

Conscious Awareness and the Brain Processing

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Abstract

The study of consciousness has been limited primarily to philosophical domain. There are a number of conceptual and methodological issues that have prevented scientific investigation of conscious experience. We began the investigation by exploring its cognitive components. Since awareness is an important component, we used neuroimaging techniques to study the brain processing of awareness using memory as a model. It is known that in the tests of ‘nonconscious memory’ subjects retrieve studied items without becoming consciously aware of retrieval. In contrast, they are fully aware in conscious memory tests. Spatial and temporal patterns of cortical activities observed during the two forms of memory were analyzed to understand neural network that might be associated with the awareness of retrieval. It appears that during conscious recollection, studied items are first retrieved nonconsciously. Thereafter, a reentrant signaling loop is activated between the extrastriate area and frontal cortex. Experiments suggest that this loop may be responsible for the awareness of nonconsciously retrieved information. Further characterization of the extrastriate-frontal connectivity may help explain the neural mechanism of conscious experience.

Concepts of consciousness in philosophical treatises have contrasting views concerning genesis and processing of conscious experience. It is not clear whether the experience involves a ‘bottom-up’ processing in which sensory experiences are progressively processed to higher order of conscious experience or is a ‘top-down’ processing in which a universal consciousness determines how sensory information is processed. There is however a consensus that conscious awareness is an important component of conscious experience. To understand the phenomena of conscious awareness, we used neuroimaging techniques to delineate associated neural networks [1]. It is known that in the tests of nonconscious memory subjects are made to retrieve studied items without becoming consciously aware of the retrieval. In contrast, they are fully aware of retrieval in conscious memory tests. We analyzed spatial and temporal patterns of cortical activities observed during the two forms of memory to understand the neural network associated with awareness.

There are a number of laboratory tests designed to elicit conscious (explicit) and nonconscious (implicit) memory [2]. While in the tests of explicit memory subjects consciously recall studied items; implicit memory tests are designed to allow retrieval without awareness of recollection [3, 4]. Interestingly, some of the tests that elicit implicit memory can also elicit explicit memory, if a different set of instructions are used (e.g. word stem completion task). Since in these tests implicit and explicit memory conditions differ only in the set of instructions,

and in the presence or absence of awareness, comparison of patterns of cortical activation elicited in the two conditions could help identify neural network, associated with the awareness of retrieval.

A test that has been extensively used to elicit both implicit and explicit memory is the word stem completion task [5-7]. In this test, after subjects have studied a list of words, they are shown first three letters (word-stem) of a studied word. To elicit implicit memory, they are asked to complete word stems using the first word that comes to mind, and to test explicit memory, they are instructed to complete stems using a studied word. Even though, in both conditions studied words are retrieved, subjects typically remain unaware of retrieval in the implicit condition. Awareness of retrieval is reported only when they are asked to use a studied word. We used this task to study temporal and spatial patterns of cortical activation during retrieval, with, and without awareness, using event-related potentials (ERPs), and positron emission tomography (PET).

The ERP study was conducted on 48 right-handed healthy young volunteers [5, 8]. Potentials were recorded over 64 scalp locations during stem completion. In the implicit task, after subjects had studied a list of 60 words, they were asked to complete 3-letter word stems using the first word that came to mind, beginning with the stems. All stems were unique and each had at least 10 target words. Half of the stems were derived from the study list and the remaining stems came from the words that were not studied. The stems of studied and non-studied words were mixed randomly and presented in a single block. At the end of implicit memory blocks, explicit retrieval was tested in the same experiment, using similar design but with a different set of instructions. Instead of saying the first word that came to mind, subjects were asked to complete stems using a studied word. The ERPs obtained in implicit and explicit conditions were averaged across subjects and were contrasted against averaged ERPs recorded during completion of the stems of non-studied words. The designs of PET experiments [9-11] were essentially similar to that of the ERP experiment described above. These experiments however included only implicit tasks and the stems of studied and non-studied words were presented in separate test blocks. Further, we used both visual and auditory stimuli in these experiments.

In the ERP study, we observed attenuation of potentials between 64 and 200 msec of stimulus presentation, in the channels located over posterior cortex, during implicit memory (Figures 1 and 2). The PET experiments localized these reduced activations in the extrastriate cortex (Brodmann's area 19) for both, visual [10], and auditory [9, 11] stimuli (Figure 3). Similar reductions have been reported in a variety of other tests of implicit memory (for review see, [4]. Consistent findings of reduced activities in the extrastriate area across different imaging and experimental techniques strongly suggest its association with implicit memory [4, 12].

It is however, not clear, how these reductions are linked to implicit memory. It appears that they represent 'repetition suppression effect' elicited by re-presentation of studied items (for discussion see, [12]. We have earlier suggested that the neural signatures of studied items are retained nonconsciously in a multimodal area (area V3A) of the extrastriate cortex, and that, the reduced activation signifies reduction in cognitive load due to quick retrieval, facilitated by the retained signature of a studied item [5, 11, 12]. The retrieval at this stage however remains nonconscious because it has not yet been processed in the areas that allow conscious awareness of retrieval. If awareness is not needed (as in implicit memory tests), the later processing never takes place, and subjects remain unaware of the retrieval.

Clinical evidence also suggests that the extrastriate cortex retains nonconscious information. For example, patients who have lesions in the primary visual area retain nonconscious information of the objects located in their 'blind' fields (blind sight), if they have intact extrastriate cortex [13, 14]. These patients, despite their claims of not seeing objects in the blind field, show remarkable ability to identify color, shape, size and movement of the these objects when forced to make a choice. However, if the lesion extends to the extrastriate area, the

nonconscious perception is also lost [15]. These observations underscore the fact that the integrity of the extrastriate is essential for retention/expression of nonconscious information.

In view of the above observations and consistent neuroimaging findings, investigators generally believe that the attenuation of extrastriate activity is a characteristic feature of nonconscious memory [4, 11, 12]. Nonetheless, under certain task conditions, attenuation in this region is observed during conscious recollection of studied words (Figure 1). It has been reported during retrieval of both visual [5, 6] and auditory [16] stimuli. This attenuation, however, differs with that obtained during implicit memory in its time course. During conscious retrieval the potentials are attenuated between 64 and 600 msec of stimulus presentation, while the reduction in implicit memory is recorded between 64 and 200 msec [5]. The additional attenuation of 400 msec during explicit memory is intriguing because its time course overlaps that of the activation in the frontal area (Figure 2). It appears that the attenuation during conscious retrieval occurs in two stages: early and late. The early attenuation that lasts up to 200 msec is probably due to the priming effect, induced by re-presentation of a studied item. This possibility is supported by the fact that similar attenuation is observed during implicit memory, and also by the cognitive evidence which indicates that nonconscious retrieval is an inherent component of conscious retrieval in a word stem completion task [6].

The late attenuation, occurring between 200 and 600 msec was one of the additional activities observed during explicit retrieval. The other was increased activation in the frontal region. Since the output of explicit task differed with that of the implicit task only in the presence of awareness of retrieval (which was neither needed nor reported in the implicit task), these additional activities might be associated with the processing of awareness. It is particularly tempting to speculate such an association because the time courses of these activities are surprisingly similar, and also because frontal cortex is believed to be the site most likely to support conscious awareness [17-19]. The association of the activity in the frontal cortex with awareness, and that in the extrastriate with non conscious information processing is further supported by the observation that in blind sight patients frontal activity is observed only when there is conscious awareness of visual events, and not, when the events are perceived non consciously. In the later condition there is activity in the extrastriate cortex [20].

It has been speculated that frontal cortex and the extrastriate play a significant role in the expression of conscious awareness [17]. The significance is not only because higher cognitive processing requires effective communication between frontal cortex and the posterior cortical areas that store domain specific information [18, 21], but also because awareness requires construction of a multilevel symbolic interpretation of the information. Neuroanatomical and psychophysical data indicate that such an interpretation can be most effectively performed by the polysensory regions of frontal cortex and extrastriate area [17]. The temporal patterns of cortical activity recorded during implicit and explicit memory also indicate that awareness of retrieval involves communication between frontal and extrastriate cortices [5]. It appears that during conscious retrieval, a studied item is first retrieved nonconsciously [6], eliciting early attenuation of extrastriate potentials. Since the task requires conscious awareness of retrieval, implicitly retrieved information is 'held' for an additional 400 msec (eliciting the late attenuation). During this late attenuation signals are relayed to the frontal cortex for higher order cognitive processing, eliciting increased activity in this area. Almost perfect overlap of the timing of the late attenuation and the frontal activity suggests activation of a reverberating circuit making a reentrant signaling loop between these areas (perhaps via intermediate inhibitory interneurons).

Establishment of a reentrant loop is considered essential for conscious awareness by some investigators because the awareness requires appreciation of different qualities of an input signal and such an appreciation can most effectively be accomplished by these loops [22, 23]. Further, our observations suggest that this loop is active for about 400 msec which is consistent with the reports that indicate that a signal can be consciously appreciated only if it stimulates the cortex

for about 500 msec [24, 25]. The extrastriate-frontal reentrant loop may be the neural mechanism of 'holding' information in the cortical circuits long enough to allow conscious awareness.

Precise neuroanatomical and neurophysiological characteristics of the extrastriate-frontal loop are unclear. It however, appears to follow the dorsal stream of occipito-frontal projection which is relayed in the parietal cortex [26]. This assumption is based on the fact that lesions localized in the dorsal projection, or in the parietal cortex are known to cause disturbances of conscious awareness. For example, patients with damage to the dorsal projection fail to recognize simple geometric shapes (visual form agnosia), but select the slots of correct dimension and orientation when asked to match slots with the wooden blocks of different shapes [27], indicating dissociation between perception and conscious awareness. A lesion in the posterior parietal area causes another kind of impairment of conscious awareness - the hemineglect. These patients neglect objects located on the contralateral visual fields, despite having the 'knowledge' of the presence of these objects [28]. In an experiment, when a right parietal patient was asked whether two pictures of a house were identical, the patient replied 'yes' ignoring flames engulfing the house on the left. However, when asked which house he would prefer to live in, he consistently selected the intact house [29], indicating retention of nonconscious knowledge of the neglected visual field. Further, when words and pictures are shown on the neglected fields of parietal patients, despite denying 'seeing' anything, they make quicker responses to congruent items presented subsequently to their healthy fields [30]. The dissociation between perception and awareness observed in these patients could possibly be due to interruption of the parietal relay of the extrastriate-frontal connectivity. Neuroanatomical and cognitive evidence, indicate that the extrastriate-frontal loop allows transfer of information between dorsolateral prefrontal cortex and the area V3A of extrastriate cortex [11, 12, 26, 31]. Since, the area V3A receives multimodal input, and is associated with implicit retrieval of both visual [10], and auditory [9] stimuli, we have earlier suggested that this area is critically associated with the brain mechanism that retains non conscious information [9, 11, 12].

It appears that implicit memory is driven by the signals that arrive at the extrastriate directly from the sub cortical structures and not from the primary sensory cortices. Since, in a typical blind sight patient, even though primary visual cortex is damaged, visual signals are nonconsciously 'perceived' if extrastriate cortex is intact, it has been suggested that these signals come directly from the superior colliculus [32]. The data of the ERP experiment also indicate that the extrastriate cortex receives signals from the source other than the primary visual area [5]. Potential changes in the extrastriate are detected at about the same time (64 msec after stimulus presentation), at which a stimulus is known to activate primary visual cortex [33]. This conclusion is also supported by the fact that the visual information retained by blind sighted patients is not very well processed [13]. However, direct experimental evidence is needed before the source of signals, and the way they are processed in the extrastriate-frontal loop can be accurately characterized. Such a characterization will help better understanding of the phenomenon of 'perception without awareness' reported in a variety of brain damaged patients. In terms of conscious experience, the significant of findings of these studies is underscored by the experiments that have found similar patterns during altered states of consciousness. These experiments have reported greater glucose utilization and higher potentials in the frontal areas, and attenuated utilization and potentials in the posterior cortical regions [34-36]. Since increased frontal activity is associated with awareness and reduced posterior cortical activation indicates nonconscious processing, these findings underscore the activation of these processes during conscious processing.

Based on the findings of our experiments discussed above, it appears that awareness involves bottom-up processing (from nonconscious processing in posterior cortex to conscious processing in frontal cortex). This may imply that conscious experience should also have similar processing. This conclusion however may be deceptive because nonconscious processing may not

necessarily be a subservient of conscious processing, and also because higher states of conscious experience may indeed be processed by the nonconscious mind. Even though current neuroscientific concepts suggest that nonconscious mind operates at a lower state of consciousness, many philosophical theories, particularly Vedic and yogic philosophical concepts suggest that components of nonconscious mind are active at higher states of consciousness. In fact, at the highest state of yogic consciousness (Samadhi), the awareness of sensory experience is completely lacking. This concept may suggest that conscious experience is supported by the downward loop of the extrastriate-frontal connectivity (i.e., frontal to extrastriate connectivity). This explains why induction of Samadhi requires awareness of sensory experience in the beginning. Voluntary concentration on sensory cues is a standard meditational technique to achieve higher levels of conscious experience. As the level of conscious experience rises, the awareness fades and is lost completely in Samadhi. This idea of 'top down' processing is consistent also with Vedic concepts of consciousness. These concepts suggest that individual conscious experience emanates from a universal consciousness that descends to the mind, brain and ultimately to the body.

These experiments have allowed us to have a view of the brain processing of awareness, in order to acquire scientific data to explain conscious experience, there is a need to construct better theoretical models that are consistent with both philosophical, and scientific concepts.

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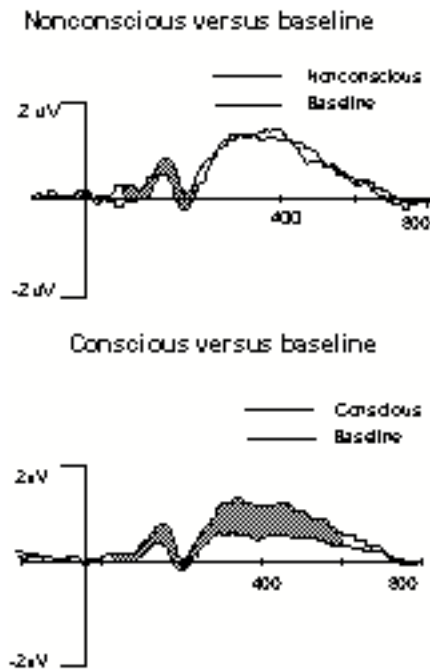


Figure 1
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Figure 1: Grand averaged event-related potentials (n=48) recorded during non-conscious (implicit) and conscious (explicit) retrieval of studied words. Potentials were attenuated over posterior cortical areas in both conditions. The reduction lasted for ~200 msec (early attenuation) during non-conscious memory and for an additional 400 msec (late attenuation) during conscious recollection. Shaded areas indicate statistically significant ($P < 0.01$) differences. The waveforms represent mean potentials across six posterior cortical channels (Reproduced from Badgaiyan, *International Journal of Psychophysiology* 55: 257-262, 2005).

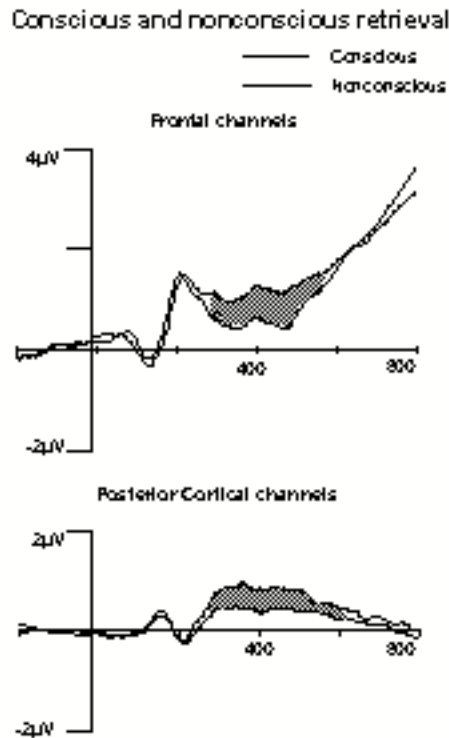


Figure 2
Badgaiyan

Figure 2. Comparison of the potentials recorded during non conscious (implicit) and conscious (explicit) retrieval reveals that the time course of the late attenuation (between 200-600 msec) observed during conscious retrieval overlaps almost perfectly with the activation in frontal area. This temporal overlap suggests activation of a reentrant signaling loop between the posterior cortical (extrastriate cortex) and frontal (dorsomedial prefrontal cortex) areas. This connectivity may be critical for making implicitly retrieved information available to conscious awareness. Shaded areas indicate statistically significant differences ($P < 0.01$). The wave forms represent mean potentials across five frontal and six posterior cortical channels (Reproduced from Badgaiyan, *International Journal of Psychophysiology* 55: 257-262, 2005).

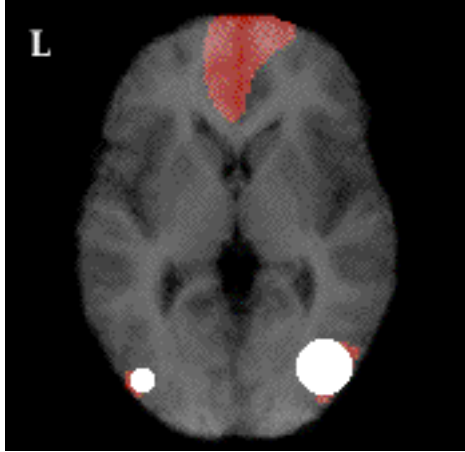


Figure 3: Within-modality auditory priming: Statistical parametric maps (SPM) showing significant decreases in blood flow (shaded white) in the extrastriate (BA 19) areas during within-modality auditory priming as compared to the stem completion baseline. The maps are superimposed over averaged structural MRI images that were transformed to Talairach space.