Voluntary action rhythmically modulates 7T BOLD visual responses in primary visual cortex

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Introduction

Behavioral visual sensitivity varies rhythmically (in the theta-range, around 5 Hz) over time when synchronized with an attentional cue, a sensory stimulus, or with the onset of a voluntary action. These behavioral rhythms may emerge from phase-resetting of endogenous neuronal oscillations by motor preparation, implicating them in sensory-motor coordination.

Aim of the study

Here we investigate the BOLD correlates of this effect using **7T fMRI**, which enabled us to measure responses to brief visual events in early visual cortex and simultaneously monitor activity over the motor cortex.

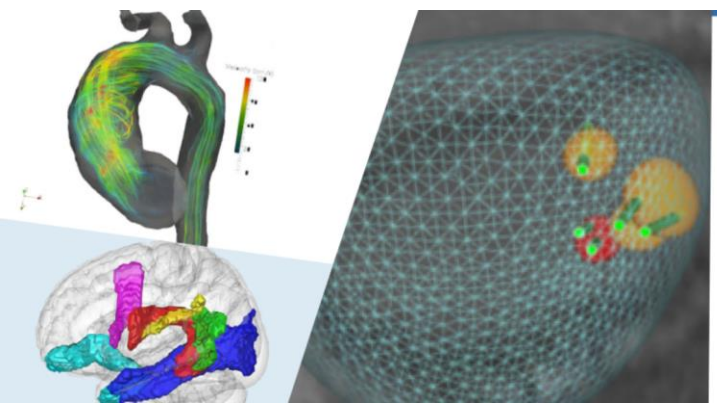
i) How early does the synchronization arise in the cortex? Is it directly modulating the BOLD of the primary visual cortex?

ii) Is the visual oscillation influenced by the motor activity? Does it mediate the precise synchronization between action and perception?

Methods

MRI scan

In a GE MR950 7T research system, we used a T2*-weighted GE-EPI sequence with TR = 3s, to measure BOLD modulations to discrimination *action for decision* and *vision and action* events. Functional data were corrected for EPI distortion, motion and slice-time acquisition, and aligned to 3D anatomies with FSL/Freesurfer.



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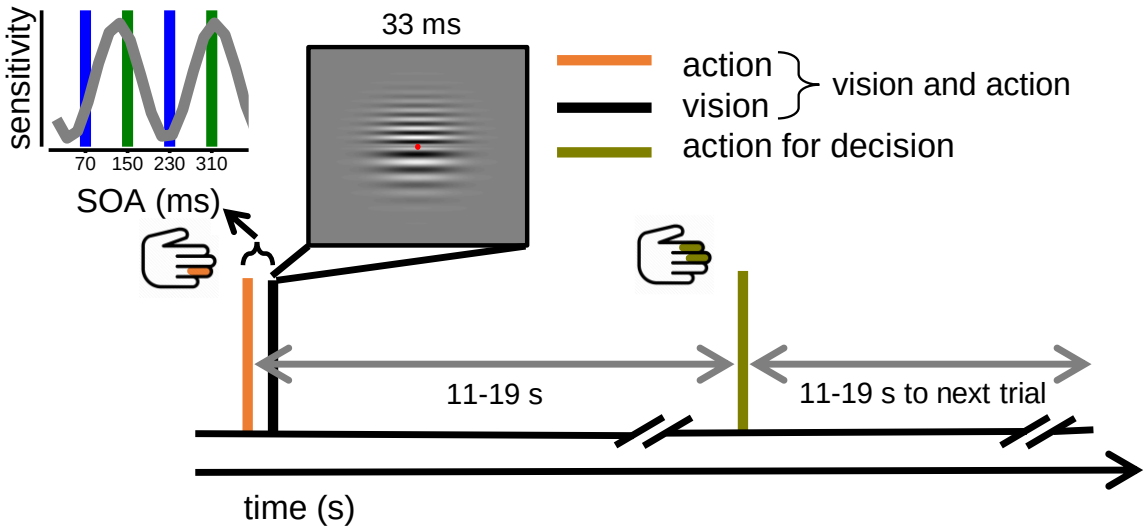
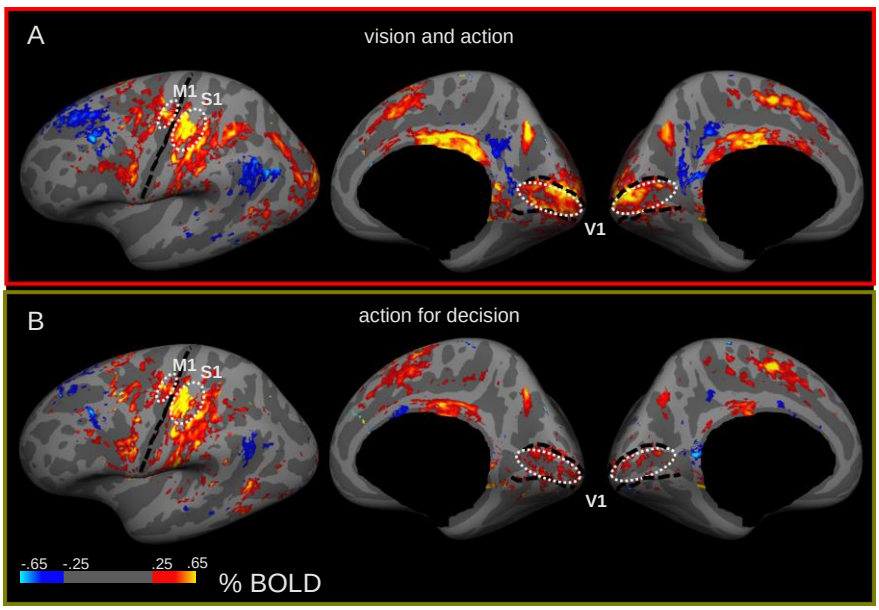
Methods

Stimuli and procedures

In an **event-related design**, we measured in **21 participants** the **V1** and **M1 and S1 BOLD responses** to a 33ms visual stimulus (frequency discrimination task). The stimulus was presented at 4 possible delays (70, 150, 230, 310ms) from the onset of a voluntary action (keypress), corresponding to the first two **peaks** and **troughs** of the **behavioral oscillation** measured outside the scanner. Participants reported their decision by means of a second keypress (different keys). They were instructed to pause between consecutive actions (about 15s).



ROI definition



BOLD responses to the motor discrimination task were observed in two separate foci around the Rolandic sulcus, systematically sparing area 3a; we used these activation maps to define the **M1** and **S1** ROIs. **V1** was defined by retinotopic mapping to include the stimulus cortical representation.

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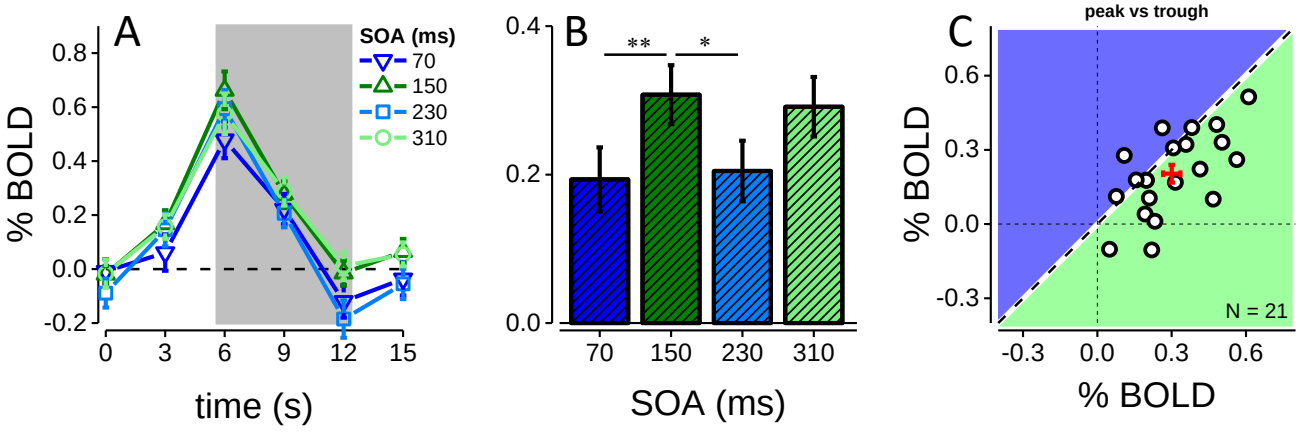
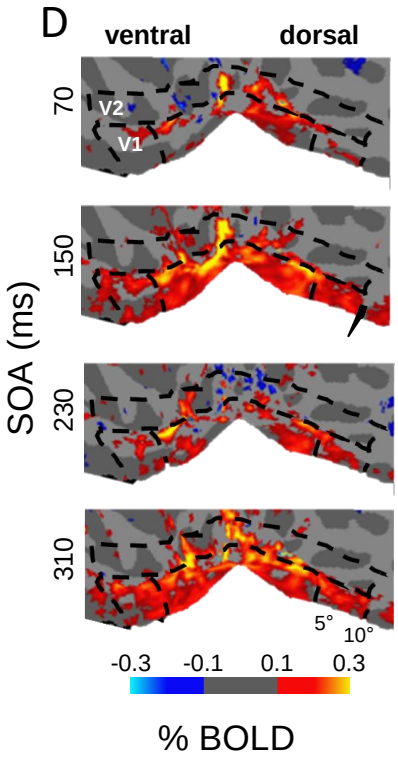
Results: V1 BOLD response





***A**: Timecourse of the BOLD response to visual stimuli in V1 for different SOAs.*

***B**: averaged BOLD response for the different SOAs. Activity was lower for stimuli delivered 70 and 230ms after the keypress, and higher for stimuli at 150, and 310ms, consistent with perceptual oscillation.*

***C**: BOLD responses for SOAs falling on the peak (abscissa, 70 and 230ms) vs. those on the trough (ordinate, 150 and 310ms) of the behavioral oscillations, revealing a stronger response for stimuli presented at the peak of the oscillation ($p<0.05$).*

***D:** BOLD response projected on the cortical surface. Dashed lines indicate the borders between V1 and V2 and visual eccentricities. A stronger and more spread activity is clearly visible for SOAs 150ms (second panel from top) and 310ms (bottom panel) compared to the activity for SOAs 70ms (top panel) and 230ms (third panel from top).*

BOLD activity in human **primary visual cortex (V1) oscillates** rhythmically and synchronously contingent with a **voluntary action**. This rhythmic modulation follows the **oscillation of behavioral discriminability** of the same visual stimulus, in the **theta range** (around 5Hz).

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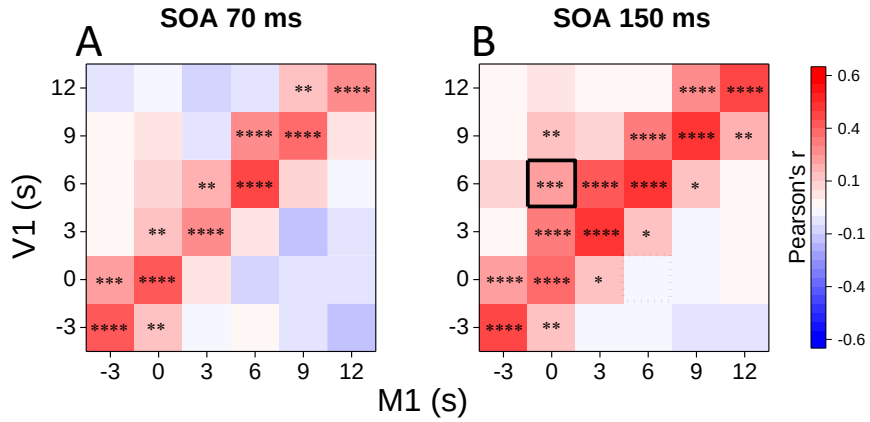
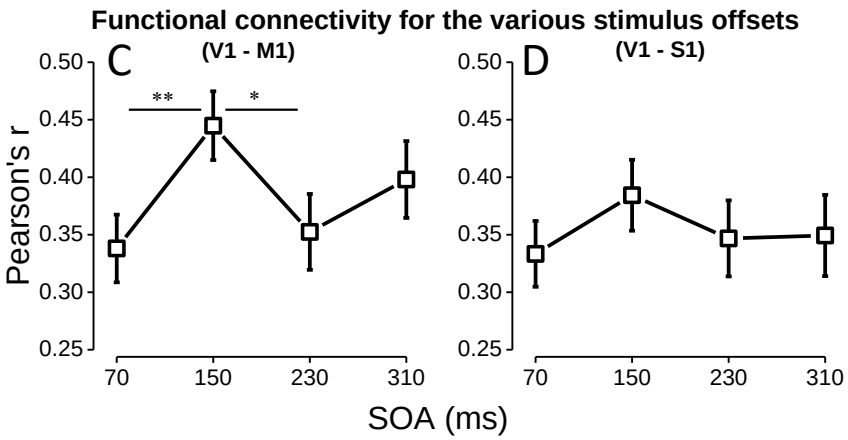
Results: V1-M1 functional connectivity





***A-B**: correlation matrix between V1 and M1 at specific times of the BOLD, for SOA of 70ms (panel A) or 150ms (panel B) . Notably, the activity in M1 at 0s (action onset before visual stimulus) is predictive of the forthcoming activity in V1. In contrast V1 BOLD at time 0 does not predict future activity of M1.*

***C-D**: coefficient of correlation between V1-M1 (panel C) or V1-S1 (panel D) peak activity, plotted as a function of SOA. The correlation between V1 and M1 is higher for SOAs 150ms and 310ms (panel C), mimicking the rhythmic dynamic observed in V1 BOLD response and in the behavior. Conversely, V1-S1 correlation does not show a similar modulation (panel D).*

The state of the **motor cortex** before action onset **predicts** the **activity of V1** at the time of visual presentation, demonstrating a form of **predictive sensory-motor communication** across a long temporal interval.

The **functional connectivity between V1 and M1 oscillates** at the same theta rhythm observed in both the V1 BOLD response and in visual sensitivity.

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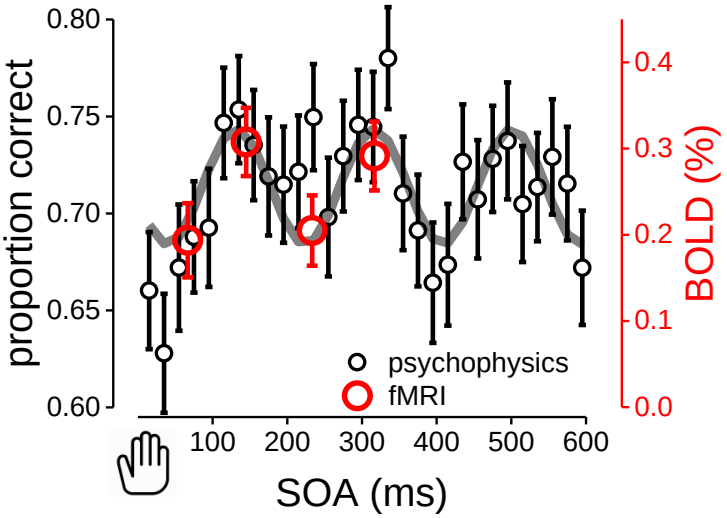
Conclusions



BOLD response in V1 fluctuates rhythmically at about 5Hz (red symbols), closely following the rhythmic variations of behavioral discrimination performance (black symbols).

i) The rhythmic modulation of vision synchronized with action execution, is already affecting neural responses in the primary visual cortex, demonstrating the existence of an early site of sensorimotor interaction.

ii) Our finding that M1 activity during action planning predicts later V1 responses demonstrates the existence of a predictive signal, which is exchanged between these distal areas through the synchronization of oscillatory activity patterns.

iii) Our results provide a direct evidence that early visual processing is shaped by motor planning before visual stimulation: action representation impacts sensory processing of forthcoming stimuli, through the synchronized and long-lasting oscillation of activity in motor and primary sensory brain areas.

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