Quantification of Cardio-Respiratory Interactions in Patients with Mild Obstructive Sleep Apnea Syndrome using Joint Symbolic Dynamics

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Cardio-respiratory coordination is an aspect of the interaction between heart and respiratory rhythm. Conventional signal processing techniques such as power spectral density and cross-correlation analysis often prove to be inadequate for characterizing the complex characteristics of the biological signals, which are inherently non-linear, non-stationary and contain superimposed noise. The concept of symbolic dynamics provides a simplified description of the dynamics of a system with the opportunity for an easy interpretation of physiological data. Accordingly, we developed a technique based on the joint symbolic dynamics of heart rate and respiratory phase to quantify cardio-respiratory interaction. This approach was tested in 123 patients with mild obstructive sleep apnea syndrome during night-time sleep. The R-R time series were extracted from electrocardiograms, and respiratory phases were obtained from abdominal displacement sensors using the Hilbert transform. Both series were transformed into ternary symbol vectors based on the changes between two successive R-R intervals and the respective respiratory phases. Subsequently, words of length 3 were formed and the correspondence between words of the two series was determined for each sleep stage to quantify cardio-respiratory interaction. In accordance with previous studies that were based on the synchrogram technique, we found a significantly higher percentage of similarity in the symbolic dynamics of R-R intervals and respiratory phases during slow-wave sleep compared to other sleep stages (slow-wave vs. stage 1, stage 2 and rapid-eye-movement sleep: 20.9 ± 4.7 vs. 15.5 ± 4.2, 17.0 ± 4.1 and 13.4 ± 2.6, $p<0.0001$, respectively). The joint symbolic dynamics approach also showed improved performance in detecting changes in cardio-respiratory interaction as compared to the synchrogram technique; thus providing an efficient tool for quantification of cardio-respiratory coordination.