    → Decrease in random phase-locking degree $\mathcal{L}_d$ [representing the degree of random phase-locking to $R_{GC}(t)$]



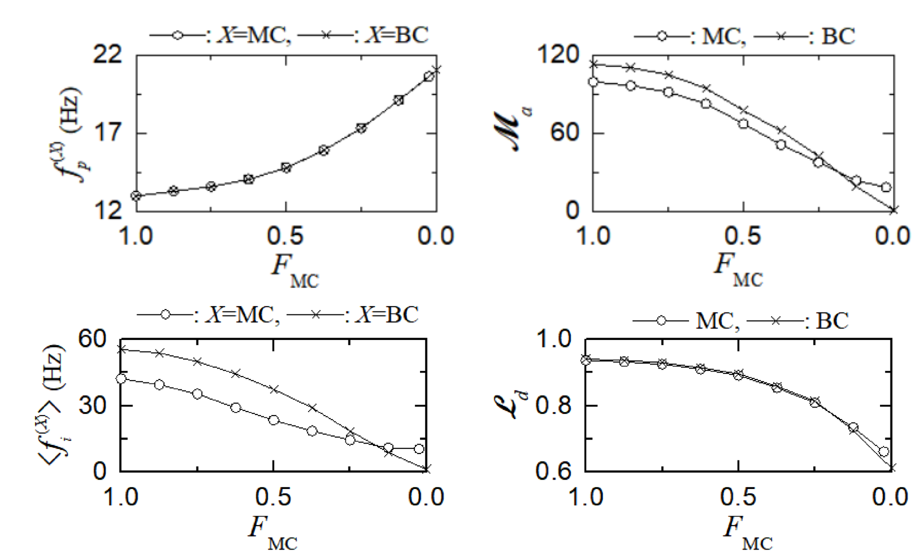


Effect of Hilar MCs on SSR of BCs & MCs

- **Effect of Hilar MCs on SSR of BCs**
  - Population Behavior: With decreasing F_{MC}, Increase in population frequency $f_p^{(BC)}$ and decrease in the thermodynamic amplitude measure $\mathcal{M}_a$ → Decrease in overall synchronization degree
  - Individual Behavior: With decreasing F_{MC}, Decrease in population-averaged mean firing rate $\langle f_i^{(BC)} \rangle$ and random phase-locking degree $\mathcal{L}_d$

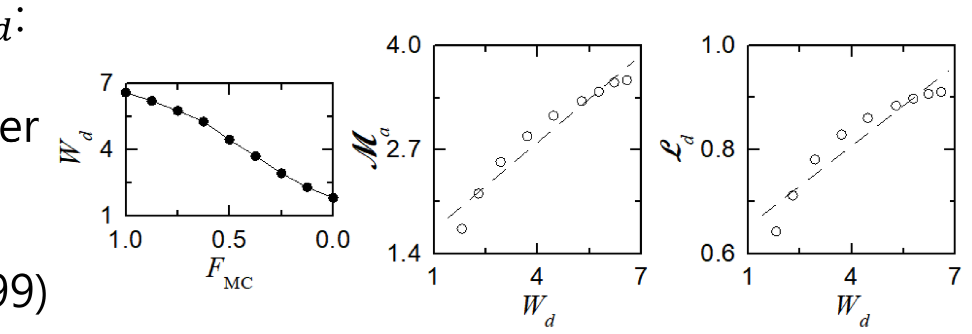


- **Effect of Hilar MCs on SSR of MCs**
  - Population Behavior: With decreasing F_{MC}, Increase in population frequency $f_p^{(BC)}$ and decrease in the thermodynamic amplitude measure $\mathcal{M}_a$ → Decrease in overall synchronization degree
  - Individual Behavior: With decreasing F_{MC}, Decrease in population-averaged mean firing rate $\langle f_i^{(MC)} \rangle$ and random phase-locking degree $\mathcal{L}_d$



Relationship between SSR and Winner-Take-All Competition

- **Qualitative Relation between SSR and Winner-Take-All Competition**
  - Winner-take-all competition degree W_d:
    With decreasing F_{MC}, W_d is decreased,
    → Winner-take-all competition: weaker
  - Population $(\mathcal{M}_a)$ and individual $(\mathcal{L}_d)$ firing behaviors in SSR: Positively correlated with W_d (r=0.9709 & 0.9599)
  - Stronger winner-take-all competition
    → Higher synchronization and the random phase-locking degrees in SSR of GCs:



Summary

- **SSR in A Spiking Neural Networks of the Hippocampal DG**
  - Emergence of SSRs of GCs, BCs, and MCs
- **Population and Individual Behaviors of SSRs**
  - Among 3 SSRs, the SSR of the GCS: Most sparse (resulting from the winner-take-all competition)
  - GCs: Multiple peak ISI histogram similar to the standard sparse synchronization due to random spike skipping
  - MCs & BCs: Exhibit bursting-like multi-spikings within the stripes
    ISI histogram: Dominant intrastripe bursting peak & interstripe skipping multi-peaks
- **Correlation between The SSR and The Winner-Take-All Competition**
  - Both the synchronization degrees and the random phase-locking degree are positively correlated with the winner-take-all degree.