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 worldwide) [T1-2, T1-5].
- Knowledge of **exact position and rotational orientation** of DBS electrode is essential **(1)** to verify the implanted 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.

New approach and main objective:

Realization of a novel, patient-friendly, clinically applicable, and industrially promising measurement method 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:
Dr. rer. nat. León M.J. Paz (Berlin, Germany)
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 containing a sensor cap with integrated magnetic field sensors and testing of this device on patients.

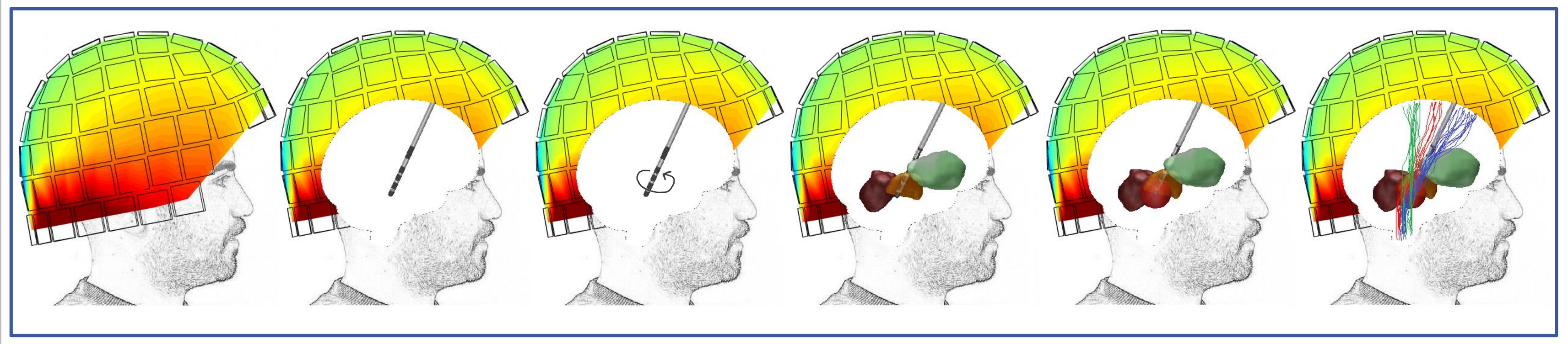
Research Plan Changes

The lack of required sensitivity of CRC sensors, the challenges of combining individual sensors into a sensor array, and the lack of sufficient investigations into the use of sensors outside the magnetically shielded chamber led to …

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

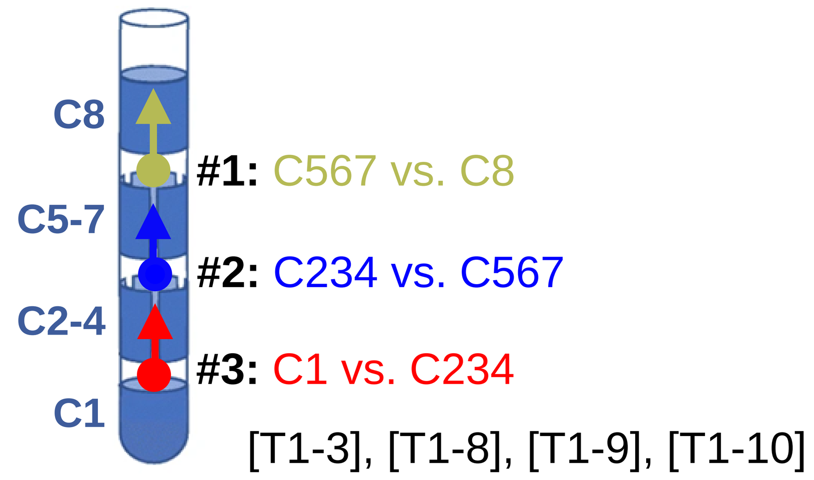
Results

Development of magnetic detection method 'MaDoPO' [T1-3]:



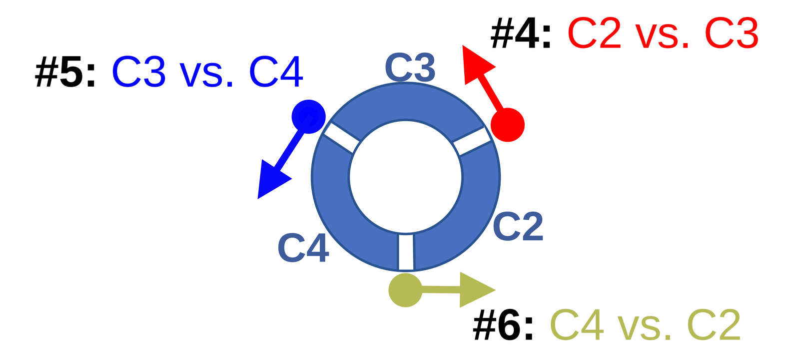
MaDoPO (magnetic detection of electrode position and orientation) exploits the spatial distribution of contacts on the electrode (C1 - C8) and measures the magnetic field distribution outside the head for a defined sequence of different electrode configurations (#1 - #6).

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]:

- Experiments were performed under **ideal conditions**.
- 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.
- Accuracy was mainly limited by the **spatial resolution** of clinically used MEG system.

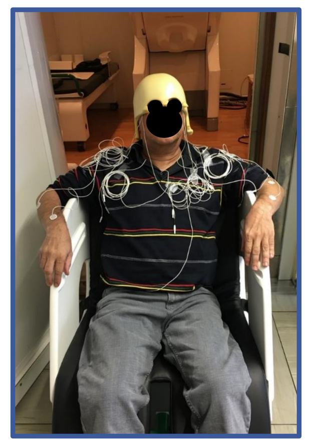
SQUID-MEG studies on patients [not yet published]:

- Experiments were performed under **real conditions**.
- 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.
- Accuracy was mainly limited by…
  (1) significant **head movements** during recording,
  (2) coupling of **additional magnetic field artifacts** due to co-movement of the DBS system, and
  (3) lack of an adjustable electrode configuration due to **shorted and open electrode contacts**.

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

- Minimization of head movement from 1.4 mm to 0.2 mm at head center.
- Head position inside MEG can be reproduced with 1 mm accuracy.

SQUID-MEG studies on patients with head-casts [not yet published]:



- Experiments were performed under **real conditions**.
- Individualized **head-casts** were used.
- Electrode position and orientation were detected with an accuracy of **6 – 8 mm** and **9 – 13°**.
- **Less accurate** compared to state-of-the-art methods.
- Accuracy was mainly limited by the **spatial resolution** of clinically used MEG system.

OPM-MEG studies on phantoms [not yet published]:

- Experiments were performed under **ideal conditions**.
- Stretchable **OPM-MEG cap** was constructed according to the international 10-20 system.
- OPMs appear to be **promising** for DBS application.
- Preliminary results indicate a **precise localization** of the DBS electrode of around 1 mm.

In summary: Scientifically, clinically, and industrially valuable research results in the field of DBS have been achieved and published through the collaboration with Boston Scientific.

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