“Carry-Over” Effects After Magnetic Stimulation – A Mechanistic Study

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Introduction

Neuromodulation is a field of medical science focused on modulating the activity of the nervous system for therapeutic purposes. Neuromodulation with magnetic fields is widely used (TMS, rTMS, dTMS, MST, and MRgFUS) and neurons are expected to return to their pre-stimulation state and function after the treatment.

However, recent research has shown that the effects of magnetic stimulation can persist even after the stimulation has ended, a phenomenon we call “carry-over” effects. These carry-over effects can have profound implications on the outcome of the stimulation. Understanding the cellular and molecular mechanisms underlying these effects is crucial for predicting and optimizing neuromodulatory outcomes.

In this context, our research aims to review the current understanding of the cellular and molecular basis underlying carry-over effects of magnetic field stimulation and highlight the need for further research to unravel the unpredictability associated with magnetic field neuromodulation.

Methods

- Micromagnetic stimulation (μMS) stimulation on *Aplysia c.* mollusk neurons of the buccal ganglion
- Trans-sheath μMS on *Aplysia c.* mollusk neurons of the buccal ganglion and recording from the axon
- Multi-compartment NEURON computational model

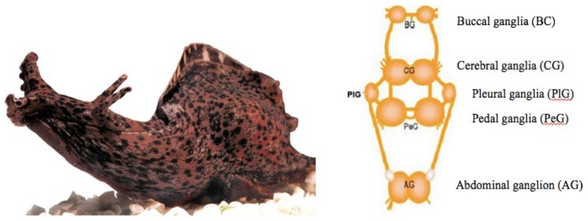

Figure 1. *Aplysia californica* and its central nervous system.

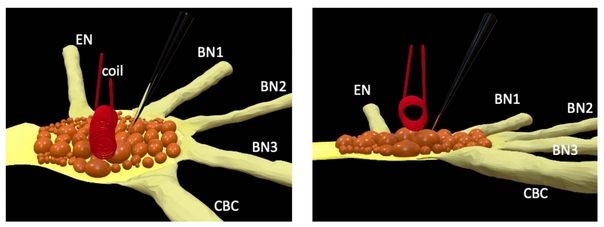

Figure 2. Position of the miniature coil for magnetic stimulation of the neurons in the buccal ganglion from *Aplysia californica*.

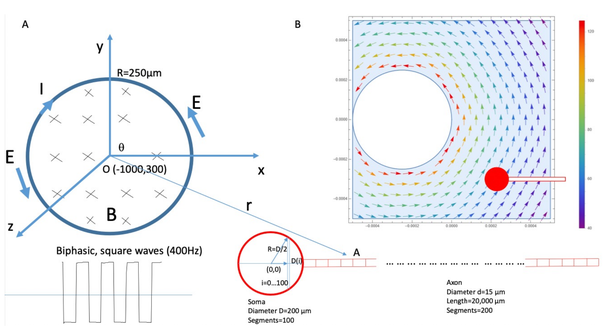

Figure 3. NEURON simulation of magnetic stimulation with a magnetic coil. Distribution of induced electric field around the coil and the modeled neuron.

Results

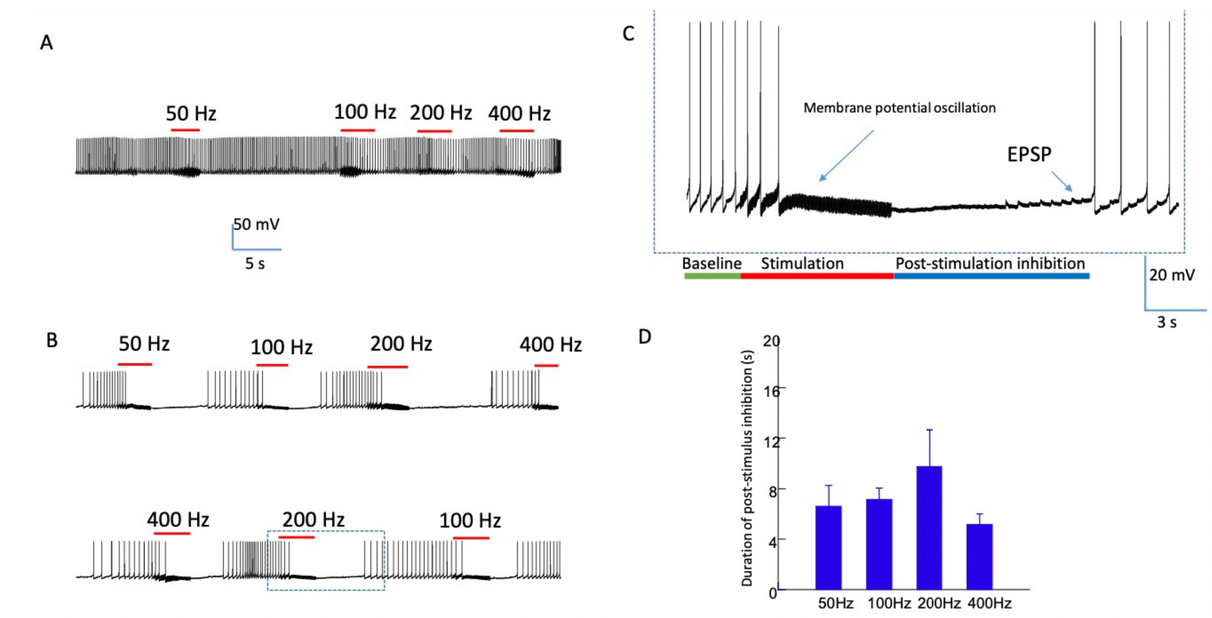

Figure 4. Carry over (post-stimulation inhibition) effects after high frequency magnetic stimulation in spontaneously firing neurons.

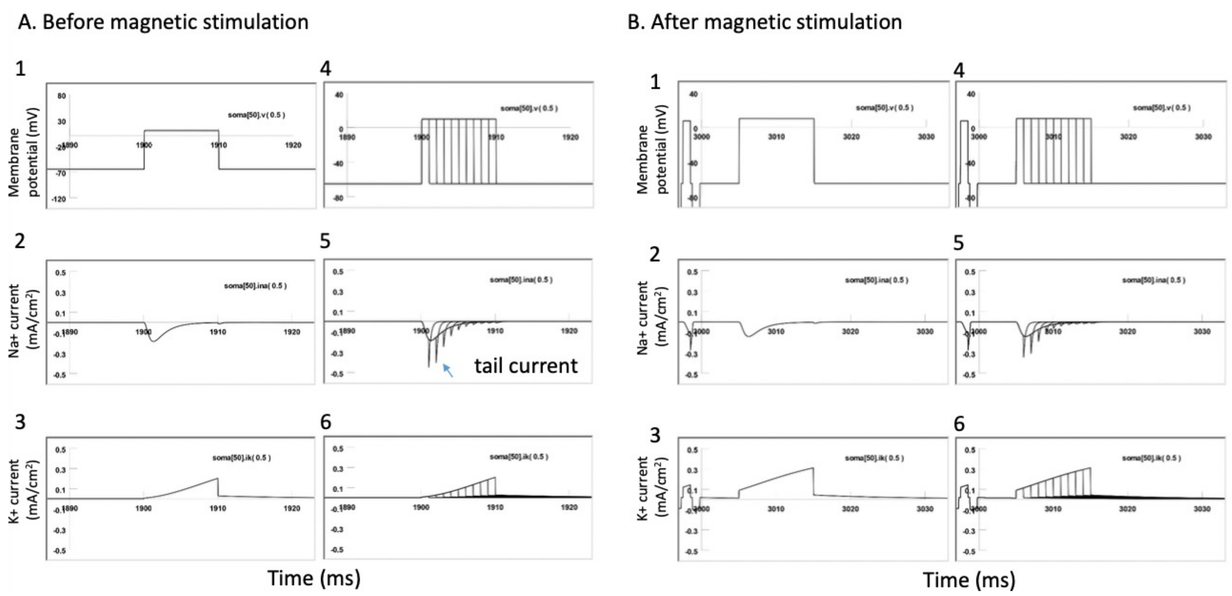

Figure 5. Carry-over effects mediated by the altered sodium and potassium channel conductance after magnetic stimulation. The sodium and potassium currents were measured and compared before and after the magnetic stimulation in a voltage clamp experiment (NEURON simulation).

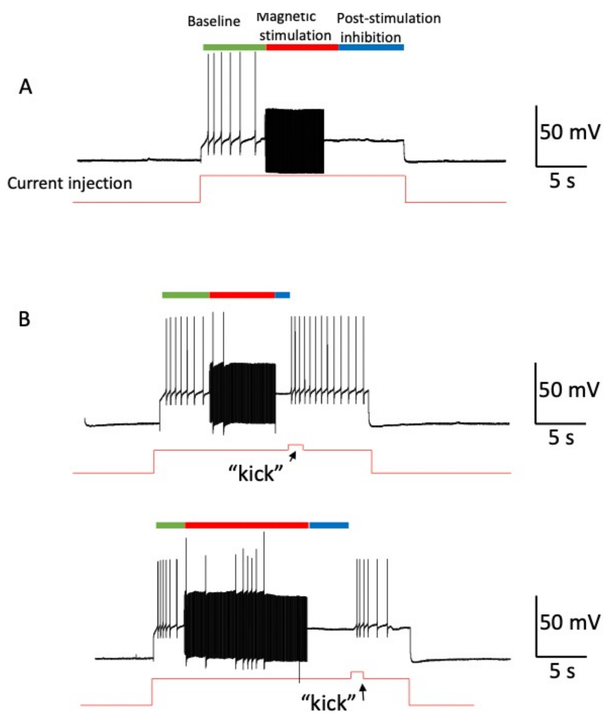

Figure 6. Electrophysiological confirmation of the elimination of carry over, post-stimulation inhibition with a short “kick” stimulus.

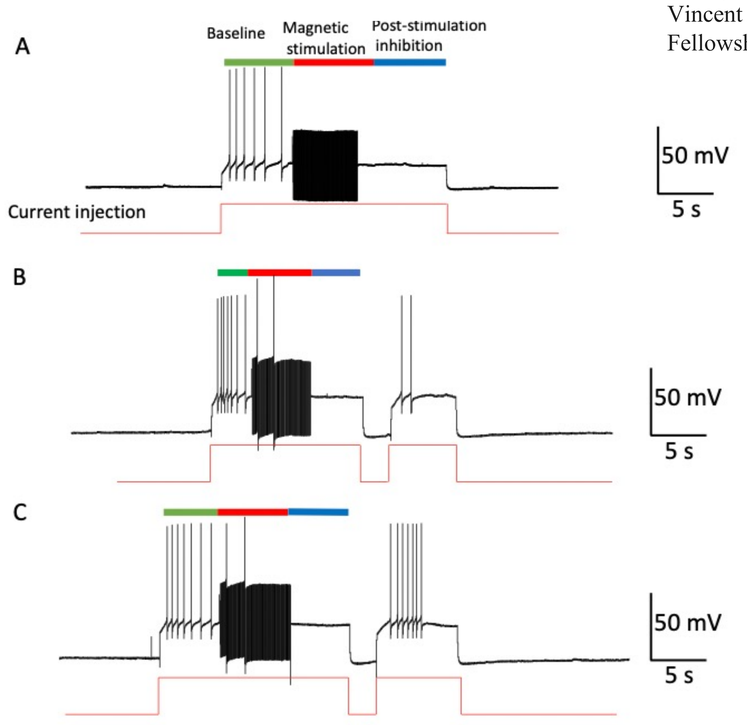

Figure 7. Electrophysiological confirmation of the elimination of carry over, post-stimulation inhibition with a short “resting”.

Discussion

→The state of neurons may be crucial for carry-over effects occurrence after magnetic field stimulation.

→Understanding the mechanisms underlying these carry-over effects is crucial for achieving optimal control of neural inhibition with magnetic stimulation.

→Further development of magnetic stimulation technology would benefit from a deeper understanding of the mechanisms responsible for carry-over effects.

→Strategies that can modulate the state of neurons may be explored to mitigate carry-over effects and improve the precision and reliability of magnetic stimulation.

→Investigating the effects of different magnetic field parameters on the occurrence of carry-over effects may provide valuable insights for optimizing the application of magnetic field stimulation in neuromodulation.

References

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Acknowledgments

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