33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

The SIESTA database and the SIESTA sleep analyzer

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Abstract— **Sleep research and sleep medicine require the recording of biosignals during sleep and their subsequent analysis. The sleep recording is called cardiorespiratory polysomnography. Currently the analysis of the recorded signals is performed by experienced and certified sleep technicians. In addition to visual sleep scoring many attempts had been made to develop computer assisted sleep analysis. In order to develop a computer assisted sleep analysis a systematic database with sleep recording from 200 healthy subjects and of 100 subjects with selected sleep disorders of high prevalence had been compiled as part of a European Commission funded research project. This database was the start for a normative polysomnography database and for the development of a computer based sleep analysis. The computer based sleep analysis is available as an internet service and is now used by many sleep centers for sleep research questions and clinical sleep evaluation in patients with sleep disorders.**

I. Introduction

The recording and analysis of sleep is getting more common in hospitals in order to investigate and treat patients with sleep disorders. The discipline of sleep medicine is now recognized with board certifications for physicians in several countries worldwide and with certifications for sleep technicians in some countries. There is also a quality assurance program for sleep centers and sleep centers can achieve a sleep center accreditation or certification if they fulfill certain quality criteria for their installation and service [1].

Today sleep disorders attract more attention in the population because our modern society requires increased performance. As a consequence sleep has to serve as an important function to restore and recreate mental and physical performance. Sleep disorders, otherwise hidden in the night, become a subject of interest. This means we have to study normal and pathological sleep in many subjects, healthy persons and persons with sleep disorders.

The recording of sleep is now well standardized. We know which signals to record and we also know how to evaluate sleep. Until today visual evaluation, the scoring of the recorded signals is still the established standard of practice. This is a time consuming work specialized sleep technicians and sleep physicians and this requires between 30 minutes and 2 hours of visual scoring in front of a computer screen per sleep recording. The actual time needed depends on the distortion of signals in terms of artifacts and in terms of pathophysiological findings. In order to automate this task many attempts were made in the past and are currently made to develop computer based sleep scoring. One major effort a few years ago was performed as part of a European Union funded project, called SIESTA [2, 3]. As the first step in this particular project a large database of sleep recordings was collected. The most important issue in the database is its uniformity in terms of signal recording, and sleep scoring.

II. Methods

A. Recording of sleep technique

The cardiorespiratory polysomnography recordings include eight signals of electroencephalogram (EEG), two leads of electrooculogram (EOG), electromyogram (EMG) of submental muscles and of tibialis muscles, respiratory airflow at the nose and the mouth, respiratory effort of thorax and abdomen, oxygen saturation and pulse rate using pulse oximetry, and one lead of electrocardiogram (ECG). EEG, EOG, and EMG are used to score the sleep into different sleep stages according to the guidelines of Rechtschaffen and Kales [4]. This early manual for scoring sleep based on analogue equipment was recently amended with the requirements related to digital sleep recording and scoring of sleep using a computer screen [5]. In addition the new manual includes parameters of respiration, movement, ECG were also specified and their evaluation was included [5].

Manuscript received March 26, 2011. This work was supported in part by the European Union Grant SIESTA. Major concepts of this study had been published in Anderer P, Gruber G, Parapatics S, Dorffner G. Automatic sleep classification according to Rechtschaffen and Kales. Conf Proc IEEE Eng Med Biol Soc. 2007. 3994-7, 2007 and Rappelsberger P, Trenker E, Rothmann C, Gruber G, Sykacek P, Roberts S, Klösch G, Zeitlhofer J, Anderer P, Saletu B, Schlögl A, Värri A, Kemp B, Penzel T, Herrmann W, Hasan J, Barbanoj MJ, Röschke J, Kunz D, Dorffner G. Das Projekt SIESTA. Klin Neurophysiol. 32, 76-88, 2001.

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When compiling a database with biosignals not only the raw biosignals need to be stored but also the recording specifications, the data scoring results and recording annotations and clinical data. In general some generic aspects in biomedical database compilations which apply to biosignals combined with clinical patient data have to be considered [6]. The database compiled for SIESTA project included raw sleep recordings, annotations, sleep scorings, clinical data and many additional questionnaire results as well as cognitive function testing.

B. Healthy volunteers

The healthy subjects were recruited over age decades in order to achieve a wide range of age distribution and an equal distribution of gender.

C. Patients

The patients with sleep disorders were selected in such a way that they present the most common sleep disorders seen in the participating sleep centers. These were obstructive sleep apnea, insomnia, periodic limb movement disorders, sleep disorders in Parkinson's disease, Alzheimer disease, sleep disorders associated with anxiety disorders.

TABLE I
PATTERNS AND ALGORITHMS FOR SLEEP ANALYSIS

Pattern	Algorithm
Artifact	Minimization: Digital filters, filter smoothers based on autoregressive models, adaptive noise cancelation with varying weights, independent component analysis (ICA)
Artifact	Identification: Voltage threshold (overflow check), discriminant analysis, adaptive thresholds (moving median), unsupervised network, distance rejection, uncertainty rejection, automatic relevance determination, probabilistic graphical methods
Delta waves	Period-amplitude analysis, Spectral analysis, Digital band-pass filter
Sleep spindles	Digital filters, Neural networks, matched filtering, wavelets
K-complexes	Neural networks, matched filtering, wavelets, model based detector
Vertex sharp wave	Model based detector
Alpha waves	Period-amplitude analysis, Spectral analysis, Digital band-pass filter
Eye blinks	Decision process based on amplitude and slopes
Eye movements	Matched filtering technique, Rapidly adapting neuronal fuzzy system, Discrete wavelet transform, Period-amplitude analysis
Tonic EMG	Trimmed root-mean square amplitude
Phasic EMG	Maximal peak-to-peak amplitude

D. Analysis methods

The signal analysis includes artifact rejection and analysis of the signals. Then pattern recognition did follow. Wavelet analysis was applied to recognize patterns previously described for automatic sleep analysis. The patterns to be identified are listed in table 1.

The analysis methods are selected according to the underlying signal characteristics and complementary methods were applied in order to maximize the result in terms of recognition. After the pattern recognition follow classification algorithms in order to decide on particular sleep stages which match the visual classification best. At this stage one unique characteristic of the SIESTA database has to be noted. All 30 second epochs of the sleep recordings had been scored by at least three experts. First two independent experts completed a sleep scoring according to the rules of Rechtschaffen and Kales [4] independent of each other. Those epochs which received tha same scoring were taken as clear epochs. Those epochs where the scoring performed by the two scorers differed were inspected by a third expert. The third expert could then follow either scorer one or two. Or the scorer could go back to both experts and discuss the particular pattern with some more sleep experts in the group. As a consequence this visual sleep scoring can be judged as a reference database for visually annotated sleep recordings.

III. RESULTS

The database of well sorted uniform sleep recordings is a major achievement of this project. Finally we recorded 200 healthy volunteers and 100 patients with selected sleep disorders.

The computer assisted analysis was finalized later and now is in full function [7, 8]. A validation study did show very good results compared to the visual scoring [8].

The database with the summarizing evaluations for sleep stages and percentages of sleep parameters is finally the basis to derive normative values for age and gender for all sleep stages and for EEG sleep patterns. By this systematic changes with age could be quantified.

The database is used for additional questions of heart rate changes with age and with sleep stage. For this new algorithms used to analyze heart rate variability had been applied and sleep stage related changes had been investigated [9]. The very well validated sleep stage scoring was the most valuable part in this additional study. The database in addition is used to investigate distributions of sleep stage transitions [10]. It is used to investigate cardiorespiratory coupling by investigating the additional respiratory signals.

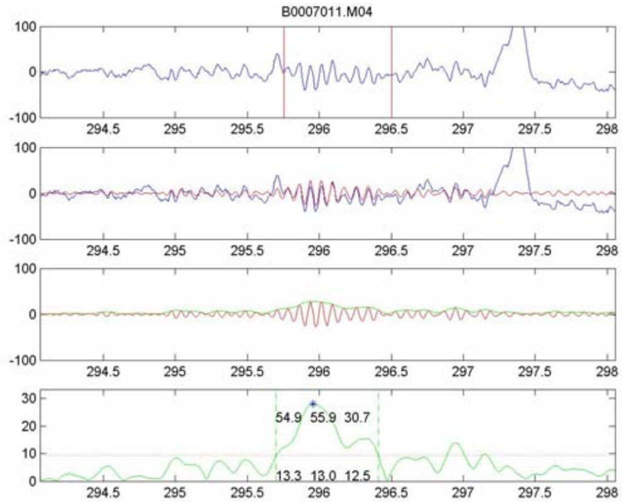

Fig. 1. A pattern database was built as a subset of the recording database. The patterns were selected according to the specifications given in table 1. This example shows a sleep spindle in an EEG signal lead and the corresponding pattern recognition in the panels below.

However the main use and purpose remains the development and validation of an automatic sleep staging. The automatic sleep staging is now used as an internet based sleep analysis for which interested sleep centers can submit their sleep recordings to the analysis and are provided back with a sleep scoring results. The sleep scoring result also includes a comparison of the achieved values against the normative database of values in terms of age and gender. By this the sleep lab can see whether a particular sleep stage duration is similar to the actual age range or above or below this normative value. This yields additional value for an evaluated sleep scoring and for a feedback to the sleep disturbed patient.

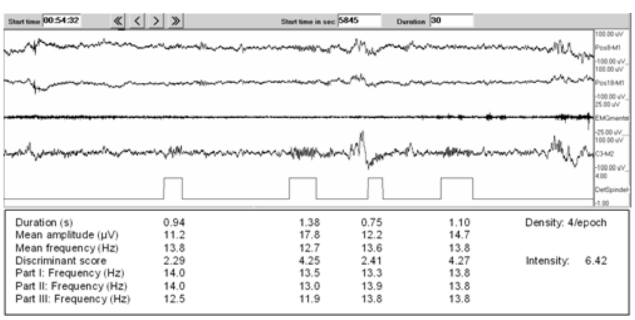

Fig. 2. The patterns were scored by a separate validation study which were performed by the sleep experts from different countries. Thereby the pattern database was validated on a per event basis in addition to the entire sleep recording evaluation. This was particularly useful to validate specific algorithms listed in table 1 and used for later exploitation of the results in specific sleep studies..

IV. Discussion

The database is the basis to derive normative values for age and gender for all sleep stages.

Due to the limited data regarding patients with sleep disorders, a normative data base for sleep disorders was not achieved. This may be a difficult task because a wide range of severity of sleep disorders can be found in addition to the large number of diagnoses.

The concept of the database does work as the basis for an internet based automatic sleep scoring. This has been marketed by the successors of the Siesta group. The automatic sleep staging has been successfully applied to a large number of clinical studies for the investigation on new pharmacological compounds on the treatment of insomnia and some other sleep disorders.

Some parts of the analysis, in particular the analysis of arousals had been used in the examination of aircraft noise effects on sleep. For this kind of research, an automatic analysis with an added visual verification of results serves best.

V. Conclusion

In summary, this approach shows the use of a carefully sampled database on the well defined question of sleep medicine and sleep research in biomedical engineering. This approach can serve as a good example for other areas in biomedical database compilations.

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