Cardiovascular Regulation during Sleep Quantified By Symbolic Coupling Traces

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Sleep is a complex regulated process with short periods of wakefulness and different sleep stages. These sleep stages modulate autonomous functions such as blood pressure, and heart rate. The method of symbolic coupling traces (SCT) is used to analyze and quantify time-delayed coupling of these measurements during different sleep stages. The symbolic coupling traces, defined as the symmetric and diametric traces of the bivariate word distribution matrix, allow for the quantification of time-delayed coupling (cf. Wessel et al. EPL 2009, 87: 10004). In this paper, the method is applied to heart rate and systolic blood pressure time series during different sleep stages for 10 healthy controls (44.8$\pm$6.7 years, BMI: 25.3$\pm$2.7 kg/m2) as well as for 18 normo- (44.6$\pm$7.6 years, BMI: 30.2$\pm$2.9 kg/m2) and 10 hypertensive patients (44.1$\pm$8.1 years, BMI: 34.1$\pm$4.9 kg/m2) with sleep apneas. Using the SCT, significant different cardiovascular mechanisms not only between the deep sleep and the other sleep stages but also between healthy subjects and patients can be revealed. For all groups and for all sleep stages we obtain the same characteristic pattern of -2 for diametric coupling and 0 for symmetric coupling ($p<0.05$). Morover, there are significant differences in the strength of the detected lags 0 and -2 ($p<0.05$ Kruskal-Wallis test). Finally, the SCT method is applied to model systems, compared with established methods, such as cross correlation, mutual information and cross recurrence analysis. Thereby SCT proves to be more specific in detecting delays of directional interactions than standard coupling analysis methods and yields additional information which can not be measured by standard parameters of heart rate- and blood pressure variability. The proposed method may help to indicate pathological changes in cardiovascular regulation and also effects of continuous positive airway pressure therapy on the cardiovascular system.