DEPARTMENT OF INFORMATION TECHNOLOGY – WAVES RESEARCH GROUP

Prof. Emmeric Tanghe (Emmeric.Tanghe@UGent.be), Prof. Thomas Tarnaud (Thomas.Tarnaud@UGent.be)

COMPUTATIONAL NEUROSCIENCE

ULTRASOUND NEUROMODULATION

- **Non-invasive** (transcranial) and reversible
- Short wavelengths ➔ **High spatial accuracy**
- Low intensities ➔ **Good safety profile**
- Capability to select for different neuron types (e.g., inhibitory vs. excitatory neurons)
- Spatial interference and transducer arrays allow **targeting of deep brain structures**

Computational modeling and experimental validation: to elucidate the underlying mechanisms and to optimize protocols

Photometry
Ring transducer
EEG

DEEP BRAIN STIMULATION

Treatment of epilepsy and Parkinson's Disease

- **Goal:** Reverse abnormal firing behavior associated with neurological diseases
- **Simulation of electromagnetic field generated by the neurostimulator:** FEM, Realistic discretized anatomical models
- **Simulation of neuronal response:** Hodgkin-Huxley formalism, Cable Theory (equivalent electrical circuit representation of neuron), Synaptic Connectivity to form neuronal networks

Intracranial electrodes
Controller
Depth electrode

OPTOGENETICS

Control neuronal activity with **light**

- Genetically express opsins (light sensitive ion channels) into neurons ➔ **Cell type selectivity**
- Use of light ➔ **High temporal precision**
- Selective **inhibition or excitation**

$$C_\mathrm{m} \frac{dV}{dt} = -I_\mathrm{Na} - I_\mathrm{K} - I_\mathrm{A} - I_\mathrm{T} - I_\mathrm{L} - I_\mathrm{CaK} - I_\mathrm{l} - I_\mathrm{ChR2}$$

AURICULAR VAGUS NERVE STIMULATION

What?

- **Stimulation** of the auricular branch of the vagus nerve using needle electrodes
- **Treatment for** epilepsy, major depression, heart failure …
- Much **less invasive** compared to implanted cuff electrodes in the neck

Model of needle electrode (left) and typical electrode positioning during auricular vagus nerve stimulation (right)

Why numerical modeling?
➔ Insight in role of different **stimulation parameters** (e.g. pulse duration and waveform, electrode position, electrode shape…)
➔ **Which fibers are stimulated**, not stimulated or blocked for different settings?
➔ **Optimization** of therapy by maximum stimulation of target fiber types while avoiding stimulation of pain fibers

Excitation threshold vs neuron diameter

Blocking threshold (mA) for small electrode displacements

	-0.1 mm	0 mm	+0.1 mm (x-direction)
-0.1 mm	1.43	1.35	1.28
0 mm	1.66	1.58	1.49
+0.1 mm	1.91	1.90	1.79

(y-direction)

To illustrate: dependency of stimulation threshold on axon diameter (realistic heterogeneous model) and dependency of the threshold for cathodal blocking on small electrode displacements (straight neuron, homogeneous model)

Contact

Tom.Plovie@UGent.be Laila.Weyn@UGent.be Joaquin.Gazrodriguez@UGent.be

Thomas.Tarnaud@UGent.be Emmeric.Tanghe@UGent.be

https://www.waves.intec.ugent.be/

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