Knowledge-Based Systems 000 (2016) 1–12

Contents lists available at ScienceDirect

Knowledge-Based Systems

journal homepage: www.elsevier.com/locate/knosys

A knowledge model for the development of a framework for hypnogram construction

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A R T I C L E I N F O

Article history:
Received 17 June 2016
Revised 10 November 2016
Accepted 18 November 2016
Available online xxx

Keywords:
Artificial intelligence
Knowledge-based system
Hypnogram
CommonKADS

A B S T R A C T

We describe a proposal of a knowledge model for the development of a framework for hypnogram construction from intelligent analysis of pulmonology and electrophysiological signals. Throughout the twentieth century, after the development of electroencephalography (EEG) by Hans Berger, there have been multiple studies on human sleep and its structure. Polysomnography (PSG), a sleep study from several biophysiological variables, gives us the hypnogram, a graphic representation of the stages of sleep as a function of time. This graph, when analyzed in conjunction with other physiological parameters, such as the heart rate or the amount of oxygen in arterial blood, has become a valuable diagnostic tool for different clinical problems that can occur during sleep and that often cause poor quality sleep. Currently, the gold standard for the detection of sleep events and for the correct classification of sleep stages are the rules published by the American Academy of Sleep Medicine (AASM), version 2.2. Based on the standards available to date, different studies on methods of automatic analysis of sleep and its stages have been developed but because of the different development and validation procedures used in existing methods, a rigorous and useful comparative analysis of results and their ability to correctly classify sleep stages is not possible. In this sense, we propose an approach that ensures that sleep stage classification task is *not* affected by the method for extracting PSG features and events. This approach is based on the development of a knowledge-intensive base system (KBS) for classifying sleep stages and building the corresponding hypnogram. For this development we used the CommonKADS methodology, that has become a *de facto* standard for the development of KBSs. As a result, we present a new knowledge model that can be used for the subsequent development of an intelligent system for hypnogram construction that allows us to isolate the process of signal processing to identify sleep stages so that the hypnograms obtained become comparable, independently of the signal analysis techniques.

1. Introduction

Identification of the different phases through which the sleep of a person passes is useful in the diagnosis of certain sleep disorders, since some of these disorders occur during specific sleep stages. In the field of sleep disorders, polysomnography (PSG) is the main technique for analyzing a patient's biomedical signals — such as brain and heart activity, eye and muscle movements and respiratory flow — plus another type of signal representing context information. Consequently, identifying sleep stages is a key task in the context of sleep studies conducted by PSG. This test has, however, some drawbacks: it is expensive, uncomfortable for the patient and results are difficult to interpret.

To facilitate the analysis of sleep stages and their temporal sequencing, clinicians typically use a graphical representation of the chronology of different sleep stages, namely, the hypnogram. The hypnogram is built in the first quadrant of a Cartesian plane, where the X-axis represents time and the Y-axis represents sleep stages. The sequence of sleep stages is illustrated by a plot of horizontal and vertical lines, with the horizontal lines indicating the duration of a particular sleep stage and the vertical lines indicating changes in sleep stages. Fig. 1 shows an example of a typical hypnogram [1]. The hypnogram, when analyzed with other physiological PSG parameters — such as the heart rate or the amount of oxygen in arterial blood — has become a valuable clinical tool for physicians to diagnose a range of clinical problems that can occur during sleep and that sometimes result in poor quality sleep. Hypnogram con-

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http://dx.doi.org/10.1016/j.knosys.2016.11.016
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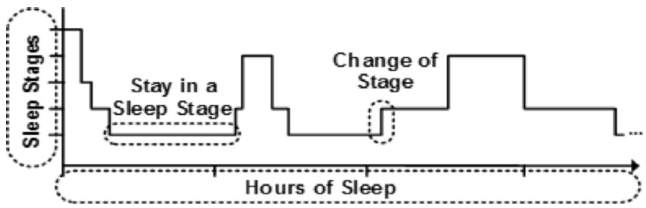

Fig. 1. Example of a hypnogram.

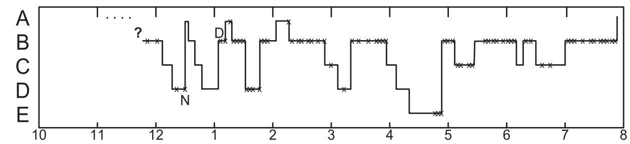

Fig. 2. An example of Loomis' hypnogram.

struction requires handling and analyzing large amounts of information and knowledge; hence, automating this task requires the building of a knowledge-intensive system (KBS).

When we build knowledge-intensive base systems, it is appropriate to use a comprehensive knowledge modeling methodology that should facilitate detailed analysis and comprehensive handling of knowledge-intensive tasks and processes; it should also provide for knowledge abstraction mechanisms that allows aspects related to implementation to be ignored. In this sense, we have proposed to build KBS for hypnogram construction using an appropriate methodology. Among the available methodologies for building KBSs, the CommonKADS methodology was selected for this work because it is a complete methodology that has become the *de facto* standard for the development of KBSs. Used extensively in a wide range of domains, it covers project management, organizational analysis and software and knowledge engineering aspects related to the development of the KBS, focusing, in particular, on modeling, reuse and risk management [2,3]. Its main advantage is that it provides a full model of an application, not just a model of the knowledge base.

Regarding clinical knowledge on sleep, the gold standard for the construction of hypnogram is the American Academy of Sleep Medicine (AASM) guidelines for the scoring of sleep and associated events [4] (version 2.2), including stages, arousals, movement and respiratory and cardiac events. In the construction of the proposed KBS, the terms specific to the domain and the sleep staging rules proposed by the AASM were used to obtain a correctly constructed hypnogram. The constructed hypnogram will improve the detection of events and diagnoses associated with sleep disorders and so will undoubtedly optimize timely therapy.

The rest of this paper is structured as follows: Section 2 provides a historical overview of the literature on sleep structure and hypnograms. Section 3 presents a summary of the most important studies of the automatic classification of sleep stages. Section 4 presents CommonKADS as the methodological framework used in this work. Sections 5, 6, 7 and 8 describe implementation of the concept level of our approach according to the CommonKADS methodology. Section 9 presents a short discussion. Finally, Section 10 presents a summary of conclusions.

2. Historical background

In 1929 the German neurologist Hans Berger demonstrated — after developing electroencephalography (EEG) — that the electrical activity of the brain is different for sleeping and awake patients [5] and identified certain patterns associated with each of these two states, documenting and defining what are known as alpha waves and beta waves. With time, knowledge regarding the electrical activity of the brain grew and new patterns of electrical signals for sleep and wakefulness were identified, such as the delta waves described in 1936 by Walter [6] and the theta waves described in 1944 by Walter and Dovey [7].

In 1937 Loomis, Harvey and Hobart [8] determined that sleep is an active state with five distinct phases or stages labeled A–E. Fig. 2 shows an example of the hypnogram of Loomis, who suggested that it was necessary to take into account 2 characteristic patterns of brain signals to correctly identify and classify sleep phases, namely, sleep spindles (also known as sigma waves) [9] and K complexes [10].

Independently of Loomis, Liberson [11] documented, in 1944, vertex sharp waves (VSW), a particular pattern of sleep that occurs early on in the night at the end of sleep onset and just before the onset of sleep spindles and K complexes.

Kleitman and Aserinsky [12] subsequently discovered rapid eye movements (REM) and Kleitman and Dement [13] discovered the recurring pattern of REM and non-REM (NREM) sleep, with NREM sleep divided into 4 stages numbered 1, 2, 3 and 4. In stages 3 and 4 sleep becomes deeper. REM sleep appears to be associated with stages 5 and 1.

This new classification of sleep stages introduced changes in the representation of hypnograms, giving them the fundamental form known to us today. Fig. 3 shows an example of the Dement and Kleitman hypnogram, with sleep stages represented on the vertical axis (awake (A) and the 4 stages) and time represented on the horizontal axis. The thick bars immediately above the EEG lines indicate periods during which REM is observed. Longer vertical lines indicate major movements (whole body position changes) and shorter lines represent minor movements. The arrows indicate the end of one EEG cycle and the beginning of the next.

Berger, Olley and Oswald [14] and Schwartz [15] subsequently improved identification of the REM stage, describing sawtooth waves and their temporary association with series of REM.

However, in the 1950s the lack of standards for classifying and identifying sleep phases made it difficult to compare results from sleep studies. In 1961, the International Federation of Electroencephalography and Clinical Neurophysiology Committee proposed unifying the terminology used in sleep studies [16] and in 1968, a committee headed by Rechtschaffen and Kales [17] established guidelines to standardize sleep stage classification — called the R&K paradigm — that included parameters, techniques and wave patterns obtained from EEG, electro-oculography (EOG) and electromyography (EMG). The guidelines also indicated analyzing this set of signals in epochs of 20 or 30 s. This approach, by specifying the fundamental characteristics of sleep stages, allowed for further standardization of hypnograms.

Nonetheless, there were difficulties in implementing the R&K rules, especially in computing the classification of sleep, given certain ambiguities. Consequently, in 2001 the Sleep Computing Committee of the Japanese Society of Sleep Research (JSSR) [18] proposed additional criteria and corrections to the R&K rules aimed at improving sleep stage classification and identification. In 2006 the Scoring of Polysomnographic Recordings Task Force of the German Sleep Society (DGSM) [19] conducted a study aimed at refining the identification of important signals in EEG patterns.

In 2007, the American Academy of Sleep Medicine (AASM) [20] also carried out a study in order to establish more precise definitions and more appropriate rules for the detection of sleep events and for the correct classification of sleep stages. Sleep stages were thus redefined as follows: (a) stage W (awake), (b) stage N1 (NREM 1), (c) stage N2 (NREM 2), (d) stage N3 (NREM 3), and (e) stage R (REM). Note that stage N3, representing slow-wave sleep (SWS), replaces the previous nomenclature referring to stages 3 and 4.

Please cite this article as: Á. Fernández-Leal et al., A knowledge model for the development of a framework for hypnogram construction, Knowledge-Based Systems (2016), http://dx.doi.org/10.1016/j.knosys.2016.11.016