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# Temporal dissection of stimulus-driven and task-driven processes during perceptual decision about 3D SFM stimuli

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**Abstract**— Analyzing the visual properties of a stimulus, such as its shape or its motion, involves a temporally constrained cascade of processes including sensory integration, attentional selection and perceptual decision. In natural conditions, these processing stages may temporally overlap. In this study, we used a time constrained paradigm designed to segregate these stages, and recorded MEG activity to characterize their cortical correlates.

The experimental sequence comprised a structure-from-motion (SFM) target flanked by pre and post masks, which limited the stimulus-driven processes in time.

The MEG responses were recorded in three perceptual tasks bearing on the presence or absence of the target SFM stimulus, on its direction of motion or on its 3D shape.

Subjects' responses were delayed to the end of the trials using a random stimulus-response mapping.

The analysis of the evoked magnetic fields reveals temporally non-overlapping responses for stimulus-driven and task-related processes.

Source reconstruction reveals that the occipital, dorsal and ventral stimulus-related areas follow different temporal profiles. The response in IPS slowly rising after the beginning of the activity in the lateral occipital cortex and falling back to the baseline prior the delayed motor response, may reflect accumulating evidence on the presented stimulus leading to a motor response, in line with the results from single cell studies in monkey LIP [1].

**Keywords**— visual motion, 3-D shape, perceptual decision, MEG, source reconstruction.

## I. INTRODUCTION

Analyzing the visual properties of a stimulus, such as its shape or its motion in the 3-D environment, involves a temporally constrained cascade of processes including sensory integration, attentional selection and perceptual decision. In natural conditions, visually dynamic events require the integration of information about form and motion. Recent studies have challenged the traditional dichotomy between form- and motion-related processes in the ventral and dorsal visual pathways, and there is now evidence that form and motion processing interact in several ways. Both figural and low-level form cues guides motion perception, whereas

motion cues can induce figural percept (see [2] for a review). However, more work is needed to better understand the perceptual decision stages and the attentional modulation required by the task. The experiments described in this paper aims at investigating these issues.

To segregate the different processing stages, we used structure from motion stimuli which yield both motion and shape percepts from motion cues only, and designed a time constrained paradigm with dynamical masks. We recorded MEG activity to characterize the cortical correlates of such perception in three perceptual tasks bearing on the presence or absence of a target SFM stimulus, its direction of motion or its 3D shape. We reasoned that the masks would isolate a time window for measuring the integration of form and motion cues by interrupting the early visual processing. By carefully choosing supra-threshold stimuli, we ensured that this integration yield to a perceptual decision, the MEG correlate of which should be detectable.

We specifically tested when the attentional modulation induced by the task takes place in the cortical activity, and if this modulation could be found in the occipital and intraparietal areas that are involved in the stimulus integration. We also searched a magnetic correlate of the perceptual decision processes in IPS, a region known to be involved in the accumulation of evidence in visual task implying motion stimuli [1].

## II. MATERIALS AND METHODS

### A. Experimental procedure

**Participants.** Sixteen people (age  $28.5 \pm 8.1$ , right-handed, normal or corrected-to-normal vision, 7 men) took part in the study after giving their informed consent. The study was approved by the Local Ethical Committee.

**SFM stimuli and motion masks.** Structure-from-motion (SFM) stimuli were made of 140 white dots ( $0.19^\circ$  visual angle) randomly distributed on a black background and back-projected on a 3D virtual surface. The surface had three possible shapes and oscillated in depth with three

possible motion directions. Stimuli were viewed through a 20° circular mask hiding the boundaries of the 3D surface. Overall, nothing but motion cues could be used to identify the shape.

For the masks, dots followed a random walk with instant speeds comprised between 0°/s and 7°/s to match that of the SFM stimuli. More details about the display can be found in [3], where identical stimuli were used.

*Experimental design.* During the MEG recording, participants underwent six runs of 90 trials (see Figure 1) each.

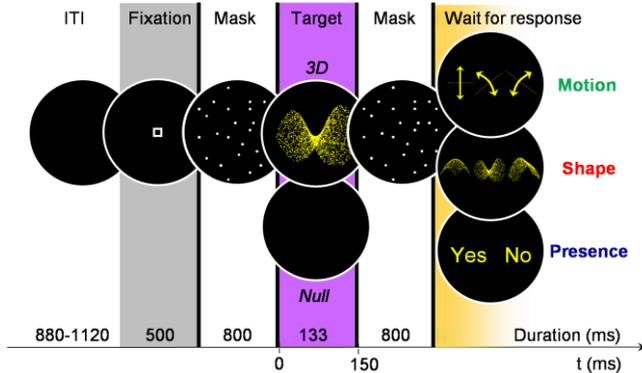


Fig. 1 Schematic time flow of a trial

Depending on the experimental run, participants had to:

- identify the target shape among three (Shape task);
- identify its motion direction among three (Motion task);
- answer whether a 3D stimulus appeared or not among the mask (Presence task). Run order was randomized across subjects.

The target, either a 3D stimulus (56 %) or a black screen (44 %) was flanked by dynamical masks to limit the duration of its visual integration. Because the stimulus-response mapping varied across trials, participants had to wait for the response screen to give their answer, so that motor activity was delayed after the end of the second mask.

Participants fixated the center of the screen but were advised to broaden their attention on the whole viewing window to ease identification. When a null target occurred in the shape and motion tasks, they had to choose a default response, which was specified at the beginning of the experiment and was randomized across subjects.

Stimulation was projected at 90 cm from the participants, using a calibrated LCD video device (60 Hz refresh rate) located outside the shielded room.

*Data acquisition.* MEG was recorded continuously during the runs (sampling rate: 1250 Hz), using a 151-channel whole-head system (axial gradiometer, CTF System, Canada). We ensured that the head position relative to the sensors did not change by more than 5 mm along the whole

experiment. Electro-oculogram was also measured for off-line artefact rejection.

## B. MEG analyses

Trials with signal artefacts (blinks, saccades, muscle signal...) were rejected using semiautomatic procedures. A 300-ms baseline was defined in the fixation period.

*Event-related magnetic field (ERF).* Trials were averaged by task and type of target, resulting in six ERF by subject.

*Source estimation.* The cortical current density was estimated using overlapping spheres for the head model and a minimum-norm constraint for the solution of the inverse problem (<http://neuroimage.usc.edu/brainstorm>). Individual anatomy was available for half subjects; scalp tessellation was then computed using BrainVISA (<http://brainvisa.info>). For the other half, we used a default head model based on the same template as that used to define the cortical surface on which results were projected (MNI “Colin 27” brain).

*Sensors and regions of interest (ROI).* The response to the 3D target condition in the Presence task was used to delineate groups of sensors and brain areas activated by structure-from-motion perception. We selected four regions of interest (see Figure 2), the activity of which was representative of the profiles encountered in all activated regions.

*ANOVA.* ERF were averaged within sensor groups and analyzed time by time in a repeated-measure ANOVA with factors Task (Shape, Motion); Target (3D, Null) and Sensors (Occip, Temp, Pariet, Centr, Front). We also performed a 2 x 2 (Task, Target) ANOVA in the selected areas.

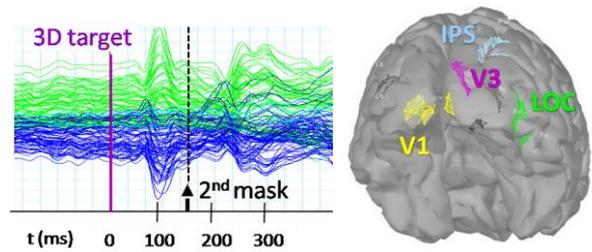


Fig. 2 Activity related to the 3D target in the Presence task (left) and selected regions of interest (right). V3: superior occipital gyrus; LOC: lateral occipital cortex; IPS: intraparietal sulcus.

## III. RESULTS

### A. Temporal dissociation of task and target effects

The ANOVA performed on the sensors revealed a temporal dissociation of the task and target effects, with significant ( $p < 0.001$  uncorrected) target x sensors and task x sensors crossed effects occurring respectively between 100

and 200 ms, and between 300 to 320 ms. These crossed effects are explained by the topographies depending on the target in the first time window, and on the task in the second time window. More precisely, the target-related effect corresponds to modulations in the occipital sensors, whereas the task-related effect better corresponds to modulations in the parietal and temporal sensors.

### B. Cascade of activity from V1 to IPS

At the source level, both the time window of the target effects and the activity profiles (see Figure 3) reveal the successive involvement of the regions of interest in processing the 3D stimulus.

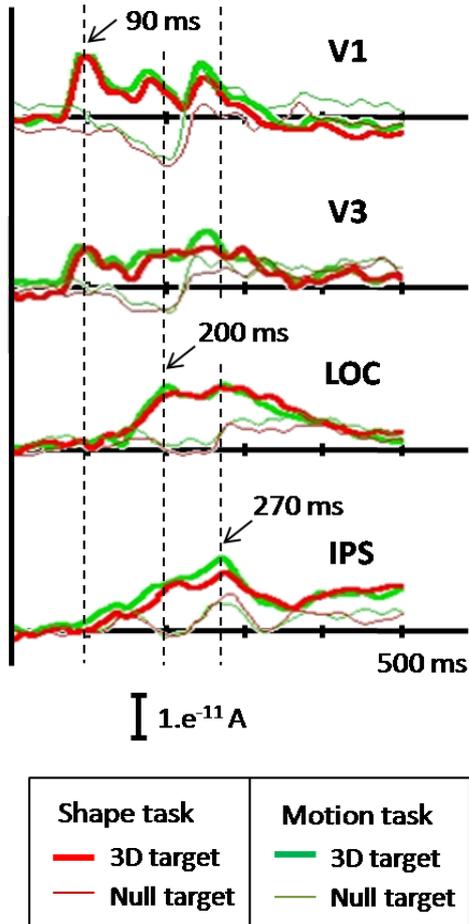


Fig. 3 Reconstructed activity in the regions of interest

The four areas indeed show very different time course after the 3D target, with tiered peak latencies. In V1, we observe a peak at 90 ms (M100 for target apparition) and another one at 240 ms, well accounted for by the M100 of the 2<sup>nd</sup> mask (onset at 150 ms). In line with this, we find a target

effect (with  $p < 0.01$  uncorrected during more than 20 samples) during the first peak (85 to 190 ms). We also find a late task effect during the M100 of the 2<sup>nd</sup> mask (230 to 250 ms). V3 also shows an early peak at 90 ms and corresponding target effects between 90 and 210 ms. LOC, with a later peak at 200ms, shows target effects between 200 and 350 ms. Neither V3 nor LOC reach significant task effect. Eventually, IPS activity rises slowly after the beginning of the activity in LOC, peaks at 170 ms, and falls back to the baseline prior the delayed motor response. It does not show any significant effect of target or task.

The activity related to the 2<sup>nd</sup> mask, which is visible in the null target condition, reveals the same succession of activity in the different areas.

## IV. DISCUSSION

We recorded activity related to structure from motion integration in a mere detection task (Presence), as well as in identification tasks (Shape and Motion) requiring selective attention to the shape or 3D motion of the stimulus.

### A. Task-related modulation

The regions of interest highlighted by the processing of SFM stimuli in the detection condition did not appear to be significantly modulated by the identification tasks, which is consistent with previous fMRI results [4] showing that the attentional selection of 3D motion and shape involve different areas from stimulus-driven activity. Rather, the task effect seems to involve more anterior visual brain regions as well as right fronto-polar areas. Further study is required to clarify whether task difficulty [5] or prospective memory due to the delayed response [6] might account for such frontal activity.

### B. From V1 to IPS

In the regions of interest, the time window of the target effect, as well as the activity profiles, revealed the successive involvement of these areas in processing the 3D stimulus. This cascade being consistent with what has been described recently for structure from motion stimuli [7].

Note that we find the implication of the superior occipital gyrus (putative V3) at earlier latencies than LOC activation, consistent with our previous proposal that this area could be involved in an intermediate stage of gross shape extraction.

Although one can wonder to what extent spiking activity can be related to MEG signal, we find in IPS a late climbing activity similar to that described in cell studies [1]. Also, the particular timing of IPS activity relative to MT/LOC is consistent with the idea that IPS might accumulate evidence

about the moving stimulus before reaching a perceptual decision, as long as information about the target is required, and available from earlier areas. Further studies modulating both the amount of information necessary to reach a decision and the possible duration of stimulus integration (between masks) would be needed to confirm the causal relation of the activity in these areas.

### C. Target-related activity and masking

In this study, we used a time constrained paradigm with masks immediately preceding and following the target in order to segregate stimulus integration stages from task related-activity and hopefully perceptual decision. Our hypothesis however, was that the dynamical masks would successfully interfere with the integration of the visual cues leading to the perception of the 3D target stimulus. It is noteworthy, that contrary to [7], we neither found massive and sustained activity in the infero-temporal areas nor a rebound of activity in the early visual areas (V1 and V3) around 500 ms. This is a first hint that target visual integration is interrupted by the masks.

Another indication is given by the response to the 2<sup>nd</sup> mask after a Null target (Figure 4.A).

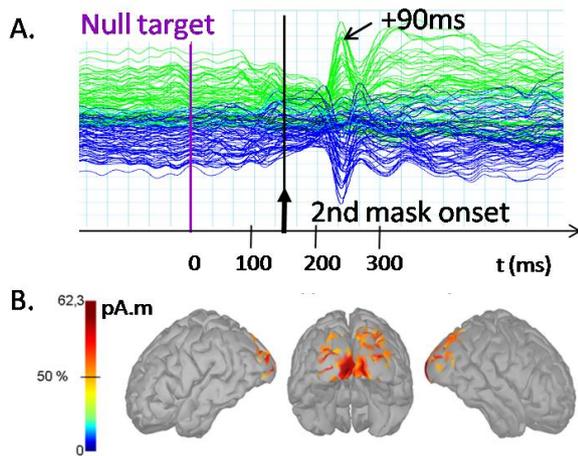


Fig. 4 Temporal window of target integration (A) and brain areas (B) defined by the response to the masks

In this condition, the mask-related M100 clearly appears in the ERF, delimiting the moment when target-related signal may not be observable anymore. Such response to the mask can also be found for the 3D target condition in V1, and to a less extent in V3 (see figure 3). Eventually, the sources of the response to the mask (Figure 4.B) appear to overlap largely with the areas involved in the 3D target

processing, suggesting that the mask effectively compete with the 3D target for access to cascade of visual processing.

## V. CONCLUSIONS

ERF revealed temporally non-overlapping effects of stimulus-driven and task-related processes in the perception of structure-from-motion stimuli.

Source reconstruction showed that the occipital, dorsal and ventral stimulus-related areas follow different temporal profiles and confirms a cascade of activity from V1 to IPS passing through MT/LOC for moving object perception.

The rising activity found in IPS may reflect accumulating evidence about the motion stimulus presented, in line with the results from single cell studies in monkey LIP [1].

## ACKNOWLEDGMENT

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