Effects of low-spatial frequency components during visual natural scene processing: A combined fMRI and ERP study

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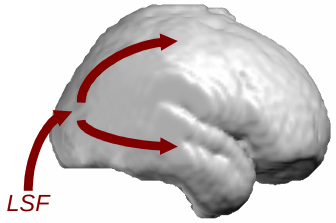
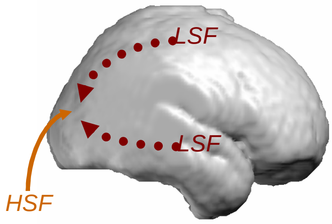
Background

Model of visual recognition (e.g., Bullier, 2001; Bar, 2003)



Low spatial frequencies (LSF) in a scene, conveyed by fast **Magnocellular visual pathways**, activate the visual areas first and then rapidly reach high-order areas (parietal, frontal and infero-temporal regions) allowing an initial perceptual parsing of a visual scene.



This initial low-pass visual analysis can then be refined by **high spatial frequencies (HSF)**, conveyed more slowly by **Parvocellular visual pathways**.
Retroinjection hypothesis : rapid **LSF** analysis might be retroinjected through fast feedback connections into lower-order areas to modulate the subsequent processing of **HSF**.

Aim

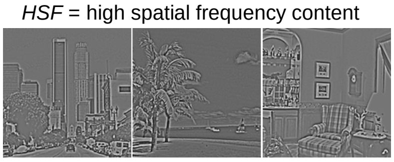
By combining functional magnetic resonance imaging (fMRI) and event-related potentials (ERPs), we investigated the cerebral substrates and temporal dynamics of such retroinjection mechanism.

Methods

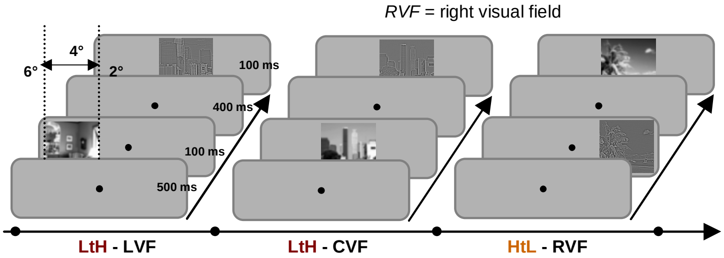
- 11 healthy right handed male volunteers
- Matching task : Participants had to decide whether or not 2 successive images of natural scenes were from the same category (city, beach or indoor)
- Stimuli

LSF = low spatial frequency content

HSF = high spatial frequency content



- Sequence: ***LtH*** = Low-to-High spatial frequencies; ***HtL*** = High-to-Low spatial frequencies
- Visual field of the first image: *CVF* = central visual field; *LVF* = left visual field; *RVF* = right visual field

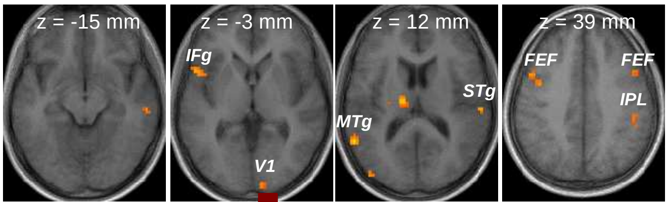


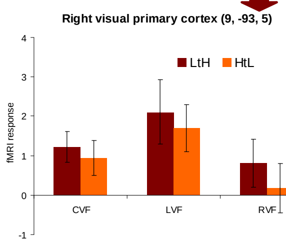
fMRI acquisition and results

Where?

- Event-related fMRI paradigm
- 1.5 T whole-body INTERA system (Philips Medical Systems), echo-planar imaging (EPI)
- Whole brain volume, 30 slices, 4 mm thick, TR = 2.5 sec
- Data analyzed using SPM2, two-stage random-effect analyses

Results: LtH > HtL





LtH sequence, relative to HtL, produced greater activation in a network of frontal, parietal and temporal areas:

- bilateral frontal eye field (FEF)
- left inferior frontal gyrus (IFg)
- right anterior superior temporal gyrus (STg)
- right inferior parietal lobule (IPL)
- left middle temporal gyri (MTg)

as well as in the occipital cortex:

- right primary visual cortex (**V1**), irrespective of the visual field of the first image

The stronger activation of V1 during the LtH sequence (relative to HtL) fits well with the retroinjection hypothesis. To assess when V1 was activated in the course of the LtH sequence, we recorded EEG in the same subjects during another experimental session.

When?

ERPs acquisition and data processing

- Continuous EEG was acquired with a Geodesics Netamps system (Electrical Geodesics, Inc., USA) from 123 scalp electrodes.

Analysis of ERP topography

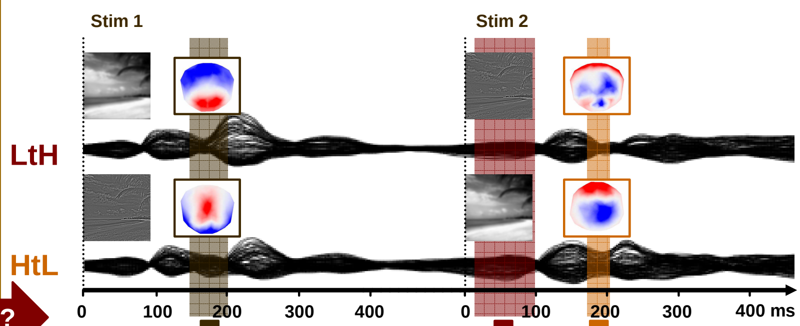
A spatial cluster analysis was applied (Pascual-Marqui et al., 1995) to identify the different spatial map configurations that predominate in each ERP map series. This approach is based on the observation that map configurations do not randomly change over time, but remain rather stable for a certain time segment before changing into a new stable configuration. Each segment map is thought to represent a given "functional microstate" of the brain or a given computational step during information processing (Michel et al., 2004)
This analysis were used to define time periods where topographies significantly differed between LtH and HtL sequence.

Analysis of source estimation (LAURA)

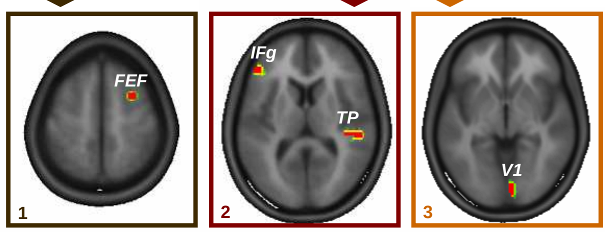
A distributed linear inverse solution was applied to each of the identified time segments that significantly differed in map topography between LtH and HtL sequences. The inverse matrices used here were based on a Local Auto-Regressive Average (LAURA) model of the unknown current density in the brain (Grave de Peralta et al., 2001).
The LAURA inverse solution was estimated for each of 4024 nodes distributed in a realistic 3D solution space and for LtH and HtL conditions separately.
Paired t-tests were then calculated for each node in the inverse solution space between conditions.

Results

Analysis of the ERP map series segmentation revealed that scalp topography differed between LtH and HtL processing over 3 different time periods:



LtH > HtL



Analysis of ERP topography and source estimation (LAURA) were in line with fMRI results, showing stronger frontal and temporo-parietal (TP, including STg and IPL) sources, in the LtH sequence (relative to the HtL) around the onset of the second stimuli, as well as in the right occipital cortex around 170-200 ms later.

Conclusion

In line with the **retroinjection hypothesis** (Bullier, 2001), fMRI and ERPs data provide convergent evidence that, during a **Low-to-High analysis** of a visual stimuli (e.g., natural scenes), low-pass signal (**LSF information**) might enhance the activation of high-order areas that can then retro-actively influence lower-order areas (e.g., V1) to enhance the subsequent processing of high-pass signal (**HSF information**).

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