T1(E)

Individualized Deep Brain Stimulation (DBS)

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biomagnetic sensing SFB 1261

Objectives and Original Planning

Motivation:

- DBS is a neurosurgical procedure used to treat patients with movement disorders such as **essential tremor**, **Parkinson's disease**, and **dystonia** (over **200,000 surgeries** performed globally) [T1-2, T1-5].
- Knowledge of **exact position and rotational orientation** of DBS electrode is essential **(1)** to verify electrode position after surgery, **(2)** to facilitate stimulation programming, and **(3)** to evaluate the benefits and side effects of DBS.

Current approach:

Detection of electrode position and orientation using **postoperative computed tomography (CT)** exposes radiation to patients.

Detection of electrode orientation using **postoperative magnetic resonance imaging (MRI)** is not possible.

MR

New approach and main objective:

Realization of a novel, patient-friendly, clinically applicable, and industrially promising technique for radiation-free detection of electrode position and orientation using magnetic field measurements outside the head [T1-3, T1-4].

CRC 1261

Application partner:

Boston Scientific Corporation (Marlborough, MA 01751, United States)

Contact persons and researchers:

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Dr. Nicholas Maling (Paris, France)

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Original planning:

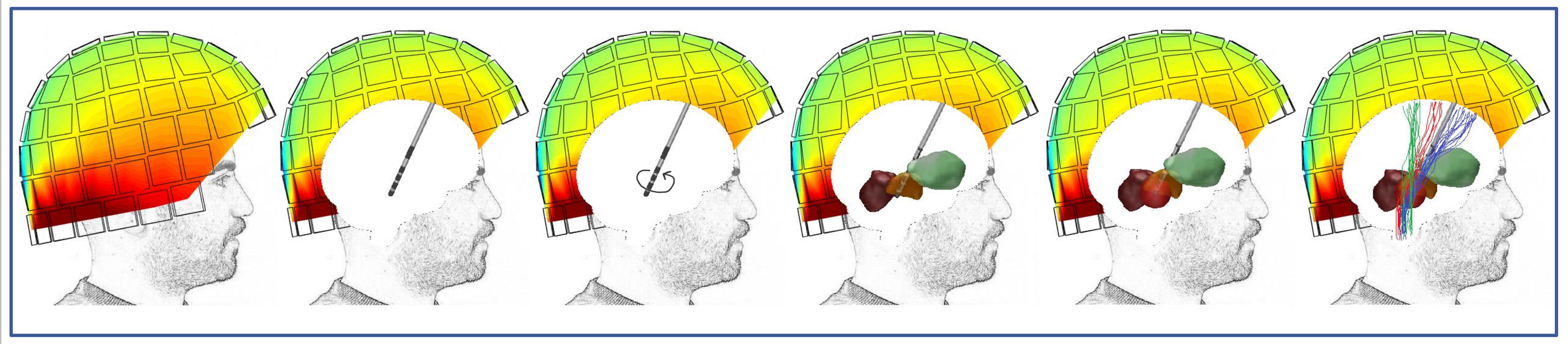
No.	Work packages
WP1	**Sensor characteristics**: Testing internal and commercially available magnetic field sensors with phantom recordings for their usability in the DBS application.
WP2	**DBS electrode localization and orientation detection**: Developing and optimizing suitable detection techniques with phantom and patient recordings using a single or an array of magnetic field sensors.
WP3	**Volume of Tissue Activated (VTA)**: Modeling and estimating the VTA of the localized electrode within the anatomical brain structures for a given set of neuromodulation parameters.
WP4	**System integration**: Developing a suitable measurement device equipped with a sensor cap with integrated magnetic field sensors, followed by its validation through patient testing.

Updates to Research Plan

- **WP2** was conducted on phantoms and patients mainly in collaboration with the University Hospital Düsseldorf (UKD), which operates a clinically available SQUID-based magnetoencephalography (MEG) system, widely recognized as the gold standard.
- **WP4** was partly conducted (so far on phantoms) in collaboration with the Physikalisch-Technische Bundesanstalt (PTB), which operates an OPM-based measurement system.

Results

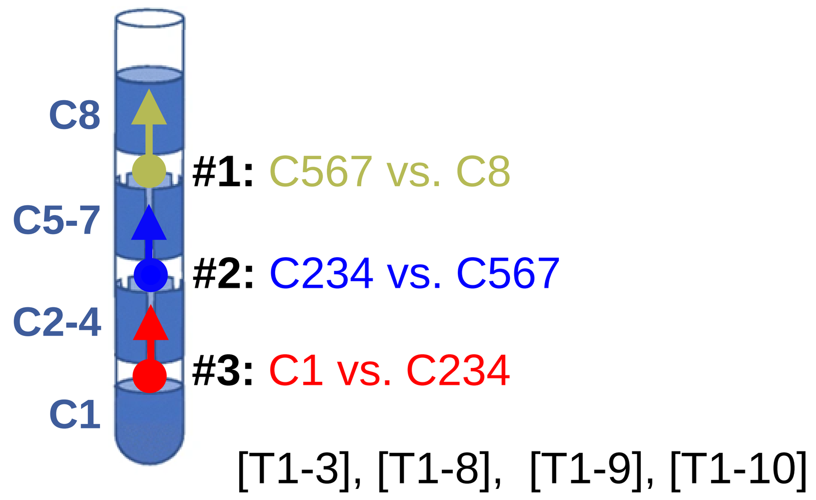
Development of MaDoPO (Magnetic Detection of Electrode Position and Orientation) [T1-3]:



MaDoPO exploits the spatial arrangement of contacts on the electrode (**C1–C8**) to measure the magnetic field distribution outside the head across a predefined sequence of electrode configurations (**#1–#6**).

Electrode localization

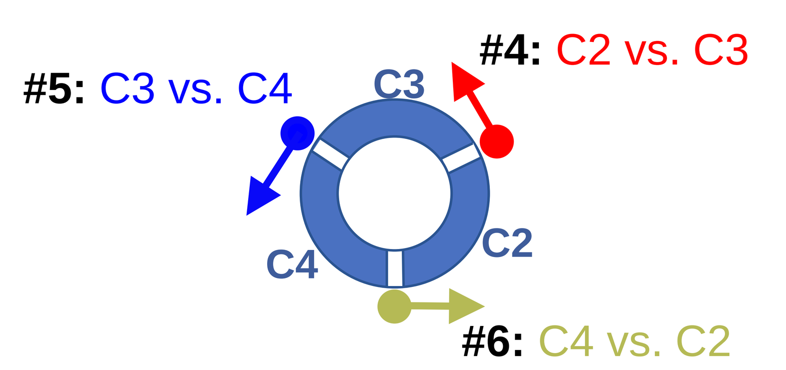
using bipolar omnidirectional stimulation



[T1-3], [T1-8], [T1-9], [T1-10]

Electrode orientation detection

using bipolar directional stimulation

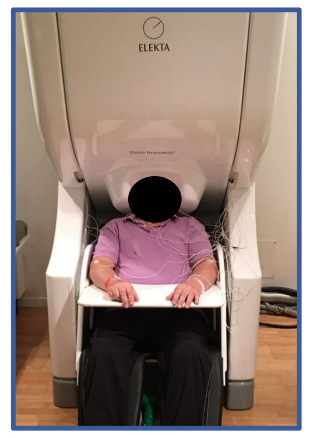


[T1-4], [T1-6], [T1-8]

SQUID-MEG experiments on phantoms [T1-3]:

- Electrode position and orientation were detected with an accuracy of **2 – 3 mm** and **4 – 5°**.
- Nearly **comparable accuracy** to state-of-the-art approaches.
- Accuracies were mainly limited by the **spatial resolution** of clinically available MEG system.
- Minimum required **limit of detection** of sensors for measuring DBS magnetic fields was determined [T1-7].

SQUID-MEG studies on patients [paper submitted]:

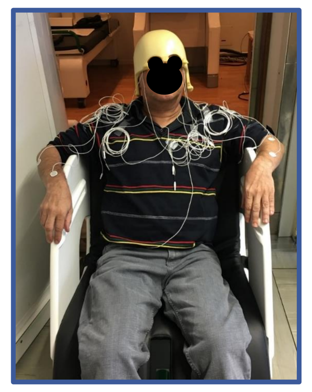


- Electrode position and orientation were detected with an accuracy of **25 – 38 mm** and **16 – 33°**.
- **Less accurate** compared to state-of-the-art methods.
- Accuracies were mainly limited by **significant head movements** during recording, resulting in a blurred magnetic field distribution measured on the sensor surface.

Development of patient-specific head-casts for SQUID-MEG [T1-1]:

- Minimization of head movement from **6 mm to 0.7 mm** at the forehead.
- Head re-positioning accuracy within MEG scanner is around **3 – 5 mm**.

SQUID-MEG studies on patients with head-casts [paper submitted]:



- Electrode position and orientation were detected with an accuracy of up to **6 mm** and **9°** with use of **head-casts**.
- Accuracy of electrode orientation detection **meets the required criteria for clinical use**.
- Accuracies were mainly limited by the **spatial resolution** of clinically available MEG system.

OPM-MEG studies on phantoms:

- Stretchable **OPM-MEG cap** was constructed.
- OPM-MEG appears to be promising for DBS applications as it comes with **higher spatial resolution** than SQUID-MEG.
- Preliminary findings suggest **precise localization** of the electrode, with an accuracy of around 1 mm.

In summary, our collaborative efforts with Boston Scientific have yielded innovative research findings of clinical importance for patients, contributing to the progress of the DBS field. Boston Scientific will continue to pursue further research in this area.

Staff Funded During Second Funding Period

Dr.-Ing. Mevlüt Yalaz (TV E13)

Dr. med. Jos Becktepe and later Dr. med. Robin Wolke (TV Ä1)

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