Tight neurovascular coupling in human sensorimotor cortex: a combined ECoG and 7T BOLD fMRI experiment

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Introduction

An often reported mismatch between expected and measured vascular responses with increasing stimulus rates has led to the notion that neurovascular coupling is non-linear, which complicates models and interpretation of fMRI [1, 2]. Here we challenge the notion by incorporating a recently discovered non-linearity between stimulus and neuronal response in the equation [3]. We assess the neurovascular coupling of the sensorimotor cortex with a motor task by combining presurgical 7T BOLD fMRI acquisition and high density intracranial electrocorticography (ECoG) grids post-implant. With increasing movement rate, the amplitude of not only the BOLD but also the ECoG broadband high frequency gamma response declined. The latter explained almost 80% of the apparent BOLD nonlinearity, indicating that the BOLD response is tightly linked to neuronal activity in human sensorimotor cortex.

Materials and Methods

Data acquisition: three right handed subjects participated. They performed four hand movement tasks with increasing movement rates of 0.3, 0.5, 1, and 2Hz (15 trials per movement rate). One trial consisted of 6 s of movement execution followed by 15 s rest. The subjects had normal hand function and were scheduled for the implantation of ECoG arrays for the clinical purpose of epilepsy monitoring. *BOLD*; presurgical BOLD data were acquired on a Philips 7T system (16-channel head coil) using GE-EPI BOLD: TR/TE = 880/27 ms, flip angle = 65°, SENSE factor = 2.5, FOV = 155 × 155 mm^2, and 13 slices on the left sensorimotor cortex (M1 and S1). *ECoG*; an 8×4-electrode grid was placed over the sensorimotor area (3mm pitch) and subjects performed the same motor task while ECoG was recorded (512 Hz). ECoG mean power in the high frequency broadband (65-95 Hz, HFB-power) were averaged over M1 and S1 separately, and across trials (N=15). All movements were recorded with a digital dataglove. Recorded data were converted to input functions for analysis. *Analysis:* Measured BOLD timecourses from M1 and S1 (including only the voxels active for all movement rates) were compared to the two predicted BOLD timecourses. These were based on (i) the behavioural data as recorded by the dataglove (input functions convolved with a subject specific HRF; 'movement-based BOLD'), and (ii) on the ECoG HFB-power responses, i.e 'ECoG-based BOLD'. In the latter, the dataglove input functions were subsequently normalized by the HFB-power for each movement (see Fig 1C).

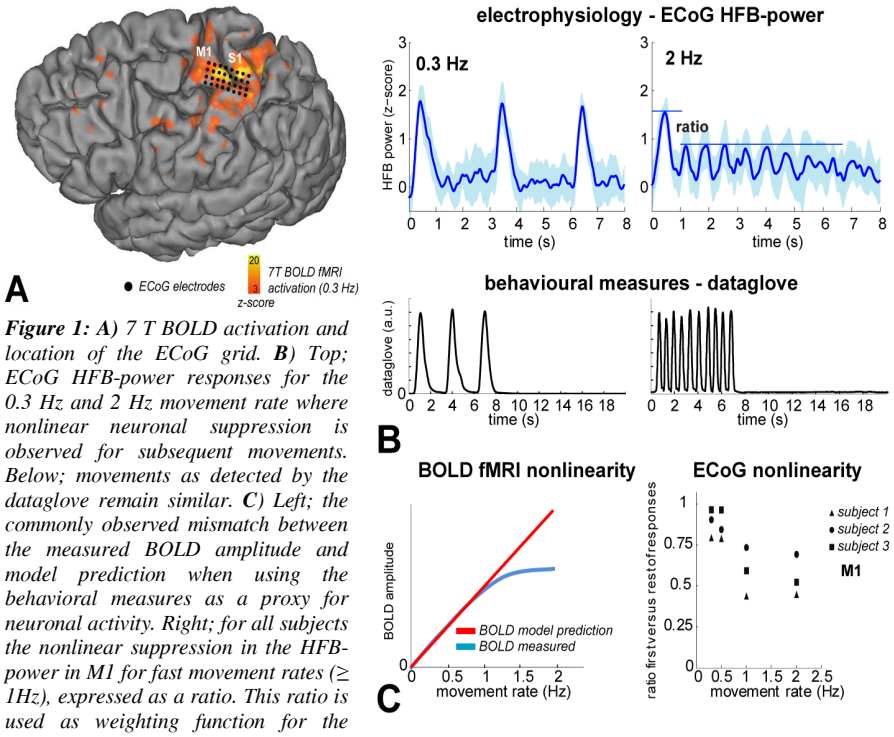

Figure 1: *A) 7 T BOLD activation and location of the ECoG grid.* ***B****) Top; ECoG HFB-power responses for the 0.3 Hz and 2 Hz movement rate where nonlinear neuronal suppression is observed for subsequent movements. Below; movements as detected by the dataglove remain similar.* ***C****) Left; the commonly observed mismatch between the measured BOLD amplitude and model prediction when using the behavioral measures as a proxy for neuronal activity. Right; for all subjects the nonlinear suppression in the HFB-power in M1 for fast movement rates (≥ 1Hz), expressed as a ratio. This ratio is used as weighting function for the 'ECoG-based BOLD'.)*

Results

Fig1A shows the location of the ECoG grid on top of the 7T BOLD sensorimotor activation for a representative subject, together with the observed nonlinear behaviour with respect to movement rate for both the BOLD amplitude (Fig1C left) and ECoG HFB-power (fig 1C right). Fig 2A shows the BOLD timecourses for the measured, movement-based, and ECOG-based BOLD (blue, red and black lines respectively) for the 0.3 and 2 Hz in M1 for a single subject. Fig 2B shows the BOLD amplitude comparison averaged over all subjects. ECoG-based BOLD shows a similar saturation behaviour to the measured BOLD with respect to movement rate. The movement-based BOLD overestimates the measured BOLD amplitude up to a factor of 1.9 for the faster movement rates (≥ 1 Hz). The ECoG-based BOLD reduced the movement-based BOLD overestimation by approximately 82±3% for M1 for all movement rates ≥ 0.5 Hz. Similar results were found for S1.

Discussion

In the present study, the apparent non-linearity of neurovascular coupling in human sensorimotor cortex was challenged in light of new evidence (ref [3]) of a mismatch between behavioral measures and electrophysiology. Here we investigated relationships between behavioral, BOLD and ECOG measures, in a human sensorimotor experiment. Our data show a nonlinear relationship for both the BOLD and neuronal responses with respect to hand movement rate, in the presence of rate-invariant movement measures. When including the subject-specific nonlinearity in ECoG HFB-power in our BOLD fMRI prediction model we obtain a high goodness-of-fit of our measured BOLD data for all movement rates. This indicates that a large portion of the BOLD nonlinearity is well explained by the HFB-power nonlinearity, and therefore the neuronal processing associated with the HFB-power. Thus, while there can be a discrepancy between hand movements and both the BOLD and ECoG responses, the latter are closely matched within the same patch of sensorimotor cortex. Further research is warranted to translate these finding to other cortices and brain functions.

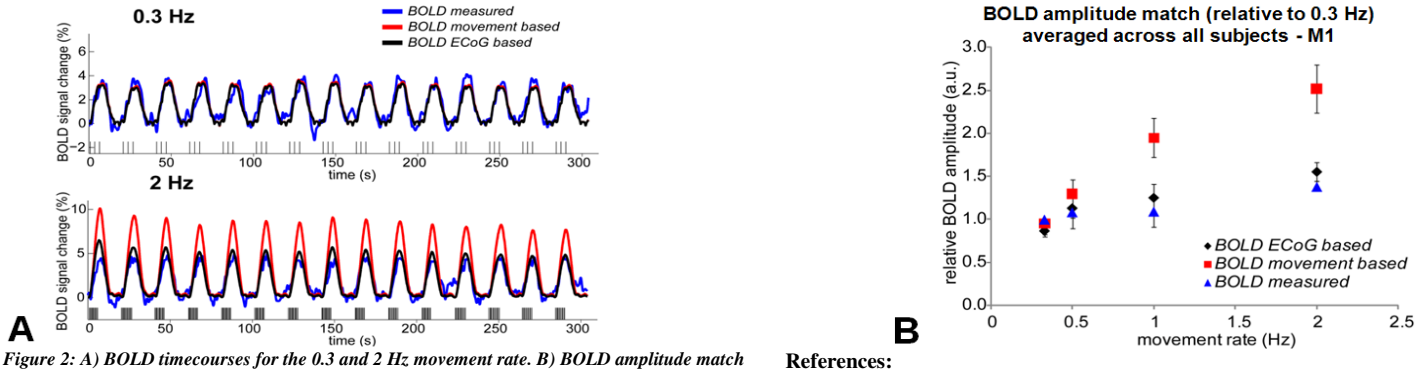

Figure 2: A) BOLD timecourses for the 0.3 and 2 Hz movement rate. B) BOLD amplitude match for the measured (blue), movement-based (red) and ECoG-based BOLD, averaged across all subjects for M1.

References:

[1] Blinkenberg et al, JCBFM 1996 [2] Jancke et al, Nsci. Let. 1998 [3] Hermes et al, J NSci 2012