Motivation

- Experimental recordings of pacemaker neurons exhibit chaotic bursting patterns.
- Chaotic bursting is modeled by fast and slow ionic processes represented by systems of nonlinear differential equations.
- Previous studies employed non-ideal explicit numerical methods to solve these stiff nonlinear equations and may result in erroneous solutions.
- Previous models capable of chaotic behavior were confined to a limited parameter space and did not investigate the effect on chaotic dynamics.
- Our goal is to employ implicit numerical methods in the absence and presence of dynamic noise to determine a minimal pacemaker model capable of chaotic bursting.

Methods

- We simulated two minimal pacemaker models with Hodgkin-Huxley ionic dynamics (Fig. 1a), using both variable-time step and fixed-time step implicit solvers (Fig. 1b). We added noise to the simulations by attaching an $I_{noise}$ to the soma and inducing a noise current generated by a uniform distribution (Fig. 1a).
- Bursting dynamics of interest were extracted from the simulation data (Fig. 1c).
- Bursting patterns were visualized by plotting the ISI duration vs. the ISI number. Different colors represented different bursts within the same run (Fig. 1d).
- For each run, chaotic bursting dynamics were detected by employing a noise-resistant numerical chaos-attraction test on the ISI time series data (Fig. 1e).

Results

Chaotic burster

- For a given $E_L$, the number of spikes/burst (Fig. 2a) and burst duration (Fig. 2b) was determined by $I_{noise}$.
- The interburst interval was dependent on both $I_{noise}$ and $E_L$ (Fig. 2c).

Non-Chaotic Burster

- High accuracy simulation of a simple pacemaker model displays no chaotic dynamics near transition from bursting to beating (Fig. 5a).
- Low accuracy simulation of the same parameter space results in chaotic dynamics near transition from bursting to beating (Fig. 5b).
- Highly accurate fixed-time-step simulation can evoke chaotic dynamics near transition from bursting to beating with the addition of dynamic noise (Fig. 5c).

Conclusion

- Computational models of pacemaker neurons are sensitive to errors caused by particular numerical integration methods.
- A minimal chaotic pacemaker model requires calcium dynamics, and displays chaos only at the transition between bursting to beating, and at parameters that change the number of spikes/burst.
- Dynamic membrane noise may play a significant role in shaping bursting patterns of pacemaker neurons.

References

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