Analysis of sleep and stress profiles from biomedical signal processing in wearable devices

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Abstract—**The present paper describes procedures for the evaluation of sleep quality and for stress management based on the analysis of the HRV and respiration signals. The analysis is though for a device aimed to provide support to people who want to develop a healthier lifestyle, with major focus on cardiovascular disease prevention.**

I. INTRODUCTION

MyHeart is a 6th Framework EU Integrated Project for fighting Cardio Vascular Diseases (CVD) by prevention and early diagnosis. Cardio Vascular Diseases cause 50% of all deaths in the EU. It is well known that a healthy and active life style can significantly reduce the risk of Cardio Vascular diseases (primary prevention) and limits the recurrence rate of acute events (secondary prevention) [1]. Therefore MyHeart aims at creating smart electronic solutions and appropriate services that empower users to take more control of their own health. The project addresses a spectrum of care, from prevention and the adoption of a healthier lifestyle to chronic disease management. The technological needs for MyHeart applications range from vital sign monitoring in daily life (ECG, respiration, skin impedance,…), body-worn low-power mixed signal hardware running detection algorithms for health status and acute cardiac event prediction, to low-power wireless links and server architectures for data handling at professional sites.

Inside MyHeart project there is the concept TakeCare that addresses people trying to find support to develop a healthier lifestyle. Today more and more people are facing problems: overweight, inactivity, bad sleep and stress contribute to develop cardio vascular diseases and are affecting millions of European people.

TakeCare system provides people with a better understanding of their overall health, motivating them to become active in staying healthy and feeling well. It is the ambition of TakeCare to provide easy-to-use technology and to develop solutions to manage bad sleep, stress, inactivity and overweight.

Manuscript received May 14, 2006. This work was supported by the MyHeart Project IST 507816 of the European Community.

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For the sleep management solution the focus is on analyzing sleep stages and sleep fragmentation.

For stress solution the focus is on providing the user a biofeedback tool to be used during relaxation exercises. The signals used for the analysis are heart rate variability and respiration.

II. HEART RATE VARIABILITY

The advantage in using HRV signal for such applications is mainly in the possibility of obtaining a useful signal without the need of clinical standard ECG leads: in fact it is necessary simply to have a good R peak recognition even in presence of a noisy trace. For a satisfactory detection of the R fiduciary point a sampling frequency of at least 200 Hz is required. Once the HRV is obtained it is sufficient to store one value for each cardiac beat (roughly 1 Hz sampling frequency), with great improvement in memory occupation.

The HRV signal reflects the status of the autonomic nervous system in controlling heart frequency, and many parameters evaluated both in the time and in the frequency domains, based on linear or non-linear models have been used or proposed in literature for the quantification of the sympatho-vagal balance in many different pathological and physiological conditions [2].

Respiration signal is here introduced for a better classification and interpretation of the HRV.

Great part of the HRV is due to the action of respiration which affects the heart frequency through the vagal nerve. Usually a rhythm is generated synchronous with respiration in a frequency range between 0.15 and 0.4 Hz. This is the high frequency (HF) component and its power is accepted as a measure of the vagal action on the heart. A second rhythm is usually present in the low frequency (LF) range around 0.1 Hz, that is strictly linked to vasomotion and is mainly related to the sympathetic action on the heart. However such a classification may sometimes fail, for example when the respiration frequency is not sufficiently regular or is very slow and overlaps the LF band. In such conditions the knowledge of the respiration signal can be of help for a more precise classification of the HR variability. A beat-to-beat sequence is extracted from respiration by sampling the signal in correspondence of each R wave, as shown in Fig.1. Proper models and filters allow to separate the HRV in variability related to respiration (due to the vagal action) and variability not related to respiration (mainly due to sympathetic action), as shown in Fig.2.

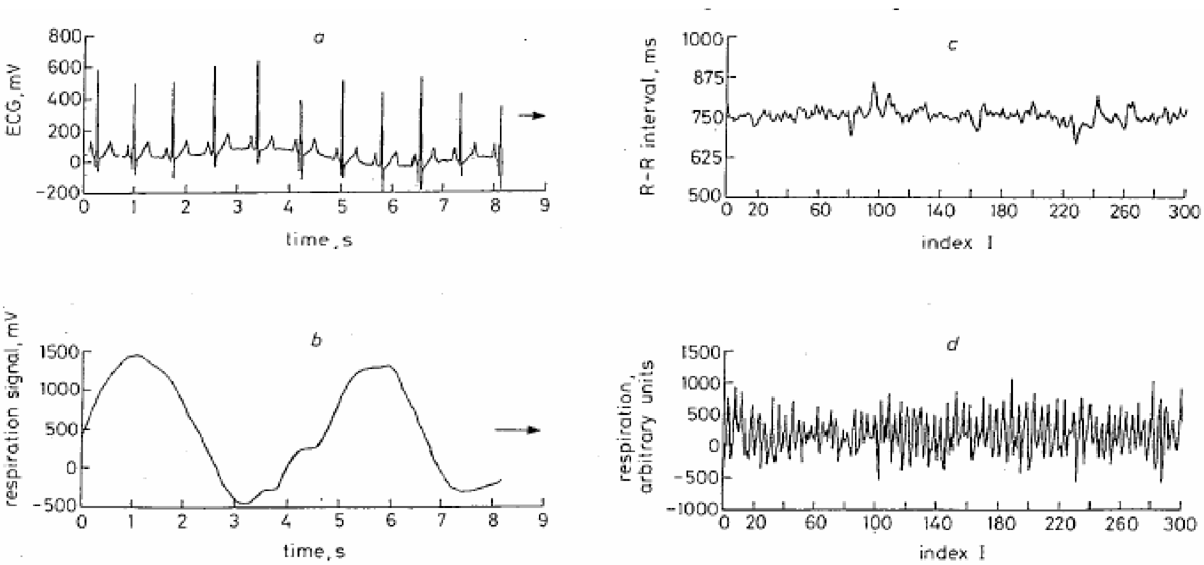

Fig.1 a) ECG and b) respiration signal recorded from anormal subject; c) interval tachogram (sequence of RR values as function of the beat number) and d) respirogram, i.e. the respiration signal resampled in correspondence of the R wave on the ECG [3]

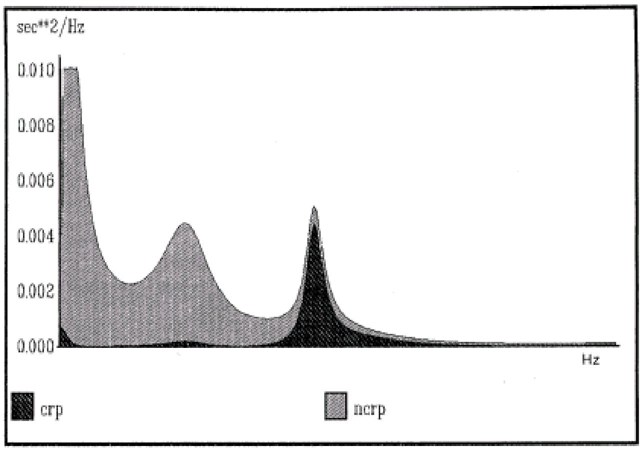

Fig.2 PSD of teh HRV signal divided into power coherent with respiration (crp) and power not coherent with respiration (ncrp)

III. Sleep Evaluation

The association of obstructive sleep apnea (OSA) syndrome, and other sleep disorders, with obesity, hypertension and cardiovascular disease has highlighted the broad public health importance of this condition.

Obstructive sleep apnea syndrome (OSAS) is considered to be a major public health problem, and also insomnia and sleep disorders may have serious implications in the daily and social life [4]. The laboratory sleep study using full polysomnography (PSG) and the scoring criteria of the American Academy of Sleep Medicine are considered the "gold standard" for sleep disorders diagnosis [5]. Parameters that are measured with PSG include: electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG), electrocardiogram (ECG), respiration (flow, chest, abdomen), oxygen saturation (SaO2). PSG has also been the standard technique for quantifying the number of arousals during sleep and for providing an index of sleep fragmentation. The high cost of in-laboratory, full-night polysomnography, together with long waiting lists for sleep studies, have led to the development of a variety of ambulatory sleep study systems [6].

A. Sleep evaluation based on HRV

Recent researches have demonstrated that different sleep stages correspond to different degrees of the sympatho-vagal balance. This can be quantified through the frequency analysis of the HRV signal [7-9]. In addition some events that occur during sleep, such as arousals, k-complexes on the EEG, sleep stage transitions and sleep apneas cause typical patterns in the RR sequences. The challenge is to base the sleep evaluation on the HRV signal and respiration analysis. Time domain analysis provides arousal detection and a definition of the *sleep fragmentation*, while frequency domain parameters, beat-to-beat calculated, are able to discriminate between REM and non REM sleep.

IV. Stress and Cardiovascular Risk

During the past two decades, considerable evidence has accumulated with respect to the association of markers of stress and other psychosocial factors with coronary disease. Both cross-sectional and prospective studies have shown a positive association between level of work stress and disease. The studies in literature have been mainly related to North American or European populations. A recent research presents analysis aimed to investigate the relation of psychosocial factors to risk of myocardial infarction in 24767 people from 52 countries [10]. In this study Psychosocial factors have been reported to be independently associated with coronary heart disease.

"Presence of psychosocial stressors is associated with increased risk of acute myocardial infarction, suggesting that approaches aimed at modifying these factors should be developed" [6].

A. How to assess the stress level

Compared with many other biological and lifestyle risk factors, stress is a more difficult construct in that no consensus exists with respect to either definition or measurement. Further, stress is inevitably a subjective measurement. The concept of stress encompasses several factors, from external stressors such as job stress, adverse life events and financial problems, to potential reactions to stress such as depression, vital exhaustion, anxiety, psychological distress, and sleeping difficulties.

Measurement of stress is complex and difficult. In the majority of the papers psychosocial stress was assessed by simple questionnaires. Stress may elude accurate quantification as it consists of several (interrelated) elements and its effects are characterized by pronounced inter-subject variability. In fact, response to stress may be difficult to assess even in the controlled laboratory environment. In [11] the 4S-Q test (Subjective Stress-related Somatic Symptoms Questionnaire) is used. It provides self-rated scales that, in line with previous and more recent studies, focuses on appraisal, coping, and health.

In the same papers [11, 12] autonomic dysregulation was proved in subject with higher levels of stress. Sympathetic predominance, vagal withdrawal and baroreflex impairment might represent the autonomic counterpart of the complex psycho-physiological changes underlying the increase in cardiovascular risk associated to chronic stress.

Computer analysis of spontaneous blood pressure and heart rate fluctuations has thus been suggested to offer an insight into autonomic cardiovascular regulation with no need of external stimulation on the cardiac and vascular targets. This approach thus appears well suited to quantitatively explore the impact of stress on autonomic cardiovascular control and as a measure of stress in association with the more standardized procedures.

B. Stress management

Treatment of stress may include many different approaches: training in cognitive-behavioral skills to manage psychological stress, by means of countering negative cognitions, priming positive coping statements to manage stress triggers, increasing pleasurable activities and maintaining social supports [13]. Among different exercises, the respiratory control have positive outcome modulating interaction between sympathetic drive and cardiovascular variability, and increasing arterial baroreflex sensitivity [14-17]. In [13] a biofeedback on heart rate variability was provided to the subjects as an aid for the correct execution of the relaxation and breathing exercise. The biofeedback greatly improves the beneficial effects of the exercises.

The beat-to-beat quantification of the HRV synchronous with respiration and its real time visualization constitutes an effective tool that provides the required biofeedback.

V. Conclusion

The information contained in the HRV signal can be related to many different conditions, both physiological and pathological. In particular we discussed the use of HRV for sleep evaluation and stress management. The advantage in the use of HRV in a home device are mainly in the possibility of obtaining a reliable signal without the need of clinical skills. The recording of standard ECG or EEG would require more complex recording set up and procedures.

In addition, the sleep situation, that excludes external confounding inputs, assures the feasibility of a reliable autonomic evaluation and a sufficient robust classification of the different states.

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