Measuring brain function using quantum sensors

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Declaration: I am a cofounder and director of Cerca Magnetics limited
Magnetoencephalography (MEG)

Measure the magnetic fields generated by current flow in the human brain
Reconstruction of MEG data relies on mathematical projection of extra-cranial magnetic fields into source space.

\[ \hat{Q}(r, t) = W(r)^T B(t) \]
\[ \min_{W(r)} \left[ \varepsilon \left( \hat{Q}^T \hat{Q} \right) \right] \text{ s.t. } W(r)^T L(r) = I \]
\[ W(r) = \frac{L(r)^T C^{-1}}{L(r)^T C^{-1} L(r)^T} \]

Possible to get images of current density change when a person undertakes a task.
MEG limitations

Cryogenic cooling means sensors are a long way from the head, reducing signal to noise.

One-size-fits-all helmets are built for adults. Brain to sensor distance even larger in infants – scanning babies/children challenging.

Because sensors are fixed in position, any movement relative to the sensor array degrades data quality – it’s hard to scan people who move.

MEG scanners are expensive to buy and maintain. They use Helium which is expensive and non-renewable.
Vision
Optically Pumped Magnetometers (OPMs)

First generation OPMs

Second generation OPMs
OPM-MEG development – 2016 - 2022

- Conventional MEG
- Simulations 2016
- Single channel recording 2017
- First wearable OPM array 2018
- Commercialisation 2022
- 192 channel system 2022
- 50 channel system 2020
- First Gen II recordings 2019

Brookes et al., Trends in Neurosciences (2022)
The advantages of OPM-MEG

Conventional MEG

OPM-MEG

Cryogenic sensors

Vacuum
Liquid helium

Current

Magnetic field vectors

OPM sensors

Brookes et al., Trends in Neurosciences (2022)
Most MEG shielded rooms have remnant field ~30 nT

Any movement of the array relative to a background field results in field shifts which can render sensors inoperable

Need improved techniques to shield external magnetic fields, including better shielded room design and improved active shielding
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- **Active shielding:** apply a field, equal and opposite to that measured inside the MSR.
  - In an optimised MSR, with degaussing, background field reduced to \~3 \text{nT}.
  - With the addition of active shielding, get to \~0.05 \text{nT}.
  - Overall shielding factor around 10^6.

Brookes et al, Trends in Neurosciences (2022)
Paediatric MEG

“Emotional faces” paradigm
- The paradigm alternated between two visual stimuli:
  - Emotional faces (happy, angry, or fearful) for a duration of 0.5 ms (40 trials of each, 120 total)
  - Concentric circles for a duration of 1 s (60 trials)

“Braille” paradigm
- The paradigm provides sensory stimulation alternately to the index and little fingers:
  - Stimulators comprise a 2 x 4 gris of plastic “pins” which tap against the finger
  - Braille stimulators tapped one finger 3 times over the space of ~0.6 s followed by a 3 s rest
Paediatric MEG

“Emotional faces” paradigm

Largest evoked responses localise to the primary visual areas.

Clear evoked response peaking around 100 ms post stimulation.

Signal to noise ratio measured as the standard deviation in the 0 – 0.5 s time window, divided by the standard deviation in a pre-stimulus window.

Largest SNR in visual areas including primary visual and fusiform areas.
"Braille" paradigm

Somatosensory stimulation delivered to the index and little finger of the left hand

We see an evoked response in low frequency and a drop in the ~10-20 Hz frequency band

Beta band response localises precisely to sensory cortex
**Ambulatory MEG**

**Experiment:**
- 3s pressing button with index finger
- 5s no pressing
- Repeated 30 times per hand (randomly presented)
- Explore space between coils during scan
- Repeat with coils on and off

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Right handed finger movement

Left handed finger movement
Hyperscanning

Ping-Pong | Rest
---|---
5 s | 7 s

Rally ping pong ball for 5 seconds then rest 25 trials
Requires more unpredictable, rapid head movements!

Null fields across two helmets simultaneously
Can measure and localise brain activity in two people simultaneously
High quality MEG data captured
Commercialisation

- Formed spin out company Cerca Magnetics Limited in 2020 to commercialise aspects of OPM-MEG technology
- Cerca supply and support an integrated brain imaging system
- Two systems fully installed, with a third scheduled for installation this month, and several more in the pipeline.
- Cerca have live quotes totalling more than £50m across 22 separate countries
- Next big challenge is to gain clinical approval for the use of the Cerca system in epilepsy
Conclusions

• Quantum sensors can get closer to the brain than conventional cryogenic sensors, meaning higher sensitivity and better spatial precision.

• Flexibility of sensor placement allows a quantum enabled system to adapt to any head shape. This means we can scan anyone - babies and adults with optimal sensor placement.

• Wearability of the system means that the sensors move with the head and so, assuming background fields are controlled, we can scan people whilst they are moving.

• Conventional scanners are extremely expensive to buy and run. Even at this early stage of development a quantum enabled system is <50% of the cost of a conventional system.
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