Non-Linear Heart Rate Variability Measures in Sleep Stage Analysis with Photoplethysmography

Matti Molkkari, Mirja Tenhunen, Adrian Tarniceriu, Antti Vehkaoja, Sari-Leena Himanen, Esa Räsänen

Tampere University, Tampere, Finland

Aims: We assess the feasibility of wrist-worn photoplethysmography (PPG) sensors for determining interbeat intervals (IBIs) for accurate non-linear heart rate variability (HRV) analysis. We examine the suitability of characteristic fractal correlations in the IBIs for the classification of different sleep stages.

Methods: Optical heart rate sensor by PulseOn Ltd was utilized for monitoring IBIs from 18 healthy young adult subjects. Reference ambulatory polysomnography recordings were scored by a sleep expert at the sleep laboratory of Tampere University Hospital. The HRV was studied by detrended fluctuation analysis by computing spectra of scaling exponents $\alpha(s)$ as a function of the scale s. Dynamic changes were tracked by calculating the spectra $\alpha(s,t)$ in a moving temporal window.

Results: The HRV metrics derived from the PPG measurements are consistent with the reference ECG data. The dynamic landscapes of the alpha spectra show distinctive fractal correlations according to the underlying sleep stages. The average behavior of these correlations is qualitatively similar across the studied subjects, but the details are particular for each individual. Furthermore, the correlations exhibit non-trivial intra-subject variability. Exploratory classification of the alpha spectra yields up to 73% and 41% average accuracies for 3-class (wake, REM, NREM) and 5-class (wake, REM, N1, N2, N3) cases, respectively.

Conclusion: Wrist-wearable PPG sensors are adequate for HRV analysis. The alpha spectra show potential for enhanced sleep stage classification. Further research is required to address individual variability. Nevertheless, economical unobtrusive ambulatory sleep stage monitoring may soon be available.
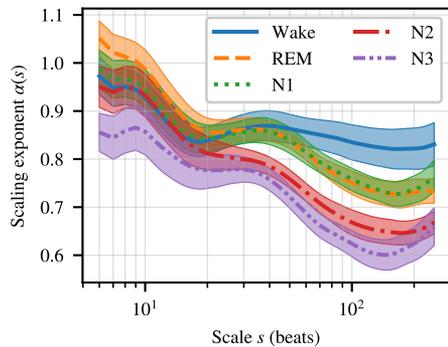
Fig: Mean alpha spectra and its standard error across the subjects during different sleep stages.