Pervasive and Mobile Computing 28 (2016) 21–34

Contents lists available at ScienceDirect

Pervasive and Mobile Computing

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

Heart rate wavelet coherence analysis to investigate group entrainment

Giorgio Quer*, Joshal Daftari, Ramesh R. Rao

University of California San Diego, 9500 Gilman Dr., La Jolla, CA 92093, United States

ARTICLE INFO

Article history:
Available online 13 October 2015

Keywords:
Heart rate variability
Wavelet coherence
Group dynamics
Wireless health

ABSTRACT

Unobtrusive, wearable sensors that measure physiological signals can provide useful information on an individual's autonomic response. In this paper, we propose techniques to jointly analyze heart rate variations from a group of individuals in order to study group dynamics. We use wavelet coherence to analyze the RR interval signals from a group of $N \geq 2$ individuals and uncover shared frequency components as a function of time. We study the intrinsic delay and accuracy limitations of a possible real time implementation. We substantiate our analysis with data obtained from Kundalini yoga meditation sessions that reveal a coherence pattern among the individuals as they perform particular prescribed activities. The methodology proposed in this paper may help quantify coherence of the autonomic response of groups involved in numerous everyday activities.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Wireless sensors are becoming part of everyday life because they are relatively inexpensive, easy to use, and unobtrusive. They can collect important physiological information from an individual, including heart rate, electrocardiography, blood pressure, temperature, galvanic skin response, movement in the three axes, muscular activity, and body composition. An interesting application of this technology is the continuous monitoring of patients with chronic diseases outside of a clinical environment [1], but the application of physiological wireless sensors is not limited to chronic diseases. An increasing number of people are tracking their daily activities to understand how to improve their habits and diet for a healthier lifestyle. The analysis, visualization and interpretation of these signals are still open problems, since most of the existing algorithms are proprietary and cannot be personalized.

The RR interval signal is a time series composed of the consecutive time intervals between two R peaks of the QRS complex, the electrical signal measured from the heart, which can be observed in an electrocardiography. The average of the inverse of the RR intervals corresponds to the average heart rate, which together with acceleration can be used to identify the activity performed by the subject [2].

RR intervals can also be used to study heart rate variability (HRV), i.e., the instantaneous and periodic variations of the heart rate. These variations are controlled by the two branches of the autonomic nervous system (ANS): the parasympathetic nervous system (PNS), which, in oversimplified terms, is responsible for the body's "relax and digest" behavior, and the sympathetic nervous system (SNS), which with a similar oversimplification is responsible for the "fight or flight" behavior. The interactions between the PNS and SNS dynamically influence the sinoatrial node, the pacemaker of the heart, which is responsible for RR interval variations: neurotransmitters associated with the PNS control the deceleration of the sinoatrial

---

* Corresponding author.
E-mail address: gquer@ucsd.edu (G. Quer).

http://dx.doi.org/10.1016/j.pmcj.2015.09.008
1574-1192/© 2015 Elsevier B.V. All rights reserved.

nodes pace, while neurotransmitters associated with the SNS control the acceleration of that pace [3]. Although RR intervals may fail to discriminate between a decrease in SNS outflow and an increase in PNS outflow, they will reveal the overall state of the ANS behavior.

In this paper, we provide a methodology for jointly analyzing RR interval signals from different subjects while they are performing group activities, e.g., team work, team sports, or group meditation. We use wavelet coherence analysis for capturing the presence of similar frequency components, as a function of time, in the RR intervals from the subjects being jointly analyzed. We detail the mathematical issues associated with the application of wavelet coherence to this problem and propose some useful extensions.

We adopt different signal processing methods to analyze the RR interval signals. We compare the spectral distribution of several RR interval signals by modifying the Welch method [4] to monitor over time the evolution of the signal spectrum. We calculate and interpret the wavelet coherence [5] between two RR interval signals, and propose a method to jointly calculate the coherence among $N > 2$ signals and to provide an undirected graph representing the temporal connections within the group. We also analyze the complexity and limitations of a possible real-time extension of these techniques in terms of precision with respect to the offline analysis and in terms of delay. We discuss the significance of these techniques by analyzing a dataset, collected over 11 Kundalini yoga sessions and discuss the significance of the techniques, their limitations and possible future extensions.

The techniques developed can be the basis of a scalable system that will allow researchers to study group effects in small groups in the same geographical area, as well as in large and heterogeneous groups via social networks. This work can be used in the study of group dynamics, defined as the interaction among two or more people in a group, performing similar activities or connected by some other form of relationship [6]. The study of the coherence in the ANS response might be of interest where the dynamics of the group are of key importance to the group as a whole, e.g. in team sports [7]. We have chosen to design and test our algorithm on Kundalini yoga meditation because this practice, similarly to other guided group meditation or prayer activities, is expected to have a direct impact on the practitioners' state of mind as well as their physiological response, and these methods can be readily applied to other settings.

Part of this work is based on the preliminary work presented in a conference paper [8], and a workshop paper [9]. The content of this paper substantially extends our prior work by exploring a larger dataset and providing new results, including a discussion of breathing rate as a variable of study.

The rest of the paper is organized as follows. Section 2 overviews some related work, then in Section 3 the data collection scenario, instrumentation, and pre-processing techniques are described. In Sections 4–6 we propose methods for the RR interval variability analysis, in terms of multiple-subjects comparison, pairwise analysis, and group analysis, respectively. The limitations of a possible real-time application are highlighted in Section 7. Finally, in Section 8 the methods' applicability and results are discussed. Section 9 concludes the paper and proposes some future research directions.

2. Related work

In a recent study by Müller and Lindenberger [10], phase synchronization measures were used to investigate coupling in cardiac and respiratory signals between choir members during a single performance. The results of this study suggest that the oscillatory coupling of cardiac and respiratory patterns can provide a physiological basis for interpersonal action coordination. This study was limited to pairs of subject and does not extend to the joint study of $N > 2$ subjects.

In [11], Berman and Syme studied the relationship between social cohesion and mortality risk as part of a nine-year research program showing that people lacking social and community ties were more likely to have a shorter life span than socially connected people. This work substantiates the importance of social cohesion and motivates our work. The joint analysis of physiological signals among different subjects presented here can help quantify the extent of group cohesion induced by particular activities.

To measure group dynamics, we use HRV, which reflects important body mechanisms and can reveal valuable information related to inflammation [12] and, indirectly, other important health conditions, such as sepsis, diabetic neuropathy, or myocardial dysfunction. With a different approach, in [13] we analyzed the RR intervals of a subject using probabilistic methods, providing insight in real time into the influences of the parasympathetic and sympathetic divisions of the ANS.

In the medical literature, the analysis of the HRV of a subject has received some attention as a method to study the ANS and as a possible predictor of cardiovascular mortality [14]. HRV analysis can be performed in the frequency domain, where different bands roughly depend on different causes of the periodic variations. The fluctuations in the high frequency (HF) range 0.15–0.4 Hz are mostly due to respiratory sinus arrhythmia (RSA) caused by the breathing pattern. The low frequency (LF) range, 0.04–0.15 Hz, is usually characterized by periodic oscillations of arterial pressure (Mayer waves). For a very slow breathing rate (e.g., 5 breaths per minute), the effects of RSA are measured also in the LF range. Finally, fluctuations in the very low frequency (VLF) range of 0.003–0.04 Hz may reflect factors related to the long-term regulation of blood pressure and water balance or fluctuations in the thermoregulatory system. The causes of the variations in the VLF range remain unclear, even if there are different hypotheses [15].

A recent meta-analysis by Thayer et al. [16] examined the relationship between HRV and ANS. HRV is identified in several papers as a potential marker for stress and health, although further study is needed to discriminate among its causes and to prove its clinical value. Isolating the influence of breathing in HRV is an open problem. Aysin and Aysin [17] proposed to modify the LF and HF frequency bands as a function of the measured breathing rate in a laboratory setting. They interpreted

Download English Version:

https://daneshyari.com/en/article/465855

Download Persian Version:

https://daneshyari.com/article/465855

Daneshyari.com