The role of amplitude, phase, and rhythmicity of neural oscillations in top-down control of cognition

Chair: Jason Samaha, University of Wisconsin-Madison
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Central to cognition is the regulation of information flow across different regions of the brain. The temporal coordination of neural oscillations has been proposed to play a key role in communication between brain regions and in anticipatory and predictive processes. This symposium will present new empirical and theoretic evidence suggesting that 1) various key spectral dynamics (i.e., phase, amplitude, degree of rhythmicity) of oscillations are important for regulating information flow across the cortex and, 2) top-down control over neural oscillations via temporal expectation and attention can bias processing in a goal-directed manner. Bonnefond will begin with evidence that the phase of visuocortical alpha-band oscillations may act as a gating mechanism in the service of anticipatory processing, with a role for left prefrontal cortex as the 'source' of such top-down control. Sack will discuss examples of oscillatory phase biases on perception in the context of temporally predictable cross-modal stimuli. Mazaheri will provide evidence that modulating the rhythmicity of lower frequency oscillations could be a mechanism to reduce maladaptive connectivity across the brain. Samaha will present work suggesting that alpha-band oscillations reflect discreet epochs of visual processing that can be guided by temporal predictions. Finally, Voytek will close with a computational account of oscillatory communication and present invasive and non-invasive electrophysiological recordings in humans demonstrating goal-directed modulated of neural communication in frontal cortex and implications for neuropathology. This survey of the field will cover many recent advances in understanding neural communication, top-down control, and human cognition and will highlight areas of active debate and avenues for further research.

Left prefrontal cortex controls alpha phase adjustment in anticipation of predictable stimuli

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While it is now consensual that alpha power (8-12Hz) can adjust in anticipation of incoming information, it remains unclear whether alpha phase can adjust as well. I will present the results of two magnetoencephalography experiments showing that alpha power and alpha phase, in visual areas, are being adjusted in anticipation of both irrelevant and relevant visual information. These adjustments prevented/optimized the processing of irrelevant/relevant stimuli as assessed by performance and stimulus-induced activity. In addition, we found in both experiments that alpha oscillations in the left prefrontal cortex controlled the adjustment of alpha phase in visual areas. The anticipatory power and phase adjustments add to the computational versatility of the alpha rhythm, since it allows for adjusting the processing capabilities of the visual system on a fine temporal scale

The role of oscillatory phase for encoding consistent temporal statistics

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Perception of temporally predictive events is enhanced by aligning high excitable phases of ongoing oscillations to the upcoming event. This mechanism has been shown useful to proactively improve perception in an environment that dynamically changes its temporal statistics. However, some temporal statistics are very consistent. For example in audiovisual speech there is a consistent relationship between the onset of lip movements and the onset of speech sounds such that different syllables have distinct visual-to-auditory onset delays. We show that these consistent delays bias participants' perception. Moreover, ongoing oscillatory phase biases the perception of these syllables in the absence of visual input. This data show that consistent temporal information gets wired on oscillatory properties and provide a unique way to categorize information.

The “rhythmicity” of oscillations in neuronal communication and temporal expectation

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Cognition and behaviour are believed to emerge from widespread, often transient, neuronal interactions in the brain. Some of these interactions are captured in the oscillatory activity present in EEG and MEG measurements. The phase-angle of these oscillations has been suggested to reflect the transient inhibitory and excitatory state of the underlying networks producing them. Furthermore, neuronal communication between networks has been suggested to be subserved by the phase-coupling of oscillations in sending and receiving regions. Using this framework, the first part of my talk will focus on new evidence that the disruption in the rhythmicity of an oscillation through external neuro-modulation such as deep-brain stimulation could lead to a reduction in pathological network ‘over-connectivity’ and translate to therapeutic improvements in disorders such as Parkinson’s and treatment of refractory obsessive compulsive disorder. The second part of my talk will focus on whether the phase of ongoing oscillations could be modulated by endogenous factors such as temporal expectation. Here, in contradiction to some of the other findings that will be presented by my colleagues in this symposium I will be providing evidence against the hypothesis that the phase of alpha activity could be modulated by top-down expectation. I will attempt to address some of the possible theoretical and methodological issues underlying this discrepancy.

The role of alpha-band oscillations in temporal prediction and perception.

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The phase of ongoing posterior alpha-band oscillations has been shown to predict the perception of near-threshold visual stimuli and subsequent cortical information flow. These observations have motivated the hypothesis that alpha-band rhythms reflect discrete “windows” of visual processing. In two studies, we investigated, 1) whether alpha-band phase can be guided by top-down control according to temporal predictions and 2), whether the frequency of alpha rhythms is related to the temporal resolution of visual perception. We found that when subjects were provided with cues predictive of the moment of visual target onset, discrimination accuracy improved and targets were more frequently reported as consciously seen. This effect was accompanied by a significant shift in the phase of alpha-band oscillations, prior to target onset, toward each individual's optimal phase for stimulus discrimination. If alpha-band oscillations do reflect phasic windows of visual processing, then the frequency of the oscillation should predict the temporal resolution of visual perception. In our second experiment, we measured two-flash fusion thresholds and identified the peak alpha frequency of our observers. We found a high correlation between the measures, such that individuals with higher alpha frequencies showed lower fusion thresholds, indicating a finer-grained temporal resolution of visual perception. Additionally, trial-to-trial variation in prestimulus alpha frequency predicted two-flash discrimination accuracy. Taken together, our results suggest that neural activity in the alpha-band may reflect discrete visual computations, the timing of which can be guided by temporal predictions so as to optimally process predicted visual information.

Noisy oscillatory networks in cognition

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Humans have an interesting capacity for maintaining multiple behavioral goals at different timescales--from the control of immediate actions to holding more abstract long-term goals in mind. This process requires the coordination of many partially overlapping functional brain networks. Neural oscillations are often modeled as a major driver in the formation of such networks, acting under the assumption that information flow is enhanced when low frequency oscillations synchronize neural firing. Surprisingly, the biological feasibility of this assumption is largely untested. Here I introduce a novel computational model for oscillatory neural communication. I show that it is the kind of excitatory-inhibitory coupling that matters most, not the degree of coupling as has been previously suggested. When the coupling between a low frequency oscillation and neural spiking is driven by a model of balanced excitatory-inhibitory inputs, information flow is enhanced. In contrast, when coupling is unbalanced, driven either by excessive excitation or inhibition, information flow is obstructed. Additionally, using a combination of invasive and non-invasive human electrophysiology, I provide evidence that interregional oscillatory coupling coordinates brief windows of spiking activity between

frontal subregions. This interregional communication occurs in a noisy neuronal environment, and I show how age-related changes in neuronal noise diminish neural communication and mediate age-related working memory impairments. Numerous neuropathologies, including Parkinson’s disease, schizophrenia, and autism, are associated with oscillatory disruptions and excitation-inhibition imbalances. Understanding the distinction between balanced and unbalanced oscillatory coupling offers a unifying mechanistic framework for understanding effective neural communication and its disruption in neuropathology.