



## Review article

## A role for the anterior insular cortex in the global neuronal workspace model of consciousness



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## ABSTRACT

According to the global neuronal workspace model of consciousness, consciousness results from the global broadcast of information throughout the brain. The global neuronal workspace is mainly constituted by a fronto-parietal network. The anterior insular cortex is part of this global neuronal workspace, but the function of this region has not yet been defined within the global neuronal workspace model of consciousness. In this review, I hypothesize that the anterior insular cortex implements a cross-modal priority map, the function of which is to determine priorities for the processing of information and subsequent entrance in the global neuronal workspace.

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## 1. Introduction

As the research on the neuronal correlates of consciousness (NCC) progresses (Bisenius, Trapp, Neumann, & Schroeter, 2015; Koch, Massimini, Boly, & Tononi, 2016), it is more and more important to develop a general model integrating these different correlates into a unified view of the functioning of consciousness (Block et al., 2014; Boly et al., 2013; de Gardelle &

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Kouider, 2009). One of the main integrative models, initially suggested by Baars (1988) and developed in cognitive neuroscience, mainly by Stanislas Dehaene and colleagues (Dehaene, 2014; Dehaene & Changeux, 2011; Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Dehaene & Naccache, 2001), is called the “Global Neuronal Workspace” (GNW) model of consciousness. According to the GNW model, consciousness is the result of the global broadcast of information throughout the cortex. A “global neuronal workspace”, constituted by interconnected high-level cortical regions such as the dorsolateral prefrontal cortex and the inferior parietal cortex, enables the global broadcast of information (Dehaene & Changeux, 2011).

The anterior insular cortex (ai) is an informational hub (Sterzer & Kleinschmidt, 2010; Touroutoglou, Hollenbeck, Dickerson, & Barrett, 2012; Uddin & Menon, 2009) and appears as a consistent neural correlate of consciousness across different experimental paradigms (Bisenius et al., 2015). But the different functional roles of the ai have not yet been integrated in the global neuronal workspace model of consciousness. Here, I suggest a functional role for the ai in a global workspace architecture. The ai has recently been hypothesized as a central component of the “salience network” (Goulden et al., 2014; Menon, 2015; Menon & Uddin, 2010). On this model, the role of the ai is to detect salient stimuli in order to determine whether stimuli should receive further cognitive processing and to facilitate access to working memory resources (Menon, 2015). My hypothesis is that the ai detects the relevance of stimuli across modalities and determines which stimuli need to be prioritized for entry in the GNW and sustained by top-down attention depending on the current goals at hand. The ai plays the role of a cross-modal priority map determining priorities of competing representations to reach conscious access.

## 2. The global neuronal workspace

In this paper, I will be primarily concerned with “access-consciousness”, defined by Block (1995) as the availability of particular information for cognitive processes such as rational decision-making, control of action, reasoning, and verbal report. In the typical cases, consciously accessed information is also reportable. While some processes are conscious in this sense, most of our cerebral processes remain unconscious. What are the differences between conscious and non-conscious processing of information? The “Global Neuronal Workspace” model, first developed by Baars (1988), tries to answer this question. The central claim of the theory is that “conscious access is the selection, amplification, and global broadcasting, to many different areas, of a single piece of information selected for its salience or relevance to current goals” (Dehaene & Changeux, 2011).

This model predicts two phases through which a stimulus becomes consciously accessed (Dehaene & Changeux, 2011; Dehaene & Naccache, 2001). First, between 100 and 300 ms, the stimulus is non-conscious and climbs up a hierarchy of sensory processors: these processes contribute only to the non-conscious construction of the percept. This first phase is identical whether or not the stimulus is consciously accessed. In the second phase, if the stimulus is strong enough (e.g., in the case of a visual stimulus: duration, luminance and contrast) and/or corresponds to the task at hand, its representation will be sustained by top-down attention and selected for conscious-access (Dehaene et al., 2006). This top-down attention process entails a long-distance phase synchrony between the fronto-parietal network and the sustained sensory areas. Once this long-distance synchrony happens, the relevant stimulus is access-conscious, i.e., available for a broad palette of cognitive processes such as verbal report or decision making (Fig. 1).

The two main predictions resulting from this model have been verified through different experimental paradigms. First, we observe an all-or-none, late (from 300 ms) and sustained firing in the fronto-parietal network constituting the global workspace only when subjects are conscious of a stimulus across different modalities (Conscious/Unconscious visual stimuli (stimulus masking): Del Cul, Baillet, & Dehaene, 2007; Del Cul, Dehaene, Reyes, Bravo, & Slachevsky, 2009; Dehaene & Naccache, 2001; Fisch et al., 2009; Gaillard et al., 2009; Attentional blink: Sergent & Dehaene, 2004; Sergent, Baillet, & Dehaene, 2005; Williams, Visser, Cunnington, & Mattingley, 2008; Conscious/Unconscious tactile stimuli: Boly et al., 2007; Conscious/Unconscious sound: Sadaghiani, Hesselmann, & Kleinschmidt, 2009; Conscious/Unconscious error: Charles, Van Opstal, Marti, & Dehaene, 2013; van Gaal, Lamme, Fahrenfort, & Ridderinkhof, 2011; Binocular Rivalry: Sterzer, Kleinschmidt, & Rees, 2009). Second, conscious stimuli (and not unconscious ones) induce long-distance synchrony at beta and gamma frequencies and a late P3b wave in the same time-window (Bekinschtein et al., 2009; Del Cul et al., 2007; Doesburg, Green, McDonald, & Ward, 2009; El Karoui et al., 2015; Fisch et al., 2009; Gaillard et al., 2009; Hipp, Engel, & Siegel, 2011; Lange, Halacz, van Dijk, Kahlbrock, & Schnitzler, 2012; Melloni et al., 2007; Schurger, Cowey, & Tallon-Baudry, 2006; Sergent et al., 2005; van Aalderen-Smeets, Oostenveld, & Schwarzbach, 2009; Wyart & Tallon-Baudry, 2009). Interestingly, along the lines of these results, patients with perturbed long-distance connectivity due to multiple sclerosis show abnormal conscious perception of masked stimuli while subliminal priming is identical to control subjects (Reuter et al., 2007, 2009). Consistent with this data, studies using TMS over parietal or prefrontal cortices show that it can cause the disappearance of a stimulus from consciousness (Kanai, Muggleton, & Walsh, 2008; Rounis, Maniscalco, Rothwell, Passingham, & Lau, 2010). Del Cul et al. (2009) also observed an elevated threshold for conscious access in patients with prefrontal lesions. Evidence in favor of the GNW also comes from studies of patients in vegetative states (patients with preserved arousal but without behavioral signs of awareness) and minimally conscious states (patients with purposeful behavior but unable to communicate). A difference between vegetative state patients and minimally conscious state patients seems to be the absence of backward connectivity stemming from the frontal cortex (Boly et al., 2011), but see King, Bekinschtein & Dehaene (2011). Although brain activity in vegetative state patients is similar to sleep and anesthesia, patients in vegetative state have

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