Stimulus-dependent synchronization of the neural network during cortical breathing and hand motion

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Abstract

Respiratory system in humans is based on a complex however harmonious neural interplay between automatic brainstem nuclei and a cortical network. The cortical drive is involved during speech, exercise, voluntary breathing or respiratory load increase, allowing in all these situations the respiratory muscles contraction to ensure adequate lung gas exchange. The cortical breathing comprises brain regions mainly coming from the sensorimotor area, insular cortex, and thalamus. Using cerebral functional magnetic resonance imaging (fMRI), we showed that the cortical network connectivity in normal subject is functionally associated with the di-oxygen level and pulmonary function. Importantly during lung disease as chronic obstructive pulmonary disease, this connectivity is altered and associated with clinical severity. Cerebral control of breathing is also impaired during sleep apnea, genetic disorders and neurodegenerative disease. Consequently, understanding the neural communication of this vital network is crucial.
Neural oscillations in motor control has been recorded in vitro and in vivo at different frequencies. At the neuronal population level, a simple motor action like finger or hand movements generate specific frequency changes. These changes and their functional consequences have been widely described in scientific literature. However, the frequency characteristics and synchronization of the network during cortical involvement of breathing is unknown.

During motor tasks, cortical oscillations are hierarchically organized: different brain regions synchronize in terms of common frequency scheme (coherence) and phase-locked frequency modulation also occurs between different cerebral areas where the phase of one region at a low frequency modulates the amplitude of another region at a higher frequency. Such cross-frequency coupling has been hypothesized to underlie information transfer between brain regions. Cross-frequency coupling likewise happens with external sensory activity to adjust sensorimotor integration As such, breathing modulates cortical oscillations and respiratory activities. A strong specific interaction also exists between neuronal activity pattern and respiration.

We used high density (EEG) to characterize and compare the dynamic changes in event related potential (ERP) source activity during two different motor tasks either breathing involving the cortex or self-paced hand motion. We deciphered on one hand the time resolved frequency distribution and synchronization of the cortical command and on the other hand the respiratory or hand motion phase-locked modulation of the network as a feedback sensory integration.

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We elucidate several important questions: 1/ The relation of the time-frequency characteristics of the network during two different motor tasks 2/ Comparison of the cortical commands and similarity in frequency shape (coherence)? 3/ Are the brain oscillations amplitude of the respiratory network elements spontaneously modulated by the respiratory rhythm and how is evolving the coupling strength when a respiratory load is applied? 4/ Is the cross-frequency coupling a task-dependent phenomenon? 5/ What is the relationship, if any, between the network activation and stimuli–feedback neural coupling?

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