SPECTRAL AND COMPLEXITY CHARACTERISTICS OF SLEEP EEG FOLLOWING ISCHEMIC STROKE

Radoslav Škoviera, Zuzana Rošťáková, Anna Krakovská, Roman Rosipal

Institute of Measurement Science, Slovak Academy of Sciences, Bratislava, Slovak Republic

Abstract

In this study a large number of Rechtschaffen and Kales sleep characteristics, spectral measures, measures of complexity and interdependency measures were evaluated for sleep electroencephalograms (EEG) of 33 patients after ischemic stroke and 57 healthy subjects. The goal is to find measures effective in separation between normal sleep EEG and sleep EEG following stroke.

We found that stroke patients had higher sleep efficiency and they spent more time in slow wave sleep but less time in rapid eye movement sleep in comparison to healthy subjects. Moreover, the coherence between the C3-M2 and C4-M1 EEG channels was found to be lower for the patients, specifically in lower frequency bands. As concerns complexity measures, the sleep EEG of patients came out significantly less complex. This is consistent with the rising hypothesis about complexity decrease of the EEG after various types of brain damage.

Keywords

sleep, EEG, stroke, Rechtschaffen and Kales scoring system, complexity measures, spectral measures

Introduction

An ischemic stroke is a loss of brain function due to lack of blood flow to the brain, caused by either blockage of a blood vessel, or by cerebral hypoperfusion. The affected area of the brain cannot function normally, which might result in a partial inability to move, or in cognitive or vision impairment.

In this study, we deal with the following question: How different is the sleep pattern of the patient after ischemic stroke in comparison to the healthy subject?

The paper is organized as follows. Firstly, the data and the methods are described. Then, the hypnograms originating from different experts are aligned. The result section introduces the characteristics that are promising in terms of distinction between the two groups of subjects.

Data

In total, 90 EEG recordings (C3-M2 and C4-M1 channels) were analyzed. First, 33 of them were collected in a sleep laboratory within 5 to 7 days after the occurrence of a stroke. The average age of subjects was 70 years, the youngest patient was 39-year-old woman, and the oldest patient was an 88-year-old woman. The control sample of 57 healthy people (age over 60) EEG recordings from two consecutive nights spent in the sleep lab was taken from the SIESTA database [1]. The average length of the EEG recording of the patients was 7.09 hours with standard deviation of 1.5 and 7.97 hours with standard deviation of 0.46 for the control subjects. The EEG signals were recorded using various devices and had different sample rates, therefore we downsampled them to uniform sample rate (100 Hz). We also applied low-pass filter to all the recordings to filter out frequencies above 40 Hz.

Methods

Several tens of traditional and novel measures were computed from the EEG signals. The set of characteristics involved relevant measures in the time domain, distribution characteristics, linear spectral measures, and measures of complexity, like average amplitude, zero-crossing rate, variance, skewness, kurtosis, spectral moments, spectral edge, fractal exponent, spectral entropy, fractal dimension, exponent of detrended fluctuation analysis, entropy, absolute spectral powers, relative spectral powers, and relative power ratios. Furthermore, interdependency measures, including coherence, phase angle and mutual information were computed for the combination of C3-M2 and C4-M1 EEG channels. The definition of these measures can be found in [2]. Some of the characteristics, namely the complexity measures represented by the fractal dimension, or entropy, are less common in the field of EEG analysis (for the review see [3][4]).

Furthermore, standardized sleep characteristics including the total sleep time, the sleep latency, the sleep efficiency, the time spent in individual sleep stages, or the number of stage shifts, were derived directly from the Rechtschaffen and Kales scores (R&K [5]). The statistical significance of differences among the sleep characteristics computed for each of the two groups of subjects was tested using the bootstrap method and the Student's t-test. This was done in the following way. Random sampling with replacement of size 33 was taken for both stroke patients and healthy subjects and the mean value was computed. This procedure was repeated 1000 times. Then, the 95% confidence interval for the difference of means was constructed. In the case of the Student's t-test, the normality was tested prior the test. If the normality was not rejected, either for stroke patients group, or for healthy subjects, the Student's t-test was used; otherwise the nonparametric Wilcoxon test for medians was applied.

We also calculated time spent in individual sleep stages based on scoring derived from the aforementioned spectral measures, measures of complexity and interdependency measures (described below).

Unification of Different Sleep Scorings

The hypnograms for the healthy subjects and the hypnograms for the stroke patients came from different sources – either from the automatic R&K scoring system Somnolyzer 24x7 [6] or from the professional sleep-scoring expert at the sleep laboratory. Therefore, we decided to create new scoring based on spectral and nonlinear characteristics mentioned above (introduced in [2][7]) as follows:

We divided the EEG recordings into 30 seconds long segments and calculated all of the aforesaid measures for each segment. Sleep stage was also determined for each segment from the R&K scorings. We randomly selected 60% of the segments from the EEG recordings of the patients and used them to train an artificial neural network. The trained network was then used to classify the individual segments of both patients and healthy subjects into one of the five sleep stages.

Results

First we evaluated sleep characteristics derived from the R&K scores. The significant results (null hypothesis for the tests described above was rejected at the significance level of 0.05) are as follows:

- The total sleep period (*tsp*), defined as the time from first appearance of any sleep stage until the final awakening, was shorter in the case of stroke patients. However, this could be caused by the clinical protocol (waking up because of taking medication or other procedures).
- Therefore, we concentrated on the total sleep time (*tst*) defined as the time spent in all sleep stages together - stage 1 (S1), stage 2 (S2), slow wave sleep (SWS), and rapid eye movement (REM) sleep. We found that during the first half of the night *tst* was longer for stroke patients.
- We also found differences in the sleep efficiency (*eff*). This characteristic is computed as a ratio of the *tst* and the time spent in bed. Stroke patients had a higher value of *eff* computed during the whole night and also when this measure was computed for each quarter of the night separately. Note that higher values of *eff* in the acute phase after stroke were found to be associated with a good long-term outcome [3].
- Sleep latency is defined as the period between the lights-off time and the first appearance of S2 or first consecutive 3 periods of S1 (whichever occurs first). This measure was higher for healthy sleepers, than for patients after stroke. Moreover, we observed that stroke patients wake up less frequently than healthy controls during the total sleep period (*tsp*).
- The total time spent in S1 and SWS was found to be longer in stroke patients. On the other hand, as concerns time in S2 and the length of the REM stage, healthy controls show higher values.
- Finally, we observed differences between the number of the sleep stage shifts. Patients after stroke did not change sleep stages as often as the healthy sleepers.

Tab. 1: Relative time (in %) spent in each sleep stage calculated according to the R&K scoring for healthy subjects and stroke patients.

	Healthy	Stroke
Wake	24.8	7.28
REM	12.51	10.44
S1	9.47	31.63
S2	43.78	26.17
SWS	9.35	24.48

The above results were obtained when accepting the original R&K scorings. Note, that R&K scores were assigned by two different scoring systems and therefore we can't rule out the effect of inter-scorer variability. After the use of the common scoring (described above), *tst* in SWS was found to be longer in the stroke patients and the time in REM sleep was longer in the healthy controls.

Next, we noticed that the coherence between the C3-M2 and C4-M1 channels tends to be lower for the patients, especially for slower frequencies (e.g. delta waves [see Fig.1]).

Tab. 2: Relative time (in %) spent in each sleep stage determined according to the selected spectral and nonlinear characteristics mentioned above.

	Healthy	Stroke
Wake	0.39	0.36
REM	12.35	9.6
S1	35.53	24.18
S2	32.64	37.59
SWS	18.52	28.28

As concerns the complexity measures, both the fractal dimension and the spectral entropy signaled lower complexity of EEG signals of the stroke patients [see Fig.2].

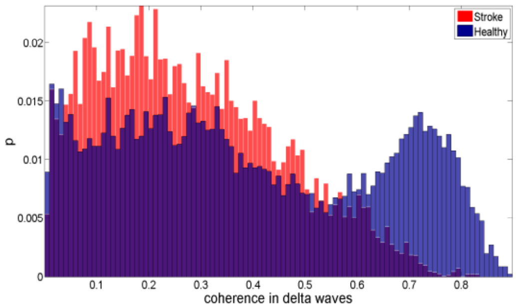

Fig. 1: Histograms of coherence in delta frequency band between C3-M2 and C4-M1 EEG channels of healthy subjects (blue) and stroke patients (red).

Conclusion

In this study, a large number of sleep measures was investigated and their performance to discriminate between healthy subjects and subjects after stroke tested.

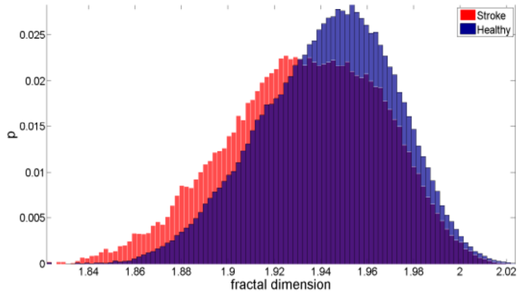

Fig. 2: Histograms of fractal dimension in SWS for healthy subjects (blue) and stroke patients (red).

In conclusion, our results indicate that sleep pattern of stroke patients recorded within 5 to 7 days after stroke show higher level of SWS and shorter time spend in REM sleep in comparison to the healthy subjects. Note that we did not control the effect of medications the stroke patients are usually subject to during the first days after the stroke and this may be important factor influencing our findings.

Moreover, the EEG of the stroke patients shows a lower level of complexity as defined by the used complexity measures than the EEGs of the healthy controls.

Acknowledgement

We would like to thank personnel at the First Department of Neurology, Faculty of Medicine, Comenius University in Bratislava for providing us sleep EEG data of stroke patients and for thorough clinical consulting. This work was supported by the MZ 2013/56-SAV-6, APVV-0668-12, VEGA 2/0043/13 and VEGA 1/0503/13 research grants.

References

[1] Klosch, G., et al. *The SIESTA project polygraphic and clinical database*. Engineering in medicine and biology magazine, 2001, vol. 20, no. 3, p. 51-57.

[2] Šušmáková, K., Krakovská, A. *Discrimination ability of individual measures used in sleep stages classification*. Artificial Intelligence in Medicine, 2008, vol. 44, p. 261–277.

[3] Vock, J., Achermann, P., Bischof, M., Milanova, M., Müller, C., Nirkko, A., Roth, C. and Bassetti, C. L. *Evolution of sleep and sleep EEG after hemispheric stroke*. Journal of Sleep Research, 2002, vol. 11, p. 331–338.

[4] Rey-Robert, B., Temprado, J. J., Berton, E. *Aging and changes in complexity in the neurobehavioral system*. Medicina (Kaunas), 2011, vol. 47, no.1, p. 1-10.

[5] Rechtschaffen, A., Kales, A. *A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects*. 1968.

[6] Anderer, P., Gruber, G., Parapatics, S., Woertz, M., Miazhynskaia, T., Klösch, G., et al. *An E-health solution for automatic sleep classification according to Rechtschaffen and Kales: validation study of the Somnolyzer 24x7 utilizing the SIESTA database*. Neuropsychobiology, 2005, vol. 51, p. 115–133.

[7] Krakovská, A., Mezeiová, A. *Automatic sleep scoring: A search for an optimal combination of measures*. Artificial Intelligence in Medicine, 2011, vol. 53, p. 25–33.

Mgr. Radoslav Škoviera
Department of Theoretical Methods
Institute of Measurement
Slovak Academy of Sciences
Dúbravská cesta 9, 841 04 Bratislava

E-mail: rado.skoviera@gmail.com