END-TO-END SYSTEM FOR THE RELATIONSHIP MODELLING OF PHYSICAL EXERCISE WITH SLEEP QUALITY

ABSTRACT

In this paper we are presenting the ongoing work of an end-to-end system that we claim it will improve the quality of sleep in people with sleep disorders through physical exercise, in a convenient and friendly for the user way. In the proposed system we incorporate various sensing devices that measure physiological parameters that the literature manifests to be strongly related with exercise and sleeping activity. The data are collected by a mobile device which handles the heterogeneity among the devices and provides secure and reliable transmission to a back-end system where the data are processed and permanently stored. Upon conclusion of the ongoing work, the system will provide the necessary modeling and relation among the exercise and sleep that will benefit people with sleep disorders.

KEYWORDS

Sleep disorder, body area network, artificial intelligence, wearable devices

1. INTRODUCTION

Chronic insomnia is a sleep disorder characterized by long-term difficulties with initiating and maintaining sleep, waking up too early, or nonrestorative sleep. It is often associated with occupational and psychosocial impairments such as daytime fatigue, mood disturbances, cognitive deficits, and poor quality of life. Physical activity and exercise has been proposed in the literature as a non-drug treatment alternative with low cost and easy access. Exercise is assumed to affect the subsequent night of sleep through alternations of physiologic systems. The tool that has dominated as the gold standard for recording the sleep activity and assessing the quality of sleep so far is polysomnography. The polysomnogram records several body functions including brain activity, eye movement, oxygen and carbon dioxide blood levels, heart rate rhythmbody muscle activity, air flow through the nose, etc. However, despite the detailed recording that this tool provides it is quite resource demanding as it needs to be performed in-lab by specialized personnel. At the same time it becomes inconvenient for the patient as he needs to spend one – or more – nights sleeping in the lab.

At the moment, application algorithms aiming at the support of the experts in improving the sleep quality of insomniac and healthy individuals aren't used in large scales. However, an application constructing an exercise schedule suitable for the age, gender, BMI, physical condition of an individual, arranging time and duration of the exercise, reminding simple advice such as the appropriate time for exercise or the last meal, could be very useful to this direction.

Therefore an automated solution that addresses the relation of physical exercise and sleep disorders in a non-invasive and cost-effective way may address the sleep disorders symptoms and consequently improve the user's quality of life. From this perspective in this work in progress we describe an end – to – end system for recording parameters that evaluate the exercise and sleep activity where algorithms could be implemented that manifest how the physical exercise is related to the sleep quality.

2. RELATED WORK AND STATE OF THE ART

Research studies present evidence that exercise or physical activity can have a beneficial effect on sleep quality. Systematic reviews and meta-analyses have shown that many aerobic or resistance exercises can act as a supported intervention for insomnia and improve quality of sleep in middle-aged and elderly with sleep complaints [Kline CE et al][Yang PY et al]. In general, the authors of these studies do not describe what type of physical activity is most prevalent or the intensity and duration of exercise. The generalization of the

results is also limited by the small sample size or the fact the many subjects are good or young sleepers as well as the type of the exercise which may be unsuitable for the elderly [Montgomery P. & Dennis J]. Ohayon et al, determined normative sleep data sleep and daily activities for over 1000 participants aged 60 years or older. He found that loss of autonomy in daily activities is associated with sleep factors including sleep duration (long vs short), wake-up time (early vs late) and bedtime (early vs late). The sleep data were collected through telephone interviews and evaluated based on the Sleep-EVAL System.

The methodology for assessing sleep quality is often based on self-evaluated reports employing questionnaires, the most popular being the Pittsburg Sleep Quality Index (PSQI), a widely used measure suitable for large-scale epidemiologic investigations [Buysse et al]. The alternative dominant methodology is polysomnography (PSG), a multi-parametric study where body functions are monitored including brain (EEG), eye movements (EOG), muscle activity (EMG) and heart rhythm (ECG).

Passos et al, studied the effects of three different types of exercise (moderate aerobic/walking, intense aerobic/running, moderate resistance/weight training) on sleep quality. Both exercise and sleep data were obtained in controlled environment. PSG data demonstrated changes in sleep onset latency (reduction by 55%) and in total wake time (reduction 30%). However, on the polysomnogram inspection, it is necessary to stick many electrodes and sensors and the subjects need to be in a laboratory setting in order to ensure reliability of results. The study in [T. Igasaki, et al] researched ways of identifying sleep quality based on hypnogram which can be obtained through an EEG. They employed Artificial Neural Network technology which resulted in 71% accuracy.

Despite the growing consensus that regular exercise can improve sleep it remains unclear how this relationship is modeled. Work in [Buman MP et al] suggests that physically inactive older adults with poor initial sleep quality are most likely to receive sleep benefits from moderate-intensity physical activity. The authors observed that a 12-month intervention of moderate aerobic exercise had antidepressant effects that improved sleep quality. Their results showed that factors like exercise intensity and even the time of the day the workout is taking place are important in modeling the relationship between exercise and sleep quality. Moreover, recent studies suggest the potential of reciprocal relationships between exercise and sleep. Specifically sleep quality also predicted subsequent exercise behavior [Dzierzewski JM et al]. Similar results observed in [Baron, K.G et al], where in case of the 16 volunteers slept poorly, their workout the next day were significantly shorter. On the other hand the participant's insomnia improved but only after the duration of 16 weeks of the intervention.

The above mentioned studies suggest that exercise and physical activity is strongly related to sleep quality. The proposed system will follow a hybrid methodology regarding the assessment of sleep quality, i.e both self-reported and objectively measured based on EEG alone. The main benefit is that the technology employed, can be used from the user/patient in his living environment without the requirement of being physically present in laboratory.

3. SYSTEM ARCHITECTURE

In this section we present the technological solution and the architecture design that allows the processing and integration of data obtained from the various medical sensors, in order to offer the appropriate services within a comprehensive integrated system.

The design of our system was driven by the requirements the application introduces, such as:

- Flexibility and Interoperability
- Security of the data, privacy and effective access policies
- Service-level and communication-level interoperability.
- User friendly non-invasive and richness of the experience for the users

A holistic view of the system's architecture is presented in figure 1, while the system's three sub-layers that it is consisted of and their functionalities are listed in Table 1. The various types of vital parameters that we needed to record in order to perform an accurate assessment of the exercise intensity and the sleep quality required respective sensor boards in the bottom layer of the wearable devices. The products of the two sub-layers (Wearable and mobile devices) that fit best to the application's requirements and design's principles are listed in table 2.

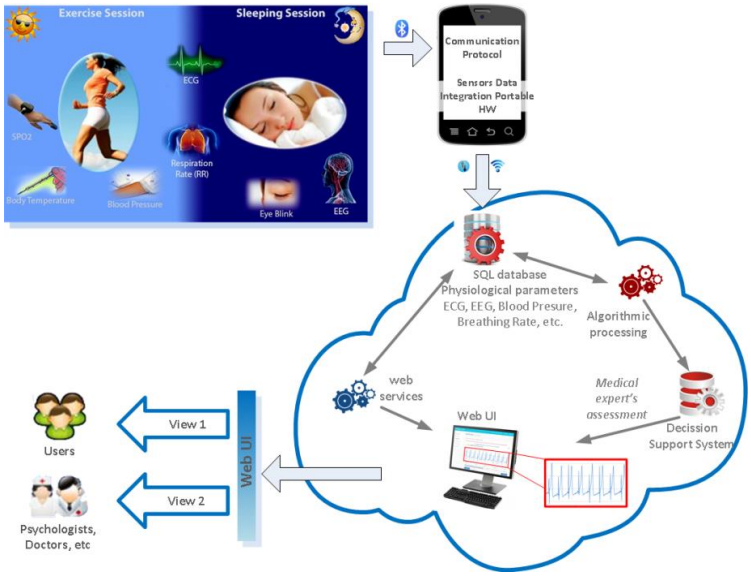

Figure 1: System Architecture

Table 1 . Systems sub-layers description

Sub Layer	Functionalities
Wearable Devices	Data gathering Signal processing algorithms for signal denoising, artifact removal and feature extraction Data transmission (Bluetooth)
Mobile device	Data collection processing and storage (at mobile device level) Data transmission to the Backend data repository (dynamically employ physical interfaces such as Bluetooth, Wi-Fi or Broadband communication) with JSON based messages Communication security provided by OpenSSL.
Backend System	Data repository and Information Interchange Algorithmic analysis and medical knowledge extraction Incorporates a short health profile for each anonymous user handled by the system, connected with user's mobile device Provides medical experts the capability to have a quick reference to relevant medical metrics and user's habits in order to deploy personalized training scenarios for each user. User Interfaces

Table 2 Sensor Boards

Sensor Board	Application Scenario	Features
Zephyr BioHarness	Sleep/Exercise Sensor Board	Encapsulates 2 conductive ECG sensor pads and 1 internal breathing sensor location. Battery Lifetime: 26 hours Bluetooth connectivity
Nonin - 4100 pulse oximiter + Nonin - 8000AA reusable SpO2 sensor (Articulated Internal Spring finger clip)	Exercise Sensor Board	Finger clip Sensor Battery Lifetime: 120 hours of continuous operation with new batteries Bluetooth Connectivity
A&D Medical - UA-767BT Automatic Blood Pressure monitor	Exercise Sensor Board	Internal Storage Capabilities storing up to 40 measuments. Bluetooth Connectivity
MyndPlay BrainBandXL	Sleep Sensor Board	Head strap with two dry sensors attached, one ear clip as a reference point Neurosky proprietary algorithms. Bluetooth Connectivity

Samsung Galaxy Nexus	Sleep/Exercise Mobile Device	OS: Android Jelly Bean Bluetooth, 3G, WiFi connectivity Internal Storage: 16GB enough for temporary storing days of records.

4. DISCUSSION

The proposed architecture is the basis for modeling the relationship between physical activity and sleep quality. The system's functionality supports non-invasive monitoring of exercise and sleep of older people in their living environment allowing the medical expert to provide personalized intervention and feedbacks.

Biosignals, such as the ECG and EEG are undergoing algorithmic processing in frequency and time domain in order to extract features such as breathing rate, heart pulse rate, QRS complex duration from ECG and additionally non-REM brainwaves such as alpha, theta, delta, and gamma extracted from EEG with frequency domain analysis utilizing Fast Fourier Transforms. These algorithms are integrated in the backend-system.

Furthermore, current work comprises the extension of the functionality of the proposed system by employing artificial intelligence algorithms in the back-end towards medical knowledge extraction. The focus is on detecting semantically enriched events from EEG processing, which can be correlated with the monitored physiological parameters and questionnaires. Under this context, a predictive analytics approach is being followed to address specific classification problems, i.e. important EEG events, towards a rule-based end-to-end system revealing the dynamics of exercise and sleep quality.

The system's architecture is being tested in real environment by employing elderly people with sleep complaints. Preliminary results confirm system's reliability and operational capacity.

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