Diagnostics of coupling between autonomous regulation of heart rate variability and respiration in different phases of sleep taking into account the age of the subjects

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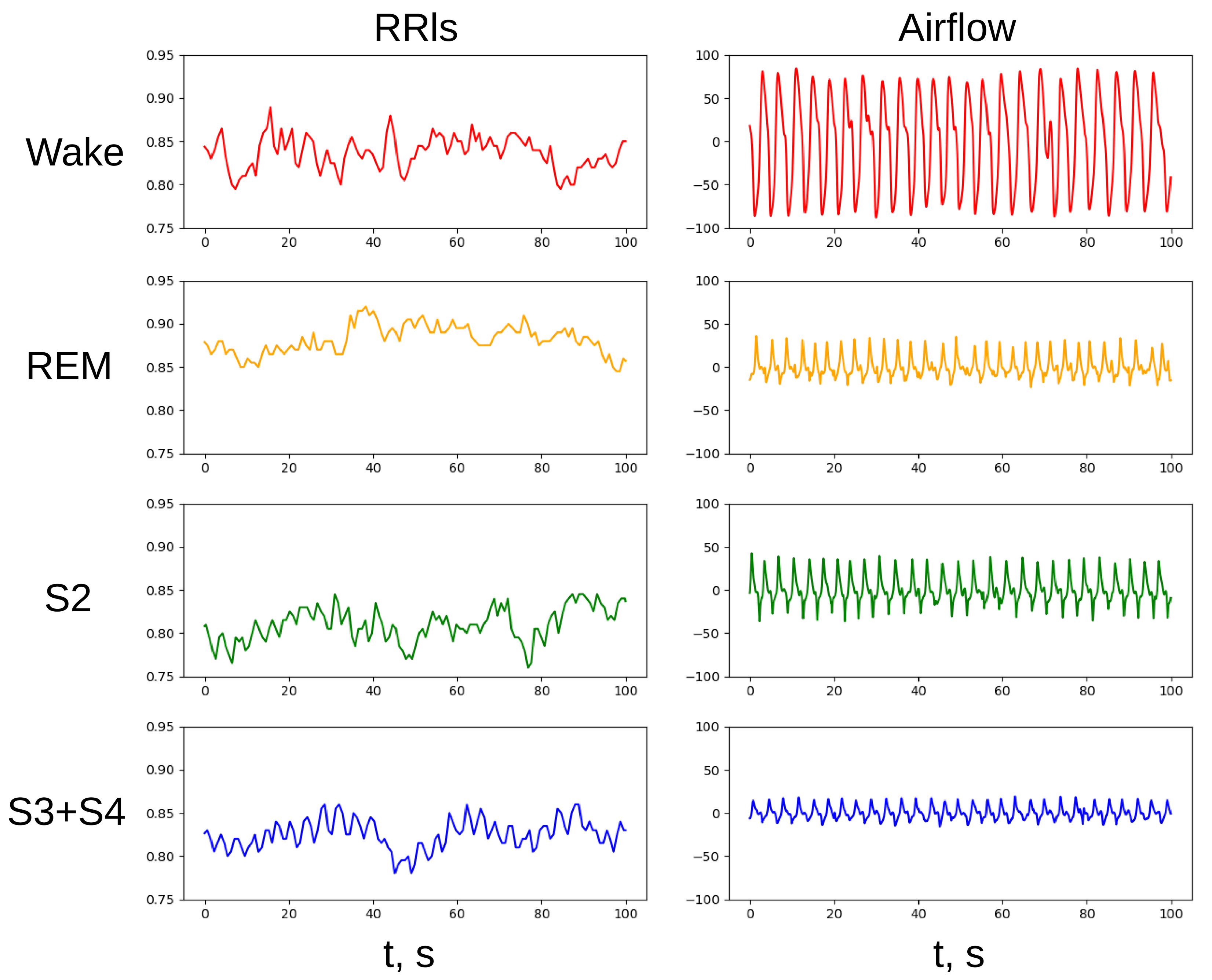
Introduction

The study of the coupling between the elements of complex biological systems is of great fundamental importance for the creation of new methods of personalized therapy and diagnostics in medicine. In this work we evaluate changes in the structure of coupling between the regulation system of the cardiovascular system and respiration in healthy subjects depending on the age and stage of sleep.

Experimental Data

We used recordings data from the SIESTA project [1], which was established to provide a data base for sleep studies. Our sample consisted of 30 healthy subjects aged 22-86 years (M = 52.1, SD = 20.8), all of whom provided written informed consent to the respective institute in which their data was collected.

Electrocardiogram (ECG) and airflow (from a respiratory belt) were simultaneously recorded each around 8 hours long. For the current study, we extracted 10-minutes consecutive recording from 4 time periods based on R&K [2] consensus sleep scoring of the EEG data. These periods were wakefulness periods immediately prior to sleep, sleep stage 2 (S2), sleep stage 3 combined with sleep stage 4 (S3+S4), rapid eye movement (REM). From ECG signal, an RR intervals (RRIs) chain, representing a sequence of time intervals between the R-peaks of ECG, was extracted.



Methods

We calculated the coherence function $Coh_{x,y}(f)$ between RRIs and airflow signals [3]. This index measures the linear correlation between two signals, $x(t)$ and $y(t)$, as a function of the frequency, f. Thus, coherence is the ratio of the cross-power spectral density, $S_{xy}(f)$, between both signals and their individual power spectral densities, $S_{xx}(f)$ and $S_{yy}(f)$:

$$Coh_{xy}(f) = \frac{S_{xy}(f)}{\sqrt{S_{xx}(f)S_{yy}(f)}}$$

The coherence function takes the values between zero and unity and characterizes the phase coherence between oscillations for the frequency . It is considered to be a linear measure of coupling.

The analysis of statistical significance using the generation of surrogate data was adopted to test the results. We used Amplitude Adjusted Fourier Transform (AAFT) surrogate data, as proposed in [4], to test the statistical hypothesis that the systems are not linearly coupled. The results were considered significant at $p < 0.05$.

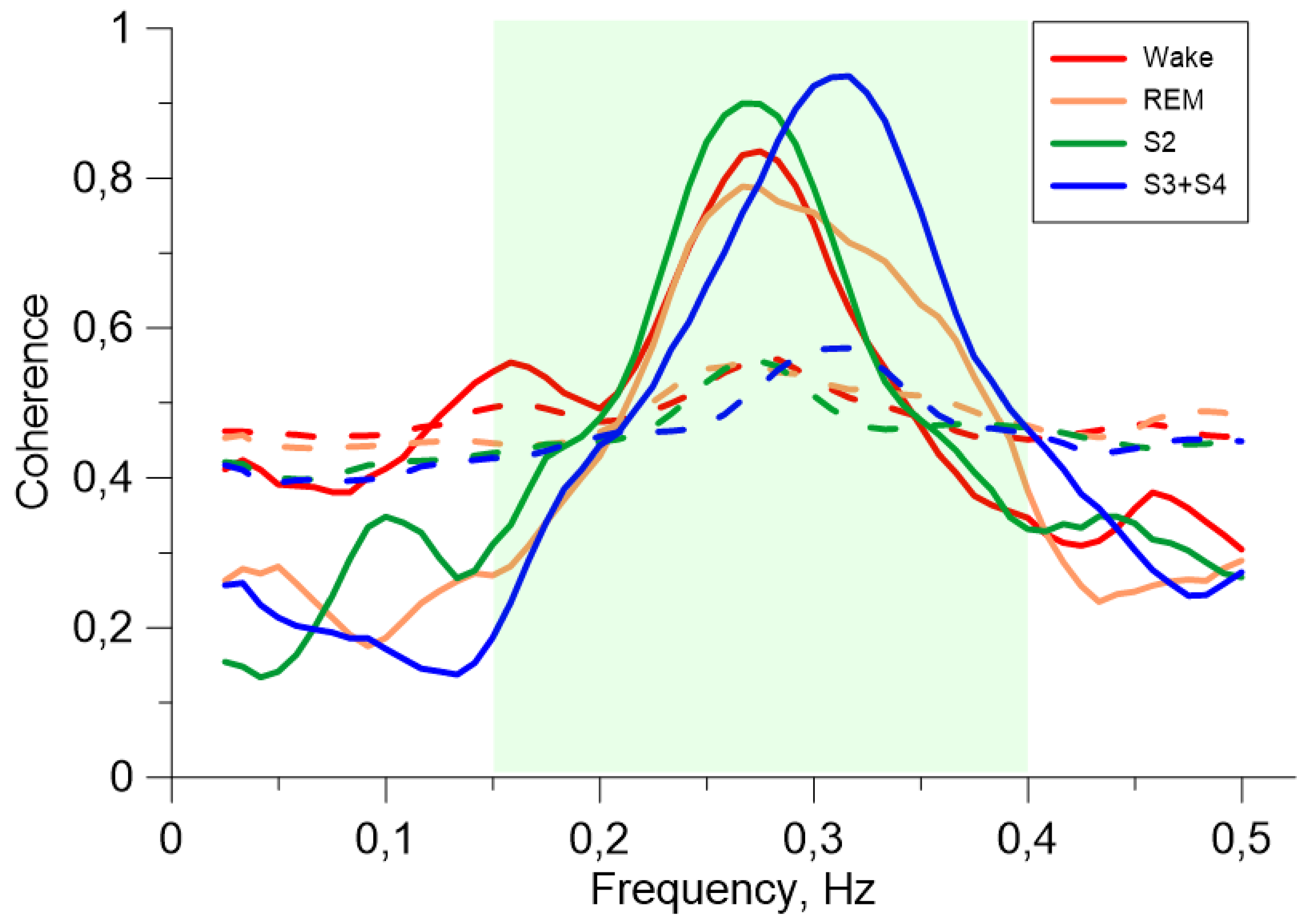


Figure 1. Function of coherence for a person. The solid lines show the values of the coherence function at different stages. Dot line is a significance level (p=0.05).

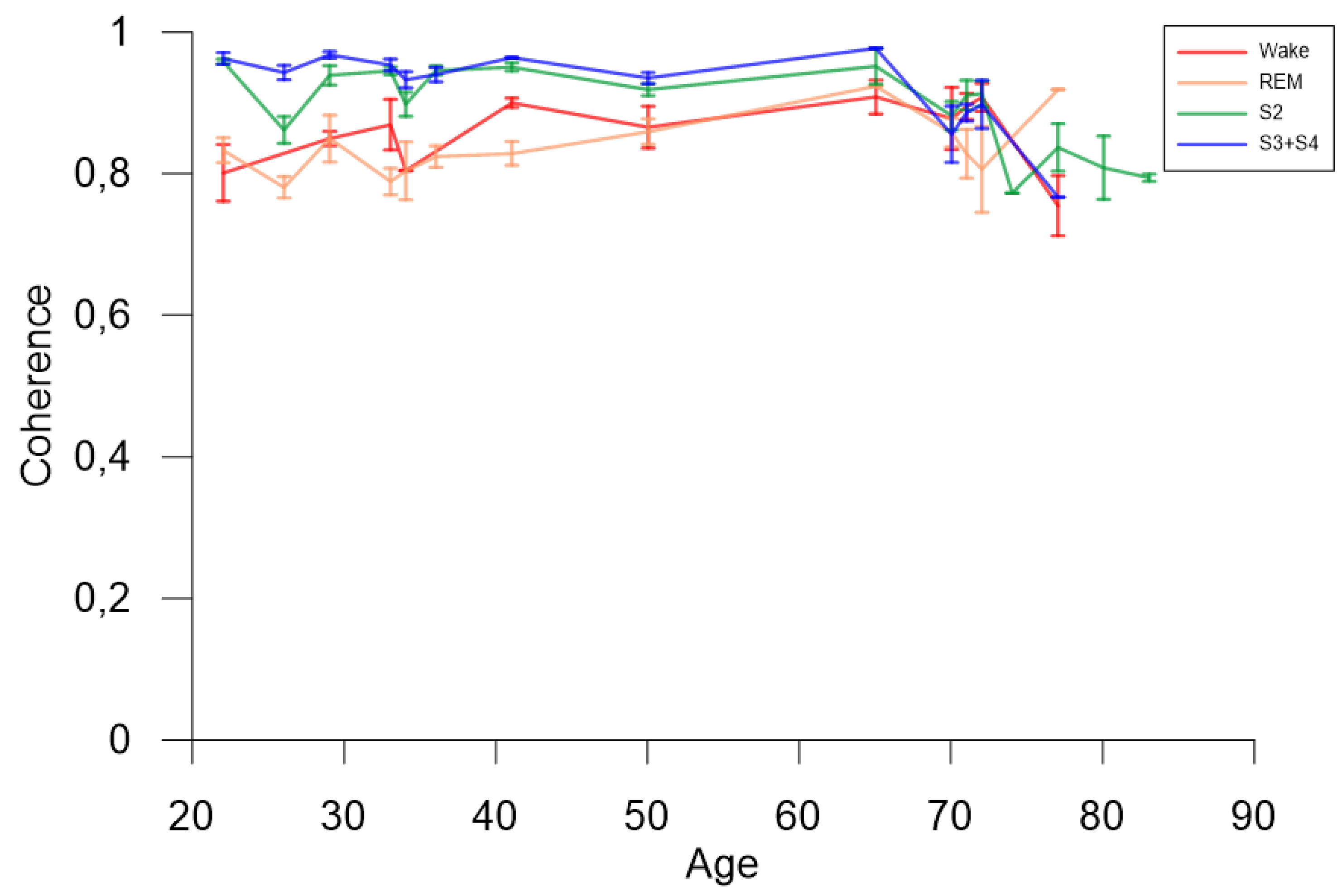


Figure 2. Maximum statistically significant values of the coherence function in frequency range 0.15-0.4 Hz depending on the age of the subjects. The solid lines show the average. Error bars show the standard error of the mean.

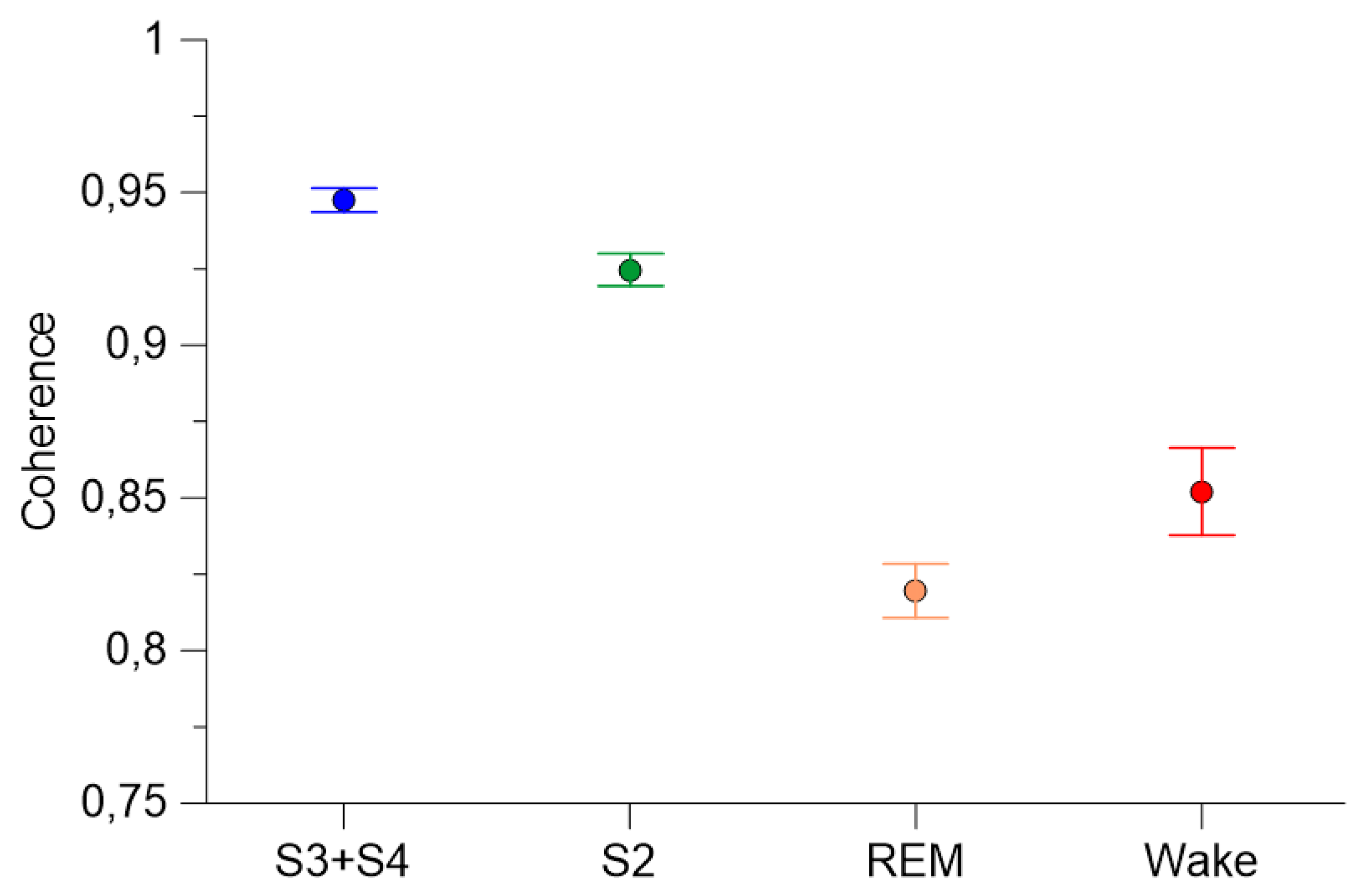


Figure 3. Maximum statistically significant values of the coherence function in frequency range 0.15-0.4 Hz for all subjects under the age of 65. The solid lines show the average. Error bars show the standard error of the mean.

Results and Conclusions

As a result of the analysis a statistically significant coupling between autonomous regulation of heart rate variability and respiration was diagnosed. It was also shown that in subjects under the age of 65 the maximum significant values of coherence function are divided into stages. In S3 and S4 stages value of coherence function remains the highest and in the REM stage value of coherence function is lower than in the S2 stage. However, in subjects over the age of 65, such a clear separation of values is not observed.

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