# The relationship between fMRI and MEG: Visual contrast response

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**Introduction** Recent studies [e.g. 1] have shown that a combination of functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG) may provide insight into the neuronal basis of the BOLD effect. The neuromagnetic field measured in MEG is thought to be largely induced by post-synaptic currents in the dendrites of active, cortical pyramidal cells. Attwell and Laughlin [2] have argued that the majority of energy expended in the human brain is also related to post synaptic events, suggesting that if the fMRI BOLD response is truly a measure of energy use in the brain, it should correlate strongly with the measured neuromagnetic response in MEG. Here, we investigate the correlation between evoked and induced MEG signals and the BOLD response elicited by a simple visual stimulus. Further, we assess the linearity of each of the MEG and BOLD responses to visual stimuli of varying contrasts.

**Methods:** Five healthy subjects took part in the study. The paradigm comprised a sinusoidal drifting grating, presented in a circular window with a visual angle of 5°. The circle was shifted through an angle of 3° into the lower left hand quadrant of the visual field. Five Michelson contrasts (0, 0.125, 0.25, 0.5 and 1) were presented pseudo-randomly with a stimulus duration of 4secs. To maintain attention, on stimulus cessation, subjects executed a button press to indicate the contrast of the stimulus. Trial length was 8secs in MEG with 20 trials per contrast and 16 secs in fMRI, with 8 trials per contrast. MEG data were acquired at a sample rate of 600Hz, on a 275-channel CTF system, in third order gradiometer configuration. Co-registration to anatomical MRI was performed using head digitisation (Polhemus Isotrack). Contiguous axial slices covering the visual cortex were acquired on both 3T and 7T Philips Achieva system running GE-EPI (*3T*:- TR=2000ms, TE=40ms, 3x3x3mm$^3$ voxels, 192mm FOV, 18 slices, SENSE factor 2) (*7T*:- TR=2000ms, TE=25ms, 2x2x2mm$^3$ voxels, 156mm FOV, 15 slices, SENSE factor 1.5).

**Data Analysis:** MEG data were analysed using synthetic aperture magnetometry (SAM) [3]. Spatial localisation of oscillatory power changes in the beta (15-30Hz) and gamma (60-80Hz) bands was achieved by comparison of an active contrast window of 0-3.9s to a passive contrast window of 4.1-7.9s. Visual evoked fields were localised with an active window of 0-0.3s and a passive window of 6-6.3s. Pseudo T-stat images (1mm$^3$ resolution) were created showing regions of activity within these bands. Virtual sensor traces were extracted from peaks of activity in the SAM images to show time courses of oscillatory power. These were obtained by applying a Hilbert transform to the virtual sensor data and averaging across trials. Linearity of the response was assessed by integration of the Hilbert envelope. An average signal value taken over the rest period was used as baseline for integration. Areas of significant (p=0.05 corrected) BOLD contrast were identified using SPM5. These regions of interest (T-stat >5.5) were then used for spatial localisation. Peaks within the SPM were used to define seed voxels with T-stat>10. 9mm cubic volumes surrounding the seed voxels were used to obtain average time-courses of the haemodynamic response. Linearity of the BOLD response was assessed by integration of the BOLD time course. An average signal value during the 0 contrast stimulus was computed and taken to be the baseline for integration.

**Results and Discussion:** Figure 1 demonstrates the excellent spatial co-localisation of the fMRI BOLD response and MEG responses. Both localise to the centre of the primary visual cortex, with activity of lower T-stat in the lateral visual areas. This experiment achieves spatial separation of the various MEG and therefore provides a method of determining the extent to which each contributes to the BOLD response. This can be seen in Figure 1 where the peak in gamma activity (Ŧ>3) and the visual evoked field (Ŧ>6) localise to the contra-lateral central visual field, in agreement with the global maximum of the BOLD response (image threshold T>5.5 for 3 and 7T). The beta band activity (Ŧ>2) however exhibits bi-lateral activity and in other slices is also found in the more lateral visual areas in both hemispheres. The BOLD localisation at both 3T and 7T shows excellent spatial agreement with the beta activity, even though the power in the β band decreases during stimulus presentation, unlike the γ activity which experiences an increase in power (Figure 2). Figure 2 shows the difference in temporal resolution of MEG and BOLD with the BOLD response peaking sometime after completion of the MEG effect. Figure 3a shows the contrast response curves for each of the MEG responses. The visual evoked field exhibits a linear response to contrast, as has previously been shown in MEG studies [4]. The gamma response exhibits a similar trend and unlike the BOLD derived contrast response curve (Figure 3b) does not seem to saturate at high contrasts. The beta response does not change with contrast in either the central or lateral visual areas, this may be reflective of an idling rhythm with a threshold on/off.

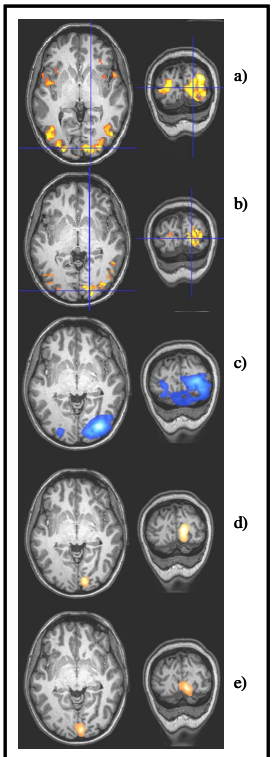


**Figure 1:** Spatial localisation in a single representative subject of BOLD responses a) 3T, b)7T and MEG data c) β band d) γ band and e) Visual evoked field.

**Conclusion:** The overlap in spatial localisation of the gamma, visual evoked field and a peak in beta activity in contra-lateral V1 suggests that some combination of all of these responses contributes to the BOLD response in this region. In the more lateral visual areas, the BOLD derived contrast response curve is very similar in shape to that obtained in the central visual areas, but the MEG activity in these regions does not include a gamma band (60-80Hz) response. The fact that the shape of the BOLD contrast response curve is not reflected in an individual MEG response may well result from neurovascular coupling effects. However, the excellent co-localisation of the MEG and BOLD data suggests the two are intimately linked. It may also imply that some combination of the MEG effects contribute towards the BOLD response.

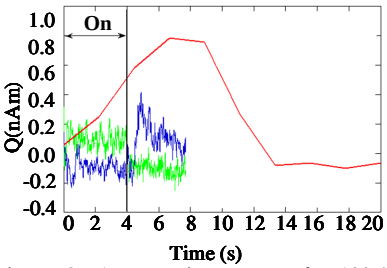


**Figure 2:** Average time-courses for 100% contrast in contra-lateral V1. Envelopes of γ and β activity shown in green and blue respectively. BOLD shown in red. Black line shows stimulus cessation.

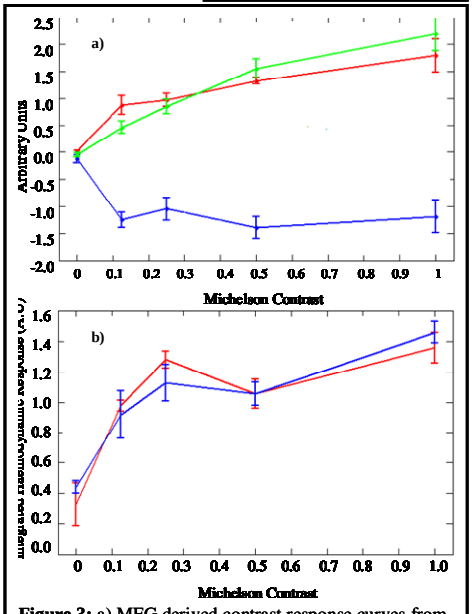


**Figure 3:** a) MEG derived contrast response curves from peak of SAM activity in contra-lateral V1. Visual evoked field shown in red, γ band activity (60-80Hz) in green and β band activity (15-30Hz) in blue. b) BOLD derived contrast response curves from contra-lateral V1. 3T results shown in red and 7T results shown in blue.

**References:** [1] Brookes et al, Neuroimage 26 (2005) 302-308, [2] Attwell and Laughlin, J. Cerebral Blood Flow and Metabolism 21 (2001) 1133-1145, [3] S.E. Robinson et. al., Biomag 98, 11th Int Conf. on Biomagnetism (1998) [4] S.Hall et al., NeuroImage, 26(1)(2005)13-17.