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Review

Conscious brain, metacognition and schizophrenia

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ABSTRACT

Recent findings indicate that the binding and synchronization of distributed neural activities are crucial for cognitive processes and consciousness. In addition, there is increasing evidence that disrupted feature binding is related to experiences of disintegration of consciousness in schizophrenia. These data suggest that the disrupted binding and disintegration of consciousness could be typically related to schizophrenia in terms of Bleuler's concept of "splitting". In this context, deficits in metacognitive capacity in schizophrenia may be conceptualized as a spectrum from more discrete to more synthetic activities, related to specific levels of neural binding and neurocognitive deficits. This review summarizes the recent research on metacognition and its relationship to deficits of conscious awareness that may be found in schizophrenia patients. Deficits in synthetic metacognition are likely linked to the integration of information during specific processes of neural binding. Those in turn may be related to a range of mental activities including reasoning style, learning potential and insight.

1. Introduction

In 1881, Eugen Bleuler began developing his view that the core problem among individuals with psychosis is determined by disruptions of thought-linkages and deficits in the coordination of different psychological functions. These anomalies were thought to lead to a "loosening of associations" related to the process of splitting. Bleuler defined the term splitting as a process of formation of complex mental structures linked to incompatible experiences producing numerous divisions in mental processes (Bleuler, 1918/1906). In his work: "Dementia praecox or the group of the schizophrenias", Bleuler (1911), introduced the term "schizophrenia" to describe the illness that replaced Kraepelin's dementia praecox (Bleuler, 1911/1955, 1918/1906; Jung, 1909). Bleuler thought that: "…the 'splitting' of the different psychic functions is one of its most important characteristics" (Bleuler, 1911/1955, p.8). According to Bleuler (1911/1955) some psychic complexes creating aggregates of thoughts, feelings and affects may dominate personality structure, while other complexes may be "split off" and operate as fragments connected with the others in an "illogical" way.

In historical context Bleuler's definition of "split mind" as a characteristic feature of disturbed cognition in schizophrenia is related to Descartes' proposal the binding multidimensional information from various sensory modalities that enables conscious experience (Bob, 2015; Barrera-Mera and Barrera-Calva, 1998). The so-called "binding problem" leads to the unresolved question where and how the information is integrated into the whole and how this information is specifically linked to previous experience in the spatio-temporal memory. An important question for further research of the integration of distributed brain activities is whether the essential integrative role can be attributed to a specific structure in the brain or whether this ability is inherent to the cognitive network as a whole. In addition it is not known how spatial convergency is provided for the synthesis of processed information that emerges and for example, there are only a few neural connections between specific visual areas that correlate with color and motion (Bartels and Zeki, 2006; LaRock, 2006; Zeki, 1994, 2003). For example, visual consciousness requires activity in many areas of the brain and the components of the high-level visual representations, closely linked to focused attention, need to access these structures, form a perceptual object and bind together various features of an object (Zeki and Bartels, 1999; Cavanagh, 2011).

A key evidence for the binding problem reported studies of primate extrastriate visual cortex which have shown that different neurons within the visual system participate on processing of different features of a seen object (Desimone et al., 1985; Schein and Desimone, 1990; Ghose and Tso, 1997). For example, Desimone et al. (1985) have found that neurons in visual area (V4) and inferior temporal cortex (IT) are sensitive to many kinds of information relevant to object

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recognition. They also found that special contribution of V4 neurons to visual processing may lie in specific spatial and spectral interactions and that many different stimulus qualities are processed in parallel mode of processing. Similar results reported Ghose and Tso (1997), who also found that V4 contains modular assemblies of cells related to particular aspects of processed object-based representations. There is also evidence in research of moving objects that other neurons in the middle temporal area and the medial superior temporal area encode various aspects related to the motion of the stimulus (Treue and Andersen, 1996; O'Keefe and Movshon, 1998).

Significant contribution to this discussion about mechanisms of large scale integration reported Crick and Koch (1992, 2003) in their studies of the visual consciousness. They proposed that the problem of binding may not be resolved only as a simple consequence of synchronization among large groups of neurons. As a basis for that opinion they emphasize the binding problem of distributed information representing a seen object by groups of synchronized excited neurons that are located at different parts of the brain. This problem has emerged in connection to findings that features of an object such as color, shape, texture, size, brightness, etc. produce activity in separate areas of the visual cortex (Crick and Koch, 1992; Felleman and Van Essen, 1991; Singer, 1993, 2001). In context of these findings the hypothetical center for brain information convergency that enables perceptual consciousness and conscious experience was termed "Cartesian theatre" (Crick and Koch, 1992; Dennett, 1991). Recent neuroscience, however, has not located a distinct place in which distributed information in the brain comes together. Additionally, there is evidence that neocortical processing is distributed during all sensory and motor functions (Singer, 1993, 2001).

The predominant view in neuroscience of consciousness is that neuronal synchronization is a phenomenon that is necessary for the large scale integration of distributed neuronal activities. There is increasing experimental evidence that coherent neuronal assemblies in the brain are functionally linked by phase synchronization among simultaneously recorded EEG signals and that this time-dependent synchrony between various discrete neuronal assemblies represents neural substrate for mental representations such as perception, cognitive functions and memory (Varela et al., 2001; Lachaux et al., 1999). These functions are related to distributed macroscopic patterns of neuronal activity which involve multiple neuronal subsystems bound into a coherent whole (Braitenberg, 1978; Van Putten and Stam, 2001). According to recent data, a mechanism that enables binding of distributed macroscopic patterns of neuronal activity, represented by neural assemblies, into the coherent whole is still unresolved and represents a fundamental problem in neuroscience [i.e., the binding problem: how the brain codes and integrates distributed neural activities during processes connected to perception, cognition and memory] (Woolf and Hameroff, 2001; Lee et al., 2003a; Arp, 2005; Fidelman, 2005; Velik, 2010). The theory of feature binding originates with distributed coding and states that neurons involved in the processing of a single object will tend to synchronize their firing, while simultaneously desynchronizing their firing from the remaining neurons not involved in the processing of the object (von der Malsburg and Schneider, 1986). An essential feature of neuronal assembly coding is that individual neurons or subsystems can participate at different times in an almost unlimited number of different assemblies (Sannita, 2000; Varela et al., 2001). The same neurons can participate in different perceptual events and different combinations of these neurons can represent different perceptual objects. Synchronization of these different perceptual objects is related to the integration of perceptions into a coherent whole (Singer and Gray, 1995). As a candidate mechanism for the integration or binding of distributed brain activities is the so-called gamma activity—high frequency oscillations according to some studies varying from 20 to 100 Hz. This activity occurs synchronously across brain regions and underlies the integration of diverse brain activities (Singer and Gray, 1995; Wang and Buzsaki, 1996; Buzsaki, 2006; Bob and Mashour, 2011).

In this context, majority of recent studies on neural correlate of consciousness have focused on EEG analysis and observed functionally relevant periods of synchronization mainly in gamma frequency band in various species and brain structures during attention, perception, motor and memory tasks (Singer, 2001; Lee et al., 2003a; Jensen et al., 2007). Together these findings suggest that a candidate mechanism for the integration or binding of distributed brain activities is the gamma activity which enables to different neuronal circuits to enter into synchrony with the perceptual information. This integrative process enables to these simultaneously active neuronal clusters oscillate together during transient periods of synchronized firing and this coherent whole enables to connect various memories and associations involved in the process and generate a coherent process of perception, cognitive processing, memory and consciousness (Buzsaki, 2006). Several recent findings suggest that the higher and the lower frequencies may play a specific role in binding and connectivity with specific manifestation in cognition and its disturbances. These results agree with the findings that disconnection and disturbed binding as a correlate of mental disintegration in schizophrenia may be related to decreased or increased synchrony (Lee et al., 2003a; Tononi and Edelman, 2000; Uhlhaas and Singer, 2006). Decreased or increased synchrony associated with schizophrenia symptoms likely reflects process of functional segregation of sets of neurons that occurs in different cortical areas and causes segregation or increased information flow across specialized brain areas of the brain (Sporns et al., 2000, 2002).

Through this mechanism gamma activity occurs synchronously across brain regions and underlies the integration of diverse brain activities (Singer and Gray, 1995). Crucial result of these studies is a direct link between visual perception and gamma synchrony in the cat visual cortex reported by Eckhorn et al. (1988). Following this finding, functional significance of synchronous gamma activity in selective attention, perceptual processing and recognition was repeatedly demonstrated in animal and human studies (Meador et al., 2005; Rodriguez et al., 2004; Jensen et al., 2007). Together these data strongly suggest that complex cognitive functions are organized at a global level that enables to integrate primitive functions organized in localized brain regions (Bressler and Kelso, 2001; Bob, 2011). In this context, current predominant hypothesis relies on the assumption of the global mode of functioning that is based on large-scale information processing that requires mechanisms of functional integration of multiple disparate neural assemblies (Varela et al., 2001; Fries et al., 2001; Jensen et al., 2007).

Although the majority of research on feature binding has focused on synchronous gamma activity, there is evidence that synchronous activities in other frequency bands may also participate in functional integration of distributed neural activities into the coherent whole (Bressler et al., 1993; Lee et al., 2003a). Following these findings Dennett (1991) proposed "a multiple drafts" theory of consciousness model that does not define consciousness as a unitary process but rather a distributed one. Instead of a single central place i.e. "Cartesian theatre," there are various events of content-fixation that occur in various places at various times in the brain (Dennett, 1991, p. 365).

On the other hand there are possible limitations and controversial points whether neural synchrony mediates visual feature grouping or just represents its neural correlate that in principle does not explain the process of feature binding or "binding problem" (Palanca and DeAngelis, 2005; Bob, 2011; Ray and Maunsell, 2015; Bosman et al., 2014; Merker, 2013). Nevertheless the evidence for this view linking consciousness and gamma activity was reported by a whole series of experimental results in cognitive neuroscience and psychology (LaRock, 2006; Varela and Thompson, 2003; von der Malsburg, 1996, 1999; van der Velde and de Kamps, 2006; Zeki, 2003).

Recent findings indicate that these characteristic mental deficits related to conscious integration in schizophrenia are typically linked to abnormalities in brain development and neurocognitive deficits in information processing, verbal memory and executive functioning (Braff et al., 2007; Green et al., 2013; Hori et al., 2012; Light and Braff, 2005;

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