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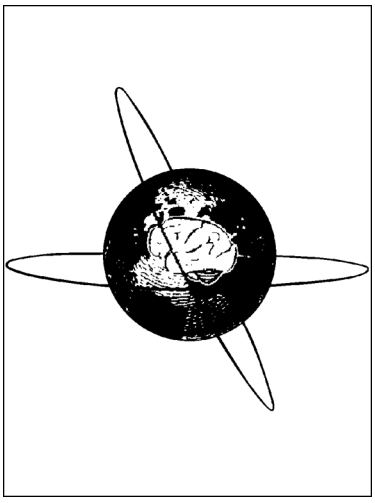

Letter to the Editor

Experiences of ictal OP-MEG

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Experiences of ictal OP-MEG

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Electroencephalography (EEG) is the gold standard investigation for epilepsy management. However, the ability of scalp EEG to detect and accurately source localise mesial temporal epileptiform activity remains controversial (Meckes-Ferber et al., 2004). Magnetoencephalography (MEG) is a non-invasive functional imaging modality similar to EEG. The localisation of MEG signals is less dependent on the anatomical model than EEG, and so can potentially be more accurate. Resecting the epileptogenic focus identified with MEG is a strong predictor of long-term seizure freedom post-surgery (Rampp et al., 2019). However, MEG has traditionally been limited by the cryogen required for the sensors, resulting in a large fixed system, meaning that patient movement is highly restricted and limiting compliance. Alternative sensors called optically pumped magnetometers (OPMs) can overcome some limitations of traditional MEG, allowing a system with movement tolerance more comparable to scalp EEG. OPM based MEG (OP-MEG) has been shown to increase the observed SNR of interictal epileptiform discharges (IEDs) in school-aged children by comparison with traditional MEG (Feys et al., 2022), and to successfully record interictal epileptiform activity from the mesial temporal lobe (Feys et al., 2025). While movement leads to interference in OP-MEG, the technique is considerably more motion tolerant than cryogenic MEG (Boto et al., 2018) and so may be more appropriate for such ictal recordings. Here we add to existing literature on ictal recordings in OP-MEG (Feys et al., 2023; Hillebrand et al., 2023) by demonstrating the ability to record seizures with varying degrees of movement from two epilepsy patients.

Ictal events were observed from two male patients. Ethical approval was given by the Essex Research Ethics Committee in the UK (REC Reference 18/EE/0220) and informed consent obtained. Demographics and clinical information can be found in Supplemental Table 1. Both patients had routine EEGs within normal limits, therefore necessitating prolonged recording. OPM data collection was performed within a Magnetically Shielded Room at UCL (Magnetic Shields Limited). 42 and 38 (for patients 1 and 2 respectively) zero-field OPMs (Gen-2.0 QZFM, QuSpin Inc.) were placed on the scalp in a bespoke 3D-printed scanner-cast, designed from the patient's MRI. Head position and rotation were recorded with 6 OptiTrack Flex 13 cameras (Natural Point Inc.). Each patient sat on a beanbag in the centre of the room with their head unconstrained for approximately 1 hour, monitored by a clinician seated in the room. During the ictal recordings, patient 1 was performing a

verb generation task, while patient 2 (who has musicogenic epilepsy) was listening to music known to activate seizures.

Analysis was performed in SPM (https://github.com/spm/spm). Six 5th order Butterworth filters were applied bidirectionally to the OPM data: band-stop filters at 50 Hz, 100 Hz, 150 Hz and 120 Hz to remove line noise and interference from the OptiTrack cameras, a low-pass filter at 130 Hz and high-pass at 3 Hz. Homogeneous Field Correction (Tierney et al., 2021) was applied to minimise environmental interference. The ictal activity was localised using an LCMV Beamformer with the Nolte single shell forward model with the inner skull surface, segmented from the participant's MRI, and a 5 mm grid source space. For patient 2, this grid was extended to 5 cm outside of the scalp surface to include facial muscle locations as possible sources of the observed data, as the seizure involved facial automatism. For patient 1, the data covariance was estimated from a 10-minute resting state recording to avoid biasing the sources to language areas, while the entire dataset recorded while the participant listened to music (10 min 36 s) was used for patient 2.

Patient 1 experienced a focal impaired awareness seizure (Figure 1A,B and Supplemental Figure 1). During the seizure, there is an observed increase in oscillatory activity within the 13 Hz – 30 Hz range, which localised to the left temporal lobe, consistent with the previous clinical assessment and MRI findings. Patient 2 indicated the beginning of the clinical seizure when experiencing an aura (time = 0 s in Figure 1C). During the seizure, the patient exhibited lip smacking and the urge to turn their head to the left, suggesting a right anterior quadrant seizure onset. Due to this head movement, large, low frequency signals are observed in the OPM data. Therefore, we have focussed on observed increased high frequency (60 Hz – 130 Hz) power, which is less likely to be induced by movement. This localised bilaterally (right > left). The peak increase in power in the right hemisphere is adjacent to the inferior frontal gyrus (pars opercularis) (MNI coordinates: (55.5, 20.1, 0.2)). The maximum in the left hemisphere within the inner skull surface was found adjacent to the inferior frontal gyrus (pars triangularis) (MNI coordinates (-55.3, 19.9, -5.5)). The peaks in both hemispheres are adjacent to the respective superior temporal pole and gyrus.

Ictal OP-MEG from patient 1 shows clear activation localising to the expected region. With patient 2, we have examined observed increases in high frequency activity during this seizure. These localised close to the superior temporal gyri, often associated with musicogenic seizures (Stern, 2015), and the inferior frontal gyri, areas which have been associated with perceiving and enjoying music (Zatorre and Salimpoor, 2013). We cannot absolutely rule out that facial muscle artefacts or eye movements, could be the cause of these high frequency signals. However, despite including facial muscles as possible sources of activity, the peak of the activity was still observed within the brain. In future, this is likely to be less of a concern as there have recently been a number of developments in post-hoc software based interference correction for OP-MEG.

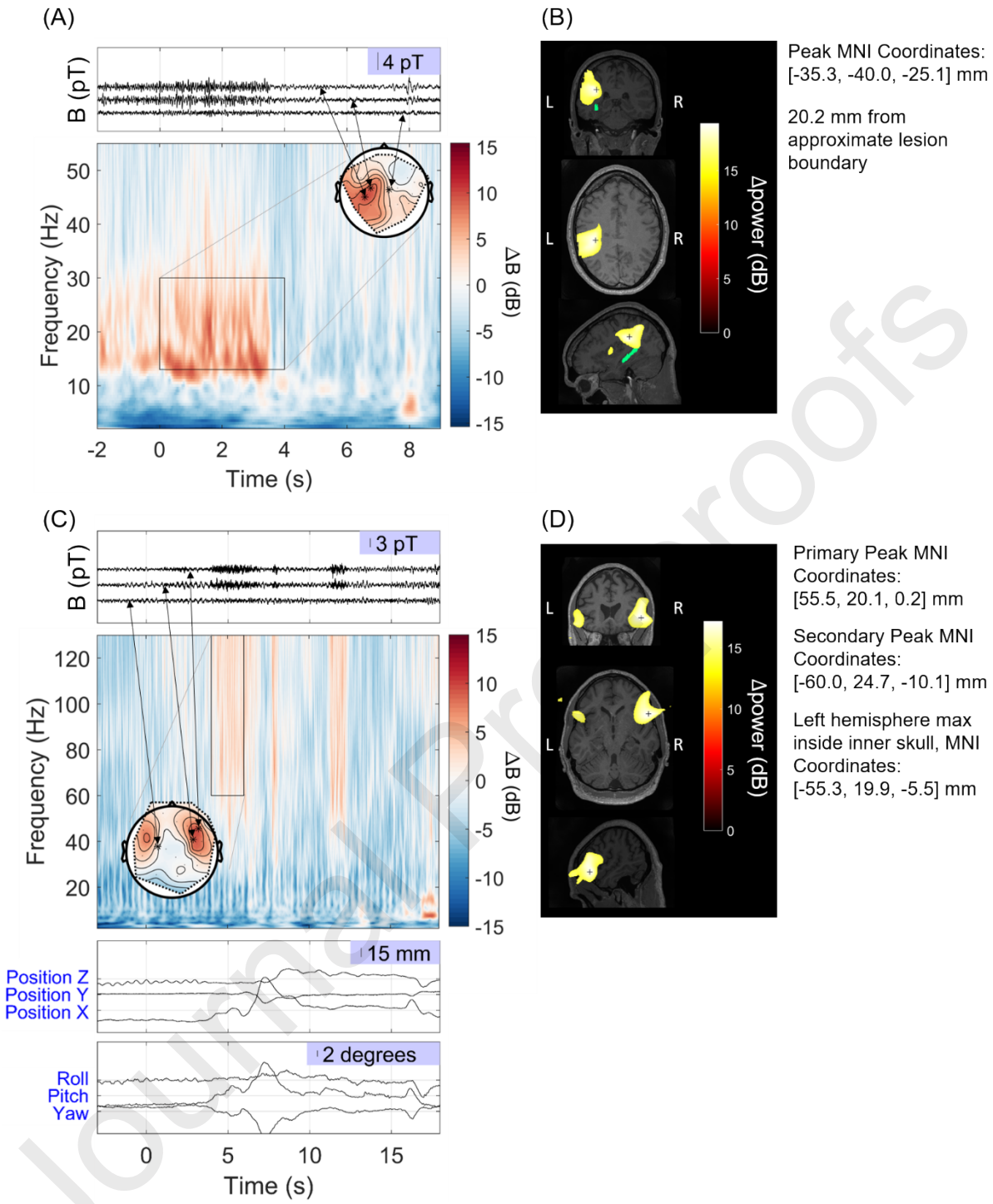
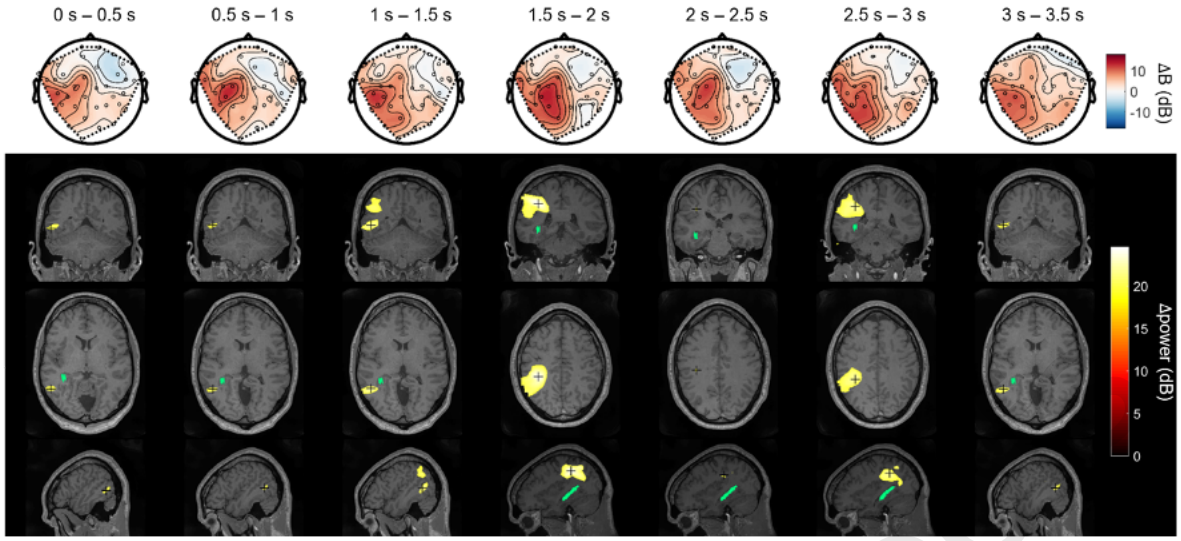


Figure 1. A) Ictal activity observed from patient 1 at the sensor-level. The seizure onset was at 0 s. The time-frequency spectrum is shown averaged over all channels, baseline corrected by the average power in a rest recording, alongside the topography of the average change in power within the window of interest (0 – 4 s, 13 – 30 Hz) (showing only the OPM channels radial to the head) and the recorded magnetic field over time for 3 radial channels: the two with the highest and the one with the median average power change within that window. There is a visible increase in oscillatory activity between 0 – 4 s. There may also be an IED, as is often observed at the end of a seizure, at 8 s. B) LCMV beamformer localisation of this 13 – 30 Hz power increase, contrasting the 0 – 3 s window with the 4 – 7 s window. Thresholded at 80% of the maximum power change. The maximum power increase lies in the left temporal lobe and is marked by a black cross. The MRI abnormality is marked in green. C) Ictal activity observed with patient 2, shown at the sensor-level. Patient reported commencement of aura at 0 s. Equivalent of (A) but with the addition of participant head position and rotation. 4 – 6 s; 60 – 130 Hz was chosen as the window of interest based on the time-frequency spectrum. D) LCMV beamformer localisation of the increase in power in 60 Hz to 130 Hz frequency range between 4 – 6 s by comparison with -7 – -5 s, thresholded at 80% of the maximum power increase. The black cross shows the peak power location.



Supplemental Figure 1. LCMV beamformer for different time windows during the event. As in Figure 1B, the MRI abnormality is shown in green.

Patient No.	Years after epilepsy onset:		Findings from clinical MRI	Findings from clinical EEG telemetry	Ictal OP-MEG localisation
	OP-MEG	Clinical EEG			
1	19	19	Left temporal lobe, 20.2 mm from lesion boundary	Left temporal lobe grey matter heterotopia	Left temporal interictal; left neocortical ictal
2	13	9	Inferior frontal gyrus (R>L)	Normal	Right temporal

Supplemental Table 1. Patient demographics and clinical characteristics.

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Anonymised OPM data will be made available upon request. Analysis code is available on GitHub (https://github.com/stephaniemellor/epilepsy_opm_data_analysis).

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