What cerebral mechanisms allow us to become conscious of events and objects in the external world? Thanks to the recent development of brain imaging techniques, we know that when we become conscious of an external stimulus, there is an increase in activity both in sensory areas (e.g. visual areas in the case of a visual stimulus) and in a network of frontal and parietal areas. Now that we know which areas are involved, understanding the dynamics of this process is the next scientific challenge: when and how do sensory and fronto-parietal areas interact to produce conscious perception?

In this project, supported by a European Research Grant (FP7-PEOPLE-2009-RG), we tackled this scientific challenge in two lines of research (detailed in the next section):

1. We tested the hypothesis that the reactivation of sensory area by top-down connexions from the attentional system (fronto-parietal areas) plays a causal role in triggering conscious perception. To this aim we performed a series of 5 experiments in experimental psychology, involving 20 healthy volunteers each, and a joint magneto-encephalography (MEG) and functional MRI (fMRI) study involving 20 healthy volunteers. The results of these experiments provide strong support to our initial hypothesis and allow unique insights into the brain mechanisms that cause conscious perception in healthy subjects.

2. We tested the preservation of attentional (fronto-parietal) brain systems in patients with disorders of consciousness (vegetative or minimally conscious states). This part of the project involved completing electro-encephalography (EEG) studies in 15 healthy volunteers (control study), and 16 patients. The results of these experiments provide an important insight into the link between attention and consciousness, and might lead to an EEG test to be included in the diagnosis of these patients.

1. Causal role of sensory reactivation in triggering conscious perception.

In previous fMRI studies I conducted as a Marie Curie Fellow at University College London, I showed that orienting attention *after* the disappearance of a visual stimulus induces top-down reactivation within low-level visual areas V1 and V2 (article published in Journal of Cognitive Neuroscience, 2010). In other words, using this procedure we can experimentally induce sensory reactivation several milliseconds after the stimulus itself has. The next step was to use this experimental procedure to test our hypothesis: if sensory reactivation does play a causal role in conscious perception, experimentally inducing such a reactivation after the offset of a stimulus at consciousness threshold should allow to switch the cerebral processing of this stimulus from non-conscious to fully conscious.

To test this proposition, we designed an experimental protocol which is an extension of classical studies on automatic orienting of attention (see Figure 1 A). Participants looked at a fixation point at the center of a computer screen. Two circles were always present to the left and to the right of fixation. On each trial, a patch containing oriented lines (Gabor patch) was briefly presented in the left or right circle. This target had a very low contrast, at the threshold of conscious perception: for the same external stimulus, sometimes the same participant would report they saw it, sometimes not. Either before or, critically, after target presentation, one of the two black circles briefly disappeared, which automatically attracted attention towards that location in space, and thus constituted an “attentional cue”.

We performed a series of 5 experiments in experimental psychology, with a total of 100 volunteers, using this procedure. The results of these experiments replicated a classic attentional effect when the attentional cue was presented *before* the target: when the participant’s attention is attracted towards the same side es where the target is going to appear (“congruent side”), conscious perception of the target increased (Figure 1.B.). Critically, this protocol tested for the first time the effect of attention after target presentation. This revealed a phenomenon of "retro-attention" that had never been described before : when the attention of the participant was attracted to the same side as the target 200 or even 400 ms after target's presentation, we observed also an important increase in conscious perception of the target, although it had disappeared from screen before the attentional cue (Fig. 1B). We obtained and reproduced this effect with various ways of assessing the perception of the target: measuring the capacity to report its orientation or to report its presence (detection), or to report own's subjective feeling of having seen the stimulus on a continuous scale going from "I haven't seen anything" to "maximal visibility".

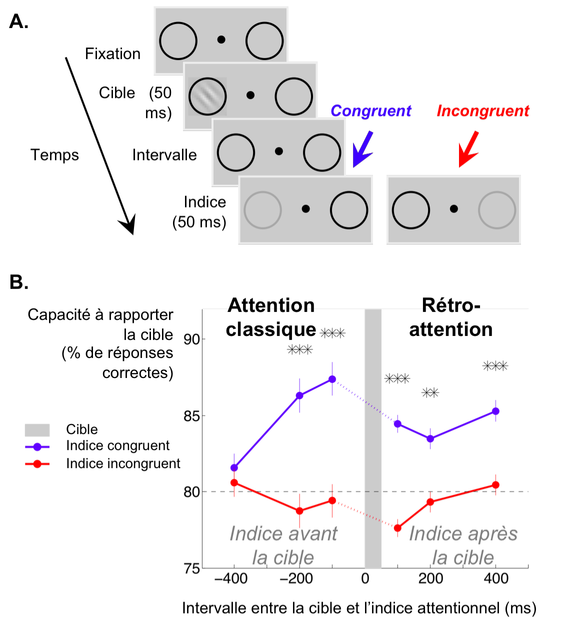

Figure 1: (A) Schéma général du protocole de rétro-attention. (B) Résultats comportementaux (18 participants) pour une tâche de discrimination d'orientation. La performance de discrimination d'orientation en l'absence d'attention est de 80% (ligne pointillée) (B). Symboles statistiques : *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.005$

In conclusion these results reveal a new "retro-attention" phenomenon that has never been described before relating to the interplay between attention and conscious perception. They bring a major argument in support of the hypothesis that reactivation of sensory areas by the attentional system plays a causal role in triggering conscious perception. The scientific article associated with these results is currently under revision in a peer-reviewed international journal.

Following this discovery, we conducted a joint fMRI / MEG study involving 20 healthy volunteers to investigate the neuronal mechanismes involved in this newly described "retro-attention" phenomenon. The analysis of this experiment are currently under way; it will bear on the highly specialized fMRI retinotopic mapping technique I learnt during my previous Marie Curie Fellowship, at University College London. Importantly, since in this experiment we experimentally triggered the conscious perception of the target at different time points following target offset, this joint fMRI / MEG study will allow for the first time to isolate the neural mechanisms of conscious perception (triggered by retroattention) independently of the initial phase of sensory processing (triggered by the stimulus itself).

2. Testing the preservation of the attentional system in patients with disorders of consciousness

A better understanding of the link between attention and conscious perception can help research on disorders of consciousness (DOC). In this part of our project we tested the level of functioning of the attentional system in vegetative or minimally conscious patients: these patients are post-comatose patients who do not communicate. It is thus very difficult to assess whether these patients are conscious or not. This research project had two objectives:

1. From the point of view of fundamental research, the objective was to identify which functions of the attentional system have to be preserved in order for an individual to become conscious of their environment.
2. From the point of view of clinical reseach, the objective was to design an easy EEG test of the level of functioning of the attentional system in each patient, to help individual prognostic and diagnostic.

We adapted to these patients classical protocols used for testing spatial orienting of attention in healthy volunteers: Posner cueing paradigm, in the auditory domain (Figure 2). This protocol was tested on 15 control healthy volunteers and 16 patients, using EEG (geodesic sensor net, 256 electrodes). Volunteers and patients listened to auditory stimuli presented via headphones. Their own name was presented to their left or to their right in order to orient their attention towards that side. After a brief interval, an audio stimulus “bip” was presented either on the same (congruent) or on the other side (incongruent). We observed in control volunteers that when the own name induced an automatic orientation of their attention, the EEG waveforms evoked by the bip were different when it was on the same side or not. These EEG waveforms constitute a neural signature of the functioning of the attentional system.

In patients, this neural signature was only observed in minimally conscious patients, i.e. only patients who showed some signs of consciousness. This seems to confirm that a preserved functioning of the attentional system is required to regain conscious perception. The scientific article associated with these results is currently under preparation. In the future, this EEG test could also be used in hospitals for helping the diagnosis of these patients.

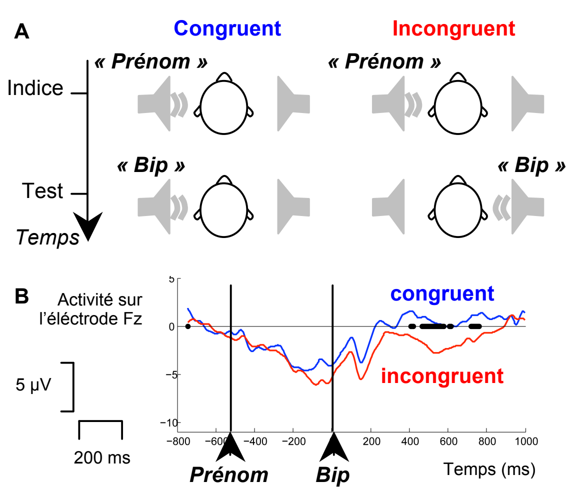

Figure 2: Schéma du protocole (A); Activité EEG enregistrée chez un patient non-communiquant au niveau de l'électrode frontale Fz. Les barres noires désignent les périodes où un effet significatif à $p < 0.05$ est observé (B)