Computers in Biology and Medicine 63 (2015) 118–123

Contents lists available at ScienceDirect

Computers in Biology and Medicine

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

Automated detection of sleep apnea in infants: A multi-modal approach

Gregory Cohen [a,*], Philip de Chazal [a,b]

[a] MARCS Institute, University of Western Sydney, Australia
[b] School of Electrical and Information Engineering, University of Sydney, Australia

ARTICLE INFO

Article history:
Received 24 December 2014
Accepted 10 May 2015

Keywords:
Infant sleep apnea
Oximetry
ECG
Minimally invasive sensors
CHIME

ABSTRACT

This study explores the use and applicability of two minimally invasive sensors, electrocardiogram (ECG) and pulse oximetry, in addressing the high costs and difficulty associated with the early detection of sleep apnea hypopnea syndrome in infants. An existing dataset of 396 scored overnight polysomnography recordings were used to train and test a linear discriminants classifier. The dataset contained data from healthy infants, infants diagnosed with sleep apnea, infants with siblings who had died from sudden infant death syndrome (SIDS) and pre-term infants. Features were extracted from the ECG and pulse-oximetry data and used to train the classifier. The performance of the classifier was evaluated using a leave-one-out cross-validation scheme and an accuracy of 66.7% was achieved, with a specificity of 67.0% and a sensitivity of 58.1%. Although the performance of the system is not yet at the level required for clinical use, this work forms an important step in demonstrating the validity and potential for such low-cost and minimally invasive diagnostic systems.

1. Introduction

Sleep apnea hypopnea syndrome (SAHS) is a widely underdiagnosed condition in which the cessation of breathing occurs repeatedly during sleep, leading to an oxygen desaturation and cortical arousal. Sleep apnea events are classified according to whether the patient exhibits respiratory effort. An apnea involving such effort is commonly caused by an obstruction of the upper airway and is referred to as an obstructive sleep apnea (OSA). An apnea event lacking any respiratory effort is generally the result of a neurological condition and is termed a central apnea (CSA). Apnea events can also result from a combination of these two factors and is then referred to as a mixed apnea event. Arousals from apnea events, although an involuntary protective mechanism, serve to fragment sleep and have a strong negative impact on sleep quality.

Estimations of the prevalence of SAHS are varied, but obstructive sleep apnea is estimated to affect up to 5% of the adult population in Western countries [1]. Although the majority of studies have focused on developed countries, preliminary data from developing countries shows an unexpectedly high prevalence of OSA in adults. A study carried out in Abuja, Nigeria reported that 19% of the 370 participants were classified as having a high risk of OSA against the Berlin questionnaire criteria [2]. Similar results were obtained from a smaller study carried out in the south-west of Nigeria [3].

SAHS is also prevalent in very young children and infants, although the occurrence of central apneas is quite common in both infants and young children [4] and durations up to 25 s are considered normal [5]. Obstructive apnea events, on the other hand, are extremely rare in healthy young children and recent studies have estimated that obstructive sleep apnea is estimated to affect between 1% and 4% of infants [6]. Whereas the most severe effects of SAHS in adults are linked to hypertension [7], cardiovascular disease [8] and the dangers arising from vehicular accidents due to daytime sleepiness [9], sleep-related breathing disorders in infants and young children have been linked to several negative developmental effects, such as cognitive impairment [10], depression [11], and attention deficit/hyperactivity disorder [12].

SAHS has also been tentatively linked to sudden infant death syndrome (SIDS) [13]. To exacerbate the problem, studies have shown that young children and infants tend to suffer more severe episodes of sleep apnea [14]. It is estimated that over 80% of individuals with sleep-related breathing disorders go undiagnosed [15], due partly to low public awareness of the issue, but primarily due to the limited availability and high costs of appropriate

* Corresponding author.
E-mail addresses: g.cohen@uws.edu.au (G. Cohen), philip.dechazal@sydney.edu.au (P. de Chazal).

http://dx.doi.org/10.1016/j.compbiomed.2015.05.007
0010-4825/

recording and diagnostic equipment. Overnight polysomnograms are considered to be the gold-standard diagnostic test for SAHS [16] but the costs involved in performing such tests, which require expensive equipment and specially trained staff, makes it prohibitively expensive for widespread diagnostic use and completely unavailable in many countries.

Whilst it is possible to perform overnight polysomnograms on infants and young children, the intrusive nature of the multitude of sensors limits the practicality and effectiveness of the technology and can lead to lower quality results in infants and young children [17]. As a result, there is a clear need for the development of a less invasive, lower cost means for the detection and diagnosis of apnea events using easily accessible and low-cost sensors.

This study explores the efficiency and potential of a multimodal approach to the automated detection of sleep apnea in infants using oximetry data from a minimally invasive finger sensor, and a single-lead ECG. Oximeter features, R–R interval features extracted from the ECG signal and the combined feature set from both sensing modalities are evaluated and compared.

1.1. Minimally invasive sensor modalities

A joint study group consisting of the American Thoracic Society, the American Academy of Sleep Medicine and the American College of Chest Physicians investigated the applicability, reliability and accuracy of potential portable monitoring devices for use in the detection of SAHS [18]. Three categories of devices were examined: devices with a minimum of seven channels (Type 2), devices with a minimum of four channels (Type 3) and devices with only one or two channels (Type 4). These were assessed against the current standard diagnostic test – a technician-assisted in-laboratory overnight polysomnogram (Type 1).

The findings of the study were cautious, especially in regards to Type 4 devices, but highlighted the need for continued research in the field and the further exploration of different sensing modalities. Oximetry data is one such modality and has often been studied as a potential means of detecting the desaturations caused by sleep apnea events, as cyclic desaturations are a potential indicator of SAHS. Direct measurements of oxyhemoglobin saturation (SaO_2) are difficult to obtain, but pulse oximetry data (SpO_2) provides an indirect and rapid approximation of SaO_2 saturation levels [19] and due to the low-cost and minimal invasiveness of the technology, unattended, overnight ambulatory oximetry recordings has been widely investigated. Unfortunately, the use of oximetry data is limited by its negative predictive value (NPV) [20], as not all apnea events lead to discernible desaturations [21]. To further complicate matters, the averaging time for commercial pulse oximeters can vary considerably, and it has been shown that sensitivity is lower and specificity higher when longer averaging times are used [22].

Oximetry sensors are peripherally attached to the body and are therefore subject to additional noise resulting from motion and poor perfusion, which often leads to artifacts that can render the data unusable [23]. It is also not possible to determine whether the desaturation was caused by an obstructive or central apnea based on oximetry data alone [24]. This is particularly relevant in the detection of apnea events in young children and infants. Despite the issues associated of oximetry, it has proven to hold some diagnostic value especially in health children with suspected obstructive sleep apnea [25] as it has a potentially high positive predictive value (PPV). Thus, oximetry alone can be used as a potential means of detecting sleep apnea episodes, but not as a reliable means of diagnostically excluding them.

Electrocardiogram (ECG) recordings have also been the focus of many efforts to develop alternative mechanisms for sleep apnea detection. Physiologically, many apnea events (but not all) are associated with a bradycardia and are followed by a recovery breath and an abrupt tachycardia [26], creating cyclic variations in heart rate. These patterns are even more evident in the R–R interval spectrum, and obstructive apnea events can be determined through visual inspection alone [27]. Examining the low frequency, and very low frequency variations in heart rate have also been shown to contain diagnostically relevant information for the detection of OSA [28] with CPAP treatment in OSA-sufferers being shown to reduce this effect on heart rate variability [29]. The ECG data has also been shown to be modulated by respiratory effort [30], and an ECG-derived respiration (EDR) signal can be extrapolated [31]. This respiratory signal holds significant importance as it provides a means to distinguish whether respiratory effort was present during an apnea event, allowing the differentiation between central and obstructive apneas.

Utilizing a multi-modal approach to the detection of sleep apnea, in which carefully selected features are extracted from the ECG and oximetry data and combined, should increase the separability of the classification classes by leveraging the different underlying modalities and providing a mechanism for noise reduction and removal.

1.2. Database

The physiological and annotation data used in this study was obtained from the National Collaborative Home Infant Monitoring Evaluation (CHIME) dataset, which was collated by the National Institute of Health (NIH), to study the effectiveness of home monitoring for apnea and bradycardia in infants, especially with reference to sudden infant death syndrome (SIDS) [32].

The database contains overnight physiological data from 1079 infants, obtained between May 1994 and February 2008 and included infants ranging in age from newborns to 27 weeks. The subjects were drawn from four groups: children suspected of suffering from apnea events, healthy term infants, pre-term infants and infants with a history of SIDS in their immediate family. A breakdown of the genders and screening conditions for the subjects used in the study is presented in Table 1.

Primarily, the data consists of overnight home recordings obtained using the CHIME home monitoring device. The device contained seven sensors, including an Aequitron ECG/Impedance device and an Ohmeda pulse-oximeter. In addition, approximately 700 of the infants in the study also underwent full in-laboratory polysomnograms. These polysomnograms were recorded using a Healthdyne ALICE3 system, consisting of 17 sensors (including ECG, EEG, pulse oximetry, respiratory effort and a nasal thermistor).

The database also contains sleep state and arousal scoring information. It is important to note that the CHIME monitor was used in conjunction with the ALICE3 equipment during the overnight polysomnograms as the technicians used the data from the CHIME monitor to do the arousal scoring. Of the 700 recordings available, only 328 subjects were found to contain complete recordings, annotations and sleep state data. Due to a number of factors such as low signal quality, damaged headers and excessively

Table 1
Gender and selection criteria breakdown.

Screening criteria	Male	Female	Total
Apnoea of infancy	42	45	87
Healthy term	44	37	81
Premature	36	30	66
Sibling of SIDS	79	81	160
Total	**193**	**201**	**394**