Computers in Industry 90 (2017) 42–49

Contents lists available at ScienceDirect

Computers in Industry

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

Detecting work-related stress with a wearable device

Lu Han[a,b], Qiang Zhang[a,b], Xianxiang Chen[a,b], Qingyuan Zhan[c], Ting Yang[c,*], Zhan Zhao[a,b,**]

[a] Institute of Electronics, Chinese Academy of Sciences, China
[b] University of Chinese Academy of Sciences, China
[c] China-Japan Friendship Hospital, China

ARTICLE INFO

Article history:
Received 2 December 2016
Received in revised form 22 May 2017
Accepted 25 May 2017
Available online xxx

Keywords:
Stress detection
Wearable computing
Electrocardiogram
Respiration
Support vector machine

ABSTRACT

Excessive stress will lower work efficiency, lead to negative emotions and even various illnesses. This paper aims at detecting work-related stress based on physiological signals measured by a wearable device. Different from common binary stress detection, this study detects three levels of stress, i.e., no stress, moderate stress and high perceived stress. The Montreal Imaging Stress Task (MIST) is used to simulate the different stress conditions, including both mental stress and psychosocial stress factors that are relevant at the workplace. A sensor-based wearable device is used to acquire the electrocardiogram (ECG) and respiration (RSP) signals from 39 participants. We extract stress-related features from ECG and RSP, and the Random Forest is used to select the optimal feature combination, which is later fed to the classifier. Four classifiers are investigated about their ability to predict the three stress levels. Finally, the combination of Random Forest and Support Vector Machine (SVM) achieve the best performance. With this method, the accuracy is improved from 78% to 84% in three states classification. And in binary stress detection, the accuracy is 94%.

1. Introduction

Work-related stress has drawn great interest in modern society. In 2007, stress was identified to be one of the most common health problem inducements in the European Union [1]. The poor match between people's working ability and demands leads to work-related stress [2]. Moderate stress can stimulate people's potential, while chronic and heavy stress may cause a series of negative effects including depression and even health problems, such as cardiovascular diseases, cerebrovascular diseases and musculoskeletal disorders [1–5]. Excessive workload and stress may make employees absent from job, which results in high economic costs [3]. If high work-related stress could be detected and monitored in time, it is less possible to cause health problems. Further, if the moderate level of stress could be recognized, it could help people maintain the appropriate working state. Therefore detection of different levels of stress is meaningful.

Physiological response corresponds to psychological change and can't be manipulated by people. The mechanism to maintain the body under a stable condition is realized by the autonomic nervous system (ANS), which contains sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). It's known that stress can activate the SNS [6]. And the PNS can bring the body back to a rest state. Intuitively, SNS activation increases the heart rate, whereas PNS decreases it. Activity of SNS and PNS can be monitored through some physiological signals, such as heart rate, heart rate variability (HRV), blood pressure and so on. Also, the respiration under stress is short and rapid, whereas it's deep and slow at a rest state. In our study, we select ECG and respiration signal to measure stress.

There have been many studies on stress detection. Liao used mental arithmetic and an alphabetic task to emulate mental stress. They used facial, physiological signals (heart rate, skin temperature, galvanic skin response), behavioral and task performance (e.g., error rate) as factors [7]. Zhai and Barreto used an interactive 'Paced Stroop Test' to emulate stress. In the test, participants had to select the font color of a word shown on the screen and the word itself named a color [8]. Katsis simulated car races to detect high stress, low stress, disappointment, optimistic and neutral state. They extracted features from facial electromyogram, RSP, electrodermal activity and ECG [9].

* Correspondence author at: 2 Yinghua Dongjie, Hepingli Beijing 100029, China.
** Correspondence author at: No. 19 North 4th Ring Road West, Haidian District, 100190 Beijing, China.
E-mail addresses: dryangting@qq.com (T. Yang), zhaozhan@mail.ie.ac.cn (Z. Zhao).

http://dx.doi.org/10.1016/j.compind.2017.05.004

Muaremi combined the recording of smartphones with subjective assessments and voice messages during workday and recording of HRV data during night. From the smartphone, they extracted audio (microphone), physical activity (accelerometer and GPS) and social interaction (phones calls, address book, calendar and battery) features. They got an accuracy of 55% using only smartphone features, while 59% using HRV features [10]. McDuff measured physiology parameters of Heart Rate and HRV captured at a distance of 3 m using a digital camera. Ball control and card sorting tasks were used to emulate mental stress [11]. In this work, the head or body motions and changes of ambient light might easily impact the accuracy in stress detection.

In stress emulating, the mental arithmetic, alphabetic task, 'Paced Stroop test' and other forms of mental stress were often used. Most studies used only mental workload to elicit mental stress, which is certainly an important stress factor in office. However, there are other factors that can elicit psychosocial stress, such as social threat from leaders and colleagues. In our study, to recognize work-related stress, we pick an experiment setting that is very close to a real office situation. Therefore we consider both mental and psychosocial factors by using the MIST which is a standardized task based on computer and psychology [12]. Furthermore, the MIST contains a no stress condition, a moderate stress condition and a high stress condition. As moderate stress is beneficial to work efficiency, one highlight of our study is to detect three levels of stress rather than simply binary stress condition (with or without stress).

After data collection, different algorithms were used to detect stress. Setz compared performances of Linear Discriminant Analysis (LDA), nearest class center and SVM with linear, quadratic, polynomial and rbf kernels in stress detection. With the features extracted from electrodermal activity, they achieved a maximum accuracy of 82.8% by LDA [13]. Liao used a Dynamic Bayesian Network to estimate a continuous stress level [7]. Researchers from the University of Memphis developed a Bayesian Network model of self-reported stress and used a SVM model to predict the instantaneous self-report. With ECG and RSP features, they obtained an accuracy of 72% on filed data [14,15].

In most studies, they only investigated the appropriate classifier to adapt to some kind of feature set. However, the combination of features was often neglected. In our study, we use the Random Forest to find the optimal feature combination, which help improving the performance of classifiers. And to get the best performance, four different classifiers are investigated.

Until now, there is no universally accepted definition of stress or standard database for stress recognition both in lab and in field. In our study, to detect different levels of work-related stress, we make contributions from four aspects.

Firstly, we combine both mental and psychosocial stress factors closing to a real-life office condition. Secondly, we try to detect three levels of stress (no, moderate and high stress) rather than simple binary classification between rest and stress. Thirdly, we use a wearable device to collect ECG and respiration signals, which can provide continuous measurement of stress levels. Finally, we use the Random Forest to find the optimal feature combination, which help improving the performance of classifiers. And to get the best performance, four different classifiers are investigated.

2. Data collection

In this study, we consider both mental and psychosocial stress by using the MIST to make the experiment closer to the real office situation. During the experiment, the participants wear the wearable device for collecting ECG and RSP signals.

There are total 39 healthy participants (male: 24; female: 15; mean age: 23.9) participating in the experiments. To ensure the validity and authenticity, the participants are told that they are taking part in an experiment investigating the relationship between cognitive performance and physiological characteristics. Actually, they are confronted with both mental and psychosocial stress.

2.1. Experiment

The Montreal Imaging Stress Task was originally created to evaluate the effects of psychological stress on physiology and brain activity [12]. It has been shown to induce moderate stress response [12]. MIST is an experimental paradigm based on computer and psychological, which mainly consists of four processes: rest, moderate stress, high stress and recovery. The no stress condition is just a rest state. The high stress condition consists of mental arithmetic under time pressure and social-evaluative threat, whereas the moderate stress condition contains only mental arithmetic and moderate social evaluation without any other pressure, which is similar to working under moderate stress.

Fig. 1 shows the experiment procedure for inducing stress in our study. After each condition, we will ask the subjects to give a self-report and questionnaires, which serve as the ground-truth stress level. In 39 subjects, 38 self-reports are consistent with the MIST processes.

We develop the MIST program using the Visual Studio application for Windows. The basic algorithm of the program creates the arithmetic tasks. The algorithm uses up to 4 numbers ranging from 0 to 99 and up to 4 operands containing addition, subtraction, multiplication and division. It is designed to create arithmetic tasks automatically and the solution will be an integer between 0 and 9. The arithmetic tasks are divided into 5 categories. For the first two easiest categories, tasks are only about 2 or 3 one-digit integers and the operands are only addition or subtraction, for example: 6 + 8–9. For the medium two categories, tasks are about 3 or 4 integers with up to 2 integers in 2-digit range and multiplication is allowed, for example: 64–5*11. For the most difficult category, tasks are about 4 integers that can be in 2-digit range. Multiplication and division will be used, for example: 12*14/21-2.

During the rest condition (for 5 min), the participants do not have any task, which is the most relaxing condition.

The moderate stress condition (for 4 min) contains only mental arithmetic and moderate social evaluation, which is similar to working on a computer under moderate stress. When the participant submits the answer, the screen will display "Right!" or "Wrong!" as a feedback. And the leader will give some friendly and moderate giveback, such as "Just do as much as you can!" or "Is there a problem for solving the tasks?". During moderate stress condition, only mild social stress is induced, whereas strong social stress is induced during high stress condition. During the moderate

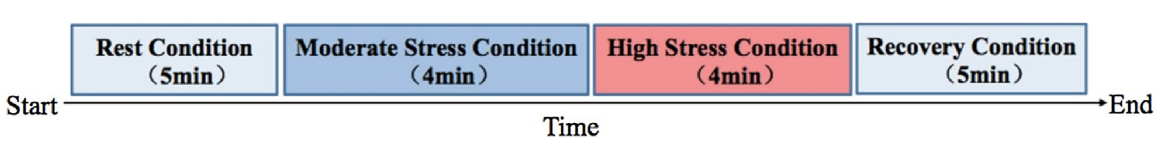

Fig. 1. The experiment procedure for inducing stress. After each condition, we will ask the subjects to give a self-report and questionnaires.