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Brain Oscillations and Cognitive Processes

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Introduction

Cognitive neuroscience now leaves little or no doubt that cognitive processes require the transient integration of numerous, widely distributed, constantly interacting areas of the brain. The most plausible mechanism for such a large-scale integration is the formation of dynamic links mediated by synchrony over multiple frequency bands. Neurons can exhibit a wide range of oscillations (~4-70 Hz) which can enter into precise synchrony over a limited period of time (millisecond scale). Brain oscillatory systems have been proposed to act as possible communication networks with functional relations to memory and cognition. This paper presents recent findings on macroscopic brain electric oscillations as an index of cognitive processing.

Brain Oscillations

Macroscopic EEG signals arising from the brain consist of several simultaneous oscillations, which can be subdivided into frequency bands such as delta (1-3 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (about 14-30 Hz) and gamma (around 40 Hz). Different neural generators are involved in the generation of brain oscillations at different frequencies. Hippocampal neural activity seems to be reflected as oscillations within the theta frequency range while the alpha rhythms seem to be mainly generated by cortico-cortical and thalamocortical neural networks. The beta rhythm is generated mainly in the motor cortices. Gamma brain oscillations have been observed in association with visual, auditory and motor tasks and might exist in a number of brain structures with somewhat different functional/behavioral correlates.

Brain Oscillations and Cognitive processes

Working memory processes seem to be reflected as oscillations within the EEG theta frequencies. Alpha frequency responses can be observed in association with tasks requiring alertness, attention and semantic memory processes. Auditory memory encoding and retrieval typically elicit distinct brain oscillatory responses: encoding elicits ~10 Hz synchronization whereas retrieval evokes ~10 Hz desynchronization (Krause et al., 1996). Memory search experimental paradigms have recently been utilized in clinical settings (Karrasch et al., in press; Ellfolk et al., under preparation). Brain oscillatory responses can be utilized to assess the neural correlates of language processing (Nikitenkova, Laine & Krause, under preparation; Herkman et al., under preparation). Beta rhythm responses have been reported in association with cognitive processing (Karrasch et al., 2004).

The relevance for Cognitive Science

Time and temporal integration of information are undoubtedly among the most important properties of human cognition. Theoretically, brain electric oscillations may serve as carrier signals for cognitive processes (e.g., “online” speech perception), appropriate to establish rapid coupling of spatially separate cell assemblies. The study of neuronal oscillations is concerned with the mutual coordination and communication between neurons in different parts of the brain. This kind of systems-level research is particularly exciting because of its potential to shed light on the transmission of information in the kinds of widely distributed neuronal networks relevant for higher cognitive processing. This integrative research may be of importance when bridging the gap between the neurophysiological and the cognitive approaches to understanding complex brain function.

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