Title: Ask and You Shall Receive: A closer look on unsolved consciousness issue

Running title: A Closer Look on Consciousness

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Abstract

Although there are numerous views about the concept of consciousness, no consensus exists regarding the meaning. However, with the aid of the latest neuroscientific developments, the misleading obstacles related to consciousness have been removed.

Over the last few decades, neuroscientific efforts in determining the function of the brain and merging these findings with philosophical theories, have brought a more comprehensive perception of the notion of consciousness. In addition to metaphysical/ontological views of consciousness e.g., higher-order theories, reflexive theories, and representationalist theories, there are some brain directed topics in this matter which include but not are limited to neural correlates of consciousness (NCC), brain loop connectivity, and lateralization.

This narrative review sheds light on cultural and historical aspects of consciousness in old and middle ages and introduces some of the prominent philosophical discussions related to mind and body. Also, it illustrates the correlation of brain function with states of consciousness with a focus on the roles of function and connectivity.

Keywords: Consciousness, Mind; Philosophy, Neuroanatomy, Neurophysiology

1. Introduction

Consciousness is one of the most intriguing topics in scientific and philosophical disputations. Living beings, especially human beings, experience phenomena, and objects; therefore, experiencing is a crucial part of this conception that paves the way to have a better understanding of consciousness. Conscious experience is a first-person experience to the nature of which a third person does not have access. These features render consciousness as one of the biggest unanswered questions in science (Jerath, Crawford, & Barnes, 2015; Koch, 2018). Over the last few decades, research into consciousness has continued in philosophical, physical, and neuroscientific realms leading to the emersion of diverse meanings related to consciousness (Jonkisz, 2012). Although there are numerous theoretical and empirical views about the concept of consciousness, there is no consensus regarding the meaning, leaving the term itself quite imprecise (Jonkisz, 2015).

The philosophical definition of the consciousness varies from that of Descartes "everything that is within us in such a way that we are immediately aware [conscii] of it…" (Jorgensen, 2010) to Sartre's, as an existentialist, who defines it as " a being such that in its being, its being is in question insofar as this being implies a being other than itself"(Sartre, 2001). Quantum physics approaches the dilemma from another point of view and suggests that "the process of human consciousness cannot be simulated classically". Hameroff and Penrose have offered "an orchestrated objective reduction (Orch OR) model" in which quantum computation occurs in the microtubule protein assemblies existing in the brain neurons. In this model, every tubulin dimer represents a qubit, showing interaction with other qubits coulombically at a limited temperature, enabling it to possess quantum information processing (Behrman, Gaddam, Steck, & Skinner, 2006).

Neuroscientists deal with the issue from a different perspective. Consciousness is thought to illustrate the association between cortical structures such as specific parts of the grey matter within neural operations in the brain, and subcortical regions in the upper brain stem, thalamus, hypothalamus, and basal forebrain (Blumenfeld, 2016; S. Laureys, Owen, & Schiff, 2004). Neurobiological theories such as the Global Neuronal Workspace, Recurrent Processing Theory, and Information Integration Theory each try to shed light on the unresolved issue of consciousness from its own perspective (Lamme & Roelfsema, 2000), but there is no consensus about the exact meaning and its features (Zeman, 2001). This review scrutinizes consciousness from cultural, historical, philosophical, and neuroscientific points of view.

1. History of Consciousness

1.1. Consciousness in old and middle ages

Consciousness, especially in its reflective form, has long been part of human history. Archeologists assume that history of consciousness dates back as far as the Neolithic period in which burial practices represent spiritual views about the human and life, and offer signs for minimally-reflective consciousness (Pearson, 1999). Others would believe that consciousness is a rather new concept in human history, dating back as far as the Homeric era, and those who lived earlier did not show any signs of reflective thought. Some scholars would go further and claim that even Greek civilization did not possess any words corresponding to "consciousness" (Wilkes, 1984). This view has been opposed by the fact Plato would famously hold the opinion that the existence of our minds precedes that of our body and outdates the body's death. Accordingly, Aristotle would define "mind" as part of the body which recognizes and understands (Gennaro, 2016). Evidence also suggests that consciousness has been part of the culture of multiple civilizations. The Maya civilization was among the first to introduce the idea of consciousness to their general faith around 2000 BCE. Because consciousness contains both internal and environmental triggers, the Mayans believed that consciousness should have existed from the beginning of human existence, having a major impact on their individual and social life (Calleman, 2001).

Primitive Indians attempted to describe human consciousness from a broader perspective (Kabat-Zinn, 2013). Indian philosopher Sri Aurobindo demonstrated that consciousness is not only about individual awareness but also comprises a distinctive state of energy (Wautischer, 2008). However, there are no specific clinical inquiries among Indian thoughts except the notion of Ayurveda (Feuerstein, 2001). Most Indian philosophers have consensus over the notion of samsara, meaning that living beings are reborn over again in an infinite cycle, the final aim of which is to be released from the round sequence (Gupta, 2003; Matilal, 1986).

Human consciousness in Chinese thought consists of three divisions. The first section explains the cosmological aspect of consciousness, determining the objective world of being for the human. In the second part, the emphasis is on human distinction according to the reflection of the mind and heart in individual and social life. The third layer is about the correlation of politics and consciousness, where the human constructs an ideal political conviction relating to the concrete world (Ch'eng & Bunnin, 2002; Cua, 2003; Feng & Bodde, 1983).

Self-awareness in Islamic philosophy ranges from Avicenna's "Flying Man" as the soul having self-awareness (which is equal to the Cartesian *cogito*), to self-awareness without the substance of Abu'l-Barakāt al-Baghdādī, and Yahya ibn Habash Suhrawardi (Kaukua, 2015b). Avicenna considers two distinguished aspects for self-awareness: first, primitive self-awareness, which is equal to the

concept of "Flying Man"; and second, reflexive self-awareness, meaning as our awareness of cognizing objects other than ourselves (Black, 2008). Mullā Sadrā accepts the concept of the "Flying Man", and thus the notion of self-awareness it denotes. However, in his legacy, this concept has two important characteristics. Sadrā believes that self-awareness is a broader concept than that of the "Flying Man", and ought to incorporate both the intellectual and the sub-intellectual forms of mental existence. Besides, he appears to believe that self-awareness is not distinguishable from other constituents of human experience (Kaukua, 2015a).

Religion plays a pivotal position in some civilizations and has an important impression on the believers' way of thinking about life. Approximately every religion has some correlated beliefs about the concept of consciousness and reveals its strong regulations through the aid of consciousness (Khalid Ali & Sulam, 2018; Mohd Abbas Abdul, 2012). However, its views on the self vary widely.

1.2. Consciousness in the modern era

Seventeenth-century probably was the finest period to the evolution of the concept of consciousness relating to science and scientific views around the world. Rene Descartes defined the meaning of though (pensée) as "all that of which we are conscious as operating in us". He explained two distinctive aspects related to consciousness (Churchland, 1996). By initiating a systematic method, he made a clear difference between the physical and the mental characteristics of consciousness that described as Cartesian dualism. He opposed the existence of unconscious mental states. John Locke elaborated on the Cartesian view of consciousness and claimed that human' sensibility is necessary to his thoughts, putting forward that "he cannot think at any time, waking or sleeping, without being sensible of it". His definition of a person is the same as consciousness. According to Locke "[A person] is a thinking intelligent Being, that has reason and reflection, and can consider itself as itself, the same thinking thing in different times and places; which it does only by that consciousness, which is inseparable from thinking, and as it seems to be essential to it: It being impossible for anyone to perceive, without perceiving, that he does perceive." (Gennaro, 2017). Gottfried Wilhelm Leibniz was among the first to distinguish awareness (outer-directed consciousness) from self-awareness (self-consciousness), believing that consciousness could not arise from mere matter. Intriguingly, Leibniz would accept the notion of minimally-conscious or unconscious mental states calling them "petit perceptions". Immanuel Kant perused the concept of consciousness from a philosophical view distinguishing the philosophical side from the study of nature and scientific matter. He proposed two components of consciousness: Apperception as an ability to be conscious of one's spontaneous actions (*understanding*), and inner sense as the consciousness of everything in mind opposed to

apperception (*sensibility*) (Gennaro, 2016; Heinämaa & Reuter, 2009). Friedrich Hegel strived to reunite consciousness with the world in a spiritual meaning structure in which the world is a spirit, and human consciousness is a subset of the world that can attain self-consciousness. Gustav Fechner in nineteenth-century believed in opposition to Descartes' theory, that mind and body were two prospects of a solitary entity; thus, mental procedures could be evaluated (Fechner, 1860; Herbart, 1824). One of the most convincing contemporary theories was explicated by William James asserting that consciousness is like flowing stream despite constant shifts and changes, and it maintains conceptual stability despite rapid alterations (James & CnpeReading, 2018). Sigmund Freud made an association between consciousness and human thoughts and actions. He conceived that the conscious mind is dependent on a further state of mind (sub-conscious) and concluded that there is a reciprocal correlation amid discrete states of mind (Mollon, 2014). The importance of the notion of the unconscious mind from Freud's philosophical viewpoint can facilitate understanding the ambiguities toward consciousness. Modern theories generally pursue Freud's psychologic perspectives, and with the aid of neuroscience, they introduce more convincing paths through specific neuroanatomical findings (Steven Laureys, Gosseries, & Tononi, 2017). Edmund Husserl states that consciousness invariably includes a self-appearance (*Für-sich-selbst-erscheinens*). For Husserl, the pure I– the I of transcendental apperception –is not a 'dead pole of identity'; it is an active living self continuously 'appearing for itself' (Moran, 2005). For Martin Heidegger, the doctrine of consciousness is different. Indeed, Heidegger does not possess such a doctrine, and he does not even use the term 'consciousness' in his masterpiece *Being and Time*. Martin Heidegger's concept of Dasein (human existence) encompasses subjectivity and self-consciousness which interprets itself through the world. In his words, the self-[consciousness] is "given with our consciousness of objects" (Grove, 2004). Sartre, in his being and nothingness, describes consciousness as a consciousness of objects and thus explains it in association with something else. In the same place, he states that "consciousness is a being such that in its being, its being is in question insofar as this being implies a being other than itself". For Sartre, there are two main types of consciousness, the pre-reflective, and the reflective consciousness. At the pre-reflective level, which is a non-observational self-acquaintance, there is no place for an 'I'. However, at the reflective level, there is an awareness that carries within itself the capacity to contemplate ourselves (Sartre, 2001).

Genetics and improvement in the diagnosis of congenital disorders reduced the complexities regarding clarification of consciousness states. David Chalmers along with Frank Jackson disputed that empirical and scientific descriptions are unable to explicate the meaning of consciousness, hence, without the existence of consciousness, the world could be similar to hunting ground for

wild zombies which act just in reaction to external triggers without having any conscious state of mind (David J. Chalmers, 1996; Jackson, 1982). Thomas Nagel suspected whether the physical explanation of brain states could ever elucidate the secrets of the subjective experience of consciousness. He deduced that there should always be an interval between consciousness and scientific exposition of the brain (Nagel, 1997). John Searle made a distinction between consciousness and other biological incidents and asserted that unlike other biological phenomena, consciousness has a subjective nature. However, the subjective part of consciousness does not deny the existence of an objective aspect (Searle, 2000). Daniel C. Dennett argued that qualia (instances of subjective, conscious experience) cannot exist as it is too incoherent and incompatible to be tangible. The model of parallelism in the brain is also a particular component of his consciousness view. He also claimed that the idea of consciousness is rooted in cultural structures derived from ancient Greek beliefs (Dennett & Weiner, 2017).

Stuart Hameroff and Roger Penrose believed that the nature of consciousness and its position in the universe is ultimately unknown. Also, they asserted that consciousness relies on biologically lucid quantum operations in association with brain neurons that these quantum actions modulate neuronal synaptic activities (Hameroff & Penrose, 2014). They proposed three versions for defining consciousness. The most crucial section explains the consciousness as the consequence of distinct physical proceedings that are known as proto-conscious events. Proto-conscious events have been assimilated within living cellular frameworks and lead to brief states of mind, which is called consciousness (Barlow, 2015).

Several contemporary neuroscientists assume that there is a meaningful relationship between the utilization of energy in the brain and neural function and also the processing of the data in the brain (Magistretti & Allaman, 2013); consequently, the supplement of energy is an inseparable backbone of brain computational structure (Sterling & Laughlin, 2015). Robert Shulman and his coworkers have asserted there is an exact association between consciousness and energy through the brain (Robert G Shulman, 2013; R. G. Shulman, Hyder, & Rothman, 2009). They revealed that by decreasing the response to an outer stimulus for instance in anesthesia, the metabolism of glucose in the brain reduces as well. Thereby the energy consumption is vital for consciousness in the brain.

In current years there has been increasing attention in the concept of brain process (Clarke & Sokoloff, 1994). There has been evidence that in a resting awake state of brain and nonexistence of outer stimulation factors, the consumption of energy in particular parts of the brain called 'dark energy' is extremely low, however, the exact function of dark energy remains unclear (Morcom & Fletcher, 2007; Raichle, 2010).

There are currently two major accepted theories trying to explain consciousness; the Global Workspace Theory (GW) and the Integrated Information (II) Theory. According to the former communicating but autonomous hubs throughout the brain are responsible for conscious experience. These torrents of unconscious parallel processing have restricted interaction with each other and strive for dissemination via a process called "winner-take-all" during which several torrents exploit a single torrent for dissemination throughout the brain (B. J. Baars, Franklin, & Ramsoy, 2013). According to the latter which is proposed by Tononi in 2008, consciousness is the integration of information. In his model, sensory inputs from various sensory organs are integrated with cognitive mechanisms to bring about conscious experience. Further, Tononi introduced a concept known as "qualia space". The concept assumes that several informational associations between different axis within qualia lead to a given conscious experience (G. Tononi, 2008). These two models primarily rely on the cortico-thalamic feedback loops. However, they neglect the vital role of the thalamus in this regard and overemphasize the role of the cortex (Jerath et al., 2015).

In what follows we dig further into the meaning of consciousness in the realm of neuroscience.

2. Neuroanatomy and neurophysiology of consciousness

2.1. Basic neuroanatomy of consciousness

In medical terms consciousness has two constituents: awareness and arousal (wakefulness). Arousal, also defined as wakefulness, alludes to the level of consciousness or the ability to experience awareness, whereas awareness defined as the content of consciousness or as Nagel puts it "the subjective character of experience" (S. Laureys, 2005). Arousal is related to the structures in the brain like hypothalamus and brainstem ascending reticular activating systems (ARAS), whereas awareness is associated with cortico-thalamic network connectivity and frontoparietal cortex (C. Di Perri, J. Stender, S. Laureys, & O. Gosseries, 2014; S. Laureys et al., 2000). Generally, a linear concordance exists between wakefulness and awareness, and along with an increase in one, the other also increases. However, in some conditions, the two aspects are dissociated from each other. Minimally conscious state (MCS) and the vegetative state (VS, or unresponsive wakefulness syndrome-UWS) are among the condition during which wakefulness is preserved, but awareness is impaired to a different extent (Carol Di Perri, Johan Stender, Steven Laureys, & Olivia Gosseries, 2014). Despite accumulating evidence, it is really hard to point structures that are "minimally sufficient and jointly necessary" for consciousness.

It has been stated that limited subcortical regions are necessary for maintaining wakefulness, whereas cortical projection structures appear to play a role in providing perceptual contents of

consciousness or awareness (B. J. Baars, 1995). In 1949 the first findings related to cerebral activities were recorded, and the role of ARAS which situated in the central thalamus and upper brain and its relationship with brain activity were described (Moruzzi & Magoun, 1949; Neylan, 1995). The ARAS, a crucial component of consciousness, consists of numerous neural circuits originating from reticular formation of the brainstem, projecting to the intralaminar nucleus of the thalamus and ending the cerebral cortex (Yeo, Chang, & Jang, 2013). Other members of this system include the pedunculopontine nucleus, parabrachial nucleus, locus coeruleus, dorsal raphe, median raphe, hypothalamus, and basal forebrain, and non-specific thalamic nuclei which take part in consciousness (P. M. Fuller, D. Sherman, N. P. Pedersen, C. B. Saper, & J. Lu, 2011). These structures and pathways stimulate awareness-related centers in the cerebral cortex through synapses in the basal forebrain and thalamus (Edlow et al., 2012). Subcortical areas of the brain, despite having a massive number of neurons have a different amount of contribution to the concept of consciousness. Cerebellum has four times more neurons than the cortex (Herculano-Houzel, 2012). However, lesions of this region have little effect on the contents of consciousness (Lemon & Edgley, 2010).

On the other hand, evidence suggests that parts of the corticothalamic system are necessary for maintaining consciousness. Several undisputed examples of UWS demonstrate that the loss of consciousness is commonly accompanied by massive lesions of the cortical grey or white matter. This frequently and significantly involves thalamus (Posner, Plum, Saper, & Schiff, 2007). The evidence, when accompanied by the fact that patients with lesions of brain structures outside the corticothalamic system (e.g., spinal cord and cerebellum) remain conscious, becomes more compelling (Giulio Tononi, Boly, Gosseries, & Laureys, 2016). Here, another unresolved issue arises, positing thalamus against other parts of the cortex. It has been proposed that the thalamus, and particularly the intralaminar nuclei, might form a "centrencephalic system" which is responsible for a conscious state (Bogen, 1997). In that light, patients with brain damages involving bilateral paramedian thalamic nuclei are often in an unresponsive state or minimally conscious state (Posner et al., 2007). However, evidence emerging from other studies contradicts these findings and shows that the thalamus may not be necessary for consciousness. Thus, lesions involving the paramedian thalamic region and causing unconscious state might involve projection from glutamatergic neurons in the parabrachial-precoeruleus complex of the brainstem. The latter is responsible for the stimulation of the cortex via a basal forebrain relay (Patrick M. Fuller, David Sherman, Nigel P. Pedersen, Clifford B. Saper, & Jun Lu, 2011). Other discussions regarding the role of primary areas vs. higher level areas, ventral vs. dorsal visual stream, posterior vs. anterior (prefrontal) cortex, lateral fronto-parietal network vs. (medial) default system, left vs. right

hemisphere, reentrant vs. feed-forward connections, and superficial vs. deep layers of cortex in a conscious experience exist. However, none of these are conclusive.

2.2. Cell types involved in consciousness

Neurosciences have always been preoccupied with the question that whether specific cell types are directly responsible for conscious experience. Research has shown that specific cell types such as the spindle neurons (also recognized as von Economo neurons) detected in layer 5 of the frontal lobe in species with bulky, complex brains, may be responsible, at least partially, for consciousness (Butti, Santos, Uppal, & Hof, 2013). On the other hand, others have indicated the important role of thin-tufted pyramidal cells in consciousness. These cells create corticocortical connections in layer 5A and their interconnections are denser than those of the neurons in layer 6. To complicated the presented picture with more evidence, scientists have revealed that supra-granular pyramidal cells have denser interconnections with other neurons in the superficial cortical layers, possess more precise topography than those found in the infra-glandular layers, and are fire more specifically in response to stimuli than the latter layer (Harris & Shepherd, 2015; Markov et al., 2014; Zhang et al., 2014). What could be interpreted from the previous discussion is that neurons in the supra-granular layer are associated with a conscious experience (B. J. He & M. E. Raichle, 2009).

2.3. Electrophysiological correlates of consciousness

Alterations in the neural activity do not inevitably associate with changes in conscious experience. From the electrophysiologic view, consciousness implies low frequency and desynchronized brain activity that is ranged between 20-70 Hz. The involved parts of the brain in consciousness like the nuclei of the thalamus are connected with cortex by way of the thalamocortical system and during the information flowing process, the oscillating loop is adjusted around 40 Hz. The neurons of the thalamic nuclei have been found to switch on particular cortical pyramidal cells and quiet other brain parts by activation of gamma-aminobutyric acid (GABA) inhibitory interneurons. Consequently, consciousness is presumed to be feasible only when the 40 Hz electrical stream established along with the brain circuits ("Review: Neural correlates of consciousness," 2009).

Apart from the mentioned waves which may play role in consciousness, several super or infra-slow waves (0.001-0.1 Hz) and slow waves (0.1-1 Hz) may also take part in the integration of faster frequencies and have a crucial role in maintaining a conscious state, integrating inputs from different sources and thus unifying consciousness. The slow and infra-slow waves are generated in the upper layers of higher-order brain regions such as the associative cortex and their existence is thought to be a mandatory non-sufficient prerequisite of consciousness. These waves are also called neural predisposition of the level/state of consciousness (NPC) as opposed to faster waves

which are neural correlates of consciousness (NCC), meaning that in normal conditions, slow/infra-slow waves provide "temporal basement" that works as "default-mode" for the coupling to faster waves (or cross-frequency coupling (CFC)). Infra-slow and slow waves travel through the cortical layers of the brain and change direction when the animal is anesthetized. Also, when a given animal is unconscious the association between these slow and fast waves breaks apart causing "temporospatial fragmentation and isolation" (Biyu J He & Marcus E Raichle, 2009; Northoff, 2013, 2017). What happens during UWRS is indeed an increase in the slow-waves power, and decrease in the faster-waves power or replacement of "temporospatial integration and nestedness" by "temporospatial fragmentation and isolation" (Northoff, 2017).

3. The Neural Correlates of Consciousness

The NCC is described as minimal neuronal operations mandatory for any specific conscious matter (Francis Crick & Koch, 1990a; Koch, 2004). According to Chalmers, NCC "is a minimal neural system N such that there is a mapping from states of N to states of consciousness, where a given state of N is sufficient under conditions C, for the corresponding state of consciousness" (David J Chalmers, 1995).

There are typically two models of NCC; first, the *content-specific* NCC is defined as the minimal neural mechanisms and activities which define a certain phenomenal difference in conscious experience, such as places, colors, or thoughts. This could be artificially stimulated via specific technics such as transcranial magnetic stimulation (TMS) when there are no real external stimuli or blocked via the same mechanisms when there are real external phenomena (Koch, Massimini, Boly, & Tononi, 2016). Second, the *full* NCC can be explained as neural prerequisites associated with conscious experiences regardless of their certain contents. This, in general, has been described as the sum of the *content-specific* NCCs (Francis Crick & Koch, 1990b) (Fig 1A). However, utmost efforts should be made to distinguish NCC from the necessary background factors which provide condition to be conscious. Such factors include the activity of heterogeneous neuronal populations within the brainstem, hypothalamus and basal forebrain, blood-brain oxygen and glucose levels, and neurotransmitters facilitating a conscious experience (Koch et al., 2016).

When it is aimed to assess *content-specific* NCC, a given stimulus is presented to the brain, and its activity is compared using specific imaging modalities with the time when this particular stimulus does not exist. For instance, it has been found that the introduction of visual stimuli triggers widespread brain activity in the frontoparietal and extra-striate occipital networks of the brain. These results have been substantiated by findings from a positron emission tomography (PET) showing that absolute cerebral blood flow decreases in both parietal and frontal cortices during

sleep. Such a finding would confirm the crucial role of these regions in consciousness. On the other hand, assessment of the *full* NCC is achieved via the comparison between the brain activity in an awake healthy subject with the same person in a condition in which his/her consciousness is severely impaired e.g. in dreamless sleep (Bai et al., 2010; Koch et al., 2016; Massimini et al., 2005). Such contrasting studies performed in healthy subjects indicate that *full* NCC is restricted to a temporo-parieto-occipital area in perceptual experiences and a frontal region in thought-like experiences. This compelling evidence suggests that the posterior cortical region can be assumed as a "hot zone" for the NCC (Siclari, LaRocque, Bernardi, Postle, & Tononi, 2014).

What could be derived from both the NCC theories, is that no specific part of the brain is directly responsible for conscious experience. Quite the contrary, it is assumed that a limited number of regions, particularly in the posterior cortical hot zone, are thought to be responsible for both full and content-specific NCC (Koch et al., 2016).

4. Loop connectivity between higher- and lower-order cortical regions and subcortical areas

Higher-order regions of the brain are considered as more favorable, particularly the prefrontal cortex, which is involved in a range of higher cognitive operations known as decision-making functions. There is considerable verification that neural activity from the frontal cortex to sensory areas is more prognostic of conscious awareness (F. Crick & Koch, 2003). However, the latest research illuminates that posterior regions contribute more to the localization of consciousness than the frontal regions of cortex. For instance, various patients have been reported with an average state of consciousness after severe frontal damage (Amberson, 1954).

The association of higher-order cortical regions with lower-order cortical areas and also with subcortical regions i.e., thalamocortical and cortico-cortical networks has been the basis for several models trying to explain consciousness (Fig 1B). This loop connectivity, which is also termed as reafferent, reverberant, recurrent, re-entrant, and feedback connectivity, explains that some higher-order loci in the cortex i.e. association areas receive input from lower-order regions of the cortex and also subcortical regions. Accordingly, the feed-back resulting from higher-order areas produces reverberating signals. These signals can provide the basis for consciousness in several ways. Such circulating signals prevent neural signals from rapid decay. Conversely, these circuits also amplify neural signals. Maintenance and amplification of neural signals in a large-scale network allow multiple cortical regions to access these representations and use these feedbacks as predictive signals to compare them with real-time feed-forward sensory data (Imas, Ropella, Ward, Wood, & Hudetz, 2005; Mashour, 2019).

However, not all things are clear in this regard. For example, the role of some subcortical region in consciousness in the aforementioned circuits is not thoroughly elucidated. Despite the association between cortex, basal ganglia and thalamus, and involvement of these regions in cognitive and motor operations (Alexander, DeLong, & Strick, 1986; McHaffie, Stanford, Stein, Coizet, & Redgrave, 2005), it remains debatable whether the basal ganglia contribute to consciousness directly, or they are connected using claustrum which is a crucial section in information gathering and its transformation into a conscious state (F. C. Crick & Koch, 2005). A recent study stated that basal ganglia, cerebellum, and prefrontal cortex do not contribute directly to conscious experience (Koch et al., 2016).

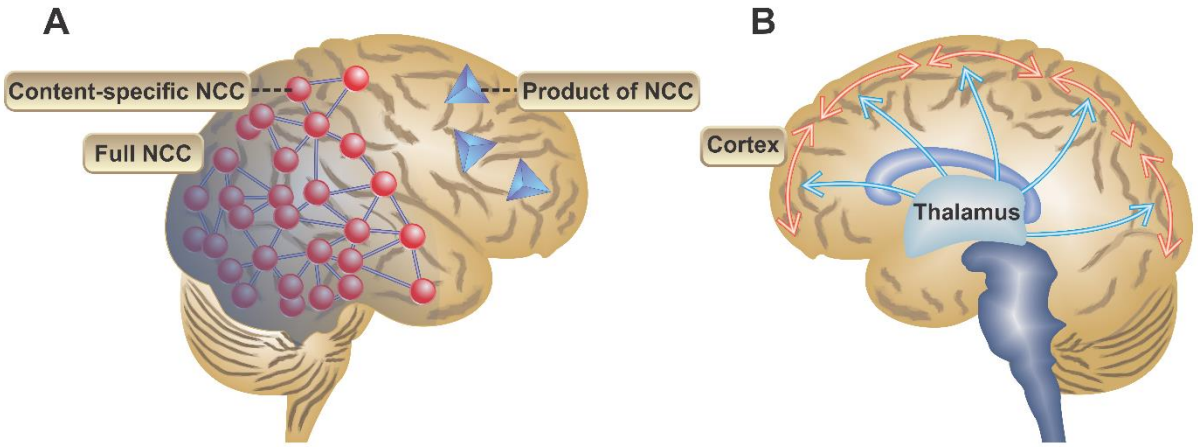

Fig. 1: (A) the *content-specific* Neural Correlates of Consciousness (NCC) as a minimal neural activity for conscious experience and *full* NCC as the sum of the *content-specific* NCCs. (B) the association of higher-order cortical regions with lower-order cortical areas and also with subcortical regions. Blue arrows show the thalamocortical and red arrows show cortico-cortical networks.

5. Lateralization of consciousness

After several years of study, Gazzaniga and his colleagues found a meaningful association between the left hemisphere and consciousness and suggested the idea of an "Interpreter" (Volz & Gazzaniga, 2017) the main objective of which is to have consistent interpretations of the world and self. While Ramachandran (Ramachandran, 1995) further suggested that the role of the right hemisphere is to recognize the inappropriate and incoherent information related to the left hemisphere. Like a detector, the right hemisphere obliges the left hemisphere to update and modify its beliefs (Gazzaniga, 1992). In healthy participants, data is moved from the right hemisphere to the left one, interpreted, and labeled. Findings showed that the "Interpreter" is situated in the left

hemisphere and it is reliant on both language and inferential thinking (Volz & Gazzaniga, 2017). On the other hand, when split-brain patients are asked to point out the related cases, they point correctly with their left hand but verbally they cannot devise a suitable relationship and do not see any stimulus. The "Interpreter" shows a vital prospect of consciousness and its localization, including the left anterior and mid-insula, and dorsal caudate (Denny, Kober, Wager, & Ochsner, 2012). The findings on split-brain patients assume that corpus callosum like the left hemisphere has an essential influence on conscious experience. Corpus callosum involves both consciousness processing systems: synchronization (Engel & Singer, 2001) and integration (G. Tononi, 2004).

6. The Global Neuronal Workspace

This theory was first proposed by Bernard Baars, in an effort to provide a cognitive/computational model for consciousness (Bernard J Baars, 1993). Accordingly, Stanislas Dehaene et al., redefined the theory from the neural perspective as follows; "a state is conscious when and only when it (or its content) is present in the global neuronal workspace making the state (content) globally *accessible* to multiple systems including long-term memory, motor, evaluational, attentional and perceptual systems". Here, several terms and conditions should be clarified. First, there is the accessibility of system X to the information in the system Y, when X utilizes that information in its calculations/processing (Dehaene & Changeux, 2011; Dehaene, Kerszberg, & Changeux, 1998; Dehaene & Naccache, 2001). In that light, only states whose content is retrieved by the workspace (neurons with distant connections linking various systems, only if they demonstrate specific neural properties) and is globally reachable to other systems are considered conscious. Second, workspace is not a solid neural structure but a swiftly evolving neural network. Third, the mere fact of accessibility is not enough to constitute the global workspace. Thus, workspace neurons should be in a sustained active condition, generating a *recurrent* activity between workspace systems (Dehaene & Naccache, 2001). However, the global neuronal workspace theory is not able to sufficiently provide an account of phenomenal consciousness. As imaging results that disclose widespread activation during access consciousness are the basis of phenomenal consciousness too (Block, 2007).

7. Recurrent Processing Theory

This theory puts forward the effort to define perceptual consciousness based on a process that is independent of the workspace, but dependent on recurrent activity in sensory areas. This recurrent activity is considered both necessary and sufficient for conscious experience and results from feedforward and feedback connections between highly interconnected sensory systems. In a four-stage state of normal visual processing (stage1: Superficial feedforward processing, stage 2: deep

feedforward processing, stage 3: superficial recurrent processing, and stage 4:widespread recurrent processing) Lamme argues that recurrent processing in stage 3 is essential and enough for a conscious experience (Lamme, 2006, 2010).

8. Higher-Order Theory (HOT)

This theory states that "one is in a conscious state if and only if one relevantly represents oneself as being in such a state", meaning that one should be able to i.e., represent that state. This is in contrast with first-order theories which maintain that a mental state is considered conscious only by the neural or representational character of the perceptual condition (Rosenthal, 2002). Experiments performed on the prefrontal cortex provide a basis to test HOT (Dehaene & Changeux, 2011; Lau & Rosenthal, 2011). However, there are several criticisms against this theory such as 1) prefrontal lesions do not distort awareness, and 2) prefrontal activity echoes attention but not awareness (Kouider, Dehaene, Jobert, & Le Bihan, 2007; Tse, Martinez-Conde, Schlegel, & Macknik, 2005).

9. Conclusion

The compelling concept of consciousness is one of the challenging discussions during human life from ancient human developments until modern neuroscientific progression. Based on cultural, religious, and social beliefs, there is usually a unique viewpoint about the origins of consciousness in different civilizations and philosophical schools. No consensus on the definite meaning of consciousness exists, though. Nevertheless, with the aid of the latest neuroscientific developments, the misleading obstacles related to consciousness have been removed. The study of brain function and its functional and anatomical connections can uncover the location of consciousness in the brain unraveling most of the unsolved issues related to states of consciousness. Neuroscientific efforts in determining the function of the brain and merging these findings with philosophical theories will bring about a more comprehensive perception of the notion of consciousness.

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