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Review article

Alpha oscillations and their impairment in affective and post-traumatic stress disorders

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ABSTRACT

Affective and anxiety disorders are debilitating conditions characterized by impairments in cognitive and social functioning. Elucidating their neural underpinnings may assist in improving diagnosis and developing targeted interventions. Neural oscillations are fundamental for brain functioning. Specifically, oscillations in the alpha frequency range (alpha rhythms) are prevalent in the awake, conscious brain and play an important role in supporting perceptual, cognitive, and social processes. We review studies utilizing various alpha power measurements to assess abnormalities in brain functioning in affective and anxiety disorders as well as obsessive compulsive and post-traumatic stress disorders. Despite some inconsistencies, studies demonstrate associations between aberrant alpha patterns and these disorders both in response to specific cognitive and emotional tasks and during a resting state. We conclude by discussing methodological considerations and future directions, and underscore the need for much further research on the role of alpha functionality in social contexts. As social dysfunction accompanies most psychiatric conditions, research on alpha's involvement in social processes may provide a unique window into the neural mechanisms underlying these disorders.

Contents

1. Introduction

1.1. Neuroscience perspective on psychiatric disorders

Psychiatric disorders are debilitating mental conditions characterized by cognitive alterations, emotional difficulties, and impaired functioning, all of which introduce considerable individual suffering and a dramatic reduction in quality of life (Massion et al., 1993; Rapaport et al., 2005; Saarni et al., 2007; Zatzick

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et al., 1997). Although therapeutic interventions (behavioral and pharmacological) exist for most disorders, such interventions are not effective for all patients, leaving many untreated (Arnone, 2005; Norrholm, 2010; Rush et al., 2006). Psychiatric disorders have long been the focus of empirical research aimed at understanding their behavioral and physiological manifestations. During the past decades, much research has been directed to elucidate the neural underpinnings of different psychiatric conditions, with the ultimate goal of identifying biomarkers that can aid in the diagnosis and development of efficient therapeutic interventions (Başar, 2013; Uhlhaas and Singer, 2012). Utilizing different noninvasive methodological approaches, neuroimaging and electrophysiological studies provided valuable insights into the functional abnormalities associated with psychiatric disorders and their relation to clinical symptoms (Drevets, 2001, 2000; Etkin and Wager, 2007; Phillips et al., 2008; Sheline, 2003). Much of this research used functional magnetic resonance imaging (fMRI), which measures brain activity with high spatial precision; however its BOLD signal is of low temporal resolution and provides an indirect measure of neuronal activity (Luck, 2014; Papanicolaou, 2009). Electroencephalography (EEG) and magnetoencephalography (MEG) techniques, on the other hand, record brain activity with high temporal resolution and their signal directly reflects electric currents and magnetic fields, respectively, which are generated by neural activity (Hämäläinen et al., 1993; Vrba and Robinson, 2001). These properties enable a noninvasive investigation of oscillatory activity and its abnormalities in psychiatric conditions – the focus of the current review.

1.2. Alpha oscillations: interpretation, measurement, and potential use as a neuromarker for psychiatric conditions

1.2.1. Neural oscillations

Neural oscillations (or "neural rhythms") are a pervasive feature of neuronal activity in the cerebral cortex (Donner and Siegel, 2011). They reflect periodic fluctuations of excitability in neural populations generated by transmembrane currents, which give rise to electric potentials known as 'local field potentials' (LFPs). The LFPs of temporally synchronized neural activities are measurable from the scalp by means of EEG and MEG recordings (Buzsáki et al., 2012; Ros et al., 2014). Neural rhythms and their behavioral correlates are highly conserved throughout mammalian evolution (Buzsáki et al., 2013; Buzsáki and Draguhn, 2004), underscoring their fundamental role in supporting brain function. Neural rhythms are thought to underpin perceptive and cognitive processes in both animals and humans (Clayton et al., 2015; Wang, 2010; Ward, 2003), supporting integrative functions such as perceptual inference, top-down attention, and decision-making (Donner and Siegel, 2011). Disruption of oscillatory behavior may therefore affect a wide range of cognitive and perceptual processes (Uhlhaas and Singer, 2010, 2006).

1.2.2. The alpha rhythm

Alpha rhythm (~8–12 Hz) is the predominant oscillation in the awake, conscious brain that functions to sustain higher intrinsic cortical functioning and serves an integrative role by synchronizing brain activity in different brain rhythms (Klimesch, 2012). Since its discovery almost a century ago (Berger, 1929), the alpha rhythm has been largely considered as an "idling rhythm". This interpretation leaned on the observation that alpha rhythm increases when subjects are not engaged in any task as well as in cortical regions that are not involved in current information processing (Pfurtscheller et al., 1996). While it is generally agreed that increased alpha is related to decreased cortical activity (Goldman et al., 2002; Laufs et al., 2003a, 2003b), technological advances in neurophysiology provide extant evidence for the functionality of the alpha rhythm, suggesting its important role in a variety of cognitive processes.

One of the most intriguing aspects of alpha rhythm's functioning is that it operates either through power (i.e., amplitude) increase or through power decrease. Klimesch et al. (2007) suggested that task-related increase in alpha power reflects top-down, inhibitory control of task irrelevant processing, while a decrease in alpha power (often termed "alpha suppression") reflects a release of functional inhibition (Klimesch et al., 2007). Others have suggested that increased alpha may reflect active (memory-related) processing (Palva and Palva, 2007). Jensen and Mazaheri, (2010) further outlined the inhibitory property of alpha oscillations in their perspective on "gating by inhibition", according to which information is routed to task-relevant brain regions by functionally blocking-off activity (through alpha power enhancement) in task-irrelevant regions. Moreover, they suggest that such alpha-mediated inhibition is required for optimal task performance. Recently, this proposal received neurophysiological support in animal research (Haegens et al., 2011). In their inquiry into the role of cortical oscillations in sustained attention, Clayton et al. (2015) proposed that in addition to the role of alpha oscillations in local cortical inhibition of task-irrelevant processes, an increase in global alpha power during tasks that require sustained attention may reflect coordinated activity in frontal and posterior brain regions associated with cognitive control. This proposal was based on studies linking global alpha power to activity in networks associated with task-related processing and sustained attention.

The role of oscillatory activity in cognitive processes has also been studied by simultaneous recording of EEG and fMRI activity (Chang et al., 2013; Sadaghiani et al., 2010; Zumer et al., 2014). For instance, Donner and Siegel (2011) systematically examined task-related oscillatory behavior and the relation between oscillatory patterns and BOLD-fMRI signal. They suggested that the link between neural oscillations and BOLD signal is not fixed, but rather process-dependent. Specifically, while the activation of local cortical regions (e.g., activation involved in the encoding of sensory information) is typically associated with decreased low-frequency activity (including alpha rhythms), thus yielding a negative correlation with BOLD signal, cortical interactions among distant brain regions, which mediate integrative functions (e.g., top-down control, decision-making), typically enhance low frequency oscillations, yielding a positive correlation with BOLD (Donner and Siegel, 2011). Together, these observations and theories reveal a complex picture of alpha functionality, which awaits further elucidation, potentially by integrating insights from research on healthy and clinical populations as well as animals.

1.2.2.1. Alpha oscillations and social processes. Cumulative evidence in social neuroscience suggests that alpha rhythm plays a key role in supporting social functioning, including the perception of biological motion (Ulloa and Pineda, 2007) and inter-individual synchronized actions (Dumas et al., 2010). We recently found that alpha rhythm is enhanced by stimuli probing social synchrony in brain regions associated with social perception and theory of mind, including the posterior superior temporal sulcus and the inferior frontal gyrus (Levy et al., 2016). Moreover, we found that oxytocin, a neuropeptide involved in social information processing, interacts with alpha activity to increase salience to specific features of individuals and contexts. This finding is congruent with previous research, indicating that oxytocin impacts alpha oscillations in the mirror neurons network (Perry et al., 2010b) and that its effects are context-bound and shaped by powerful social experiences (Bartz et al., 2011).

Alpha activity was also shown to be involved in the perceptual processing of others' pain – the most ancient precursor of empathy that indexes the ability to increase emotional arousal and