Classification Tools Heart Rate Variability

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Contributor: Michał Meina , Ewa Ratajczak , Maria Sadowska , Krzysztof Rykaczewski , Joanna Dreszer , Bibianna Bałaj , Stanisław Biedugnis , Wojciech Węgrzyński , Adam Krasuski

Chronic stress is the main cause of health problems in high-risk jobs. Wearable sensors can become an ecologically valid method of stress level assessment in real-life applications. We sought to determine a non-invasive technique for objective stress monitoring. Data were collected from firefighters during 24-h shifts using sensor belts equipped with a dry-lead electrocardiograph (ECG) and a three-axial accelerometer. Levels of stress experienced during fire incidents were evaluated via a brief self-assessment questionnaire. Types of physical activity were distinguished basing on accelerometer readings, and heart rate variability (HRV) time series were segmented accordingly into corresponding fragments. Those segments were classified as stress/no-stress conditions. Receiver Operating Characteristic (ROC) analysis showed true positive classification as stress condition for 15% of incidents (while maintaining almost zero False Positive Rate), which parallels the amount of truly stressful incidents reported in the questionnaires. These results show a firm correspondence between the perceived stress level and physiological data. Psychophysiological measurements are reliable indicators of stress even in ecological settings and appear promising for chronic stress monitoring in high-risk jobs, such as firefighting.

HRV, accelerometers, stress

1. Introduction

Firefighting is one of the most life-threatening, emotionally traumatic and stressful occupations. Firefighters routinely encounter stressors of various strength and intensity. They are exposed to severe acute and chronic stress, which can result in depression or occupational burnout [1]. Working in hazardous conditions causes exposure to a whole variety of extreme situations, such as witnessing death, suffering or participation in life-threatening events, perceived as a source of high stress that can result in post-traumatic stress disorder (PTSD) [2][3][4][5][6]. In addition to traumatic incidents, further sources of stress stem from daily working conditions, including organisational and administrative factors that reflect paramilitary, hierarchical, task- and tool-oriented, traditional power and command structures [7][8][9]. Furthermore, shift work system contributes to increased sleepiness and fatigue, and enhances the risk of injuries [10][11][12]. Chronic stress results in significant deterioration of health, frequent use of drugs and alcohol, and, in extreme cases, suicide, which is particularly related to symptoms of PTSD [13] and other psychiatric disorders [12][14]. Moreover, chronic stress causes an increased susceptibility to other stressors, which further leads to cardiovascular problems—the main cause of line-of-duty deaths among firefighters [15][16]. This reveals an appalling lack of continuous health monitoring and insufficient support of physical activity programs in high-risk jobs, such as firefighting service [17][18][19].

Among firefighters, chronic stress is the main cause of health problems, especially heart-related diseases however, these problems do not appear overnight. It takes months or even years of psychophysiological changes to develop a chronic condition and it is usually not possible to pin-point the exact event that triggered this shift. Additionally, the amount of exposure to acute stress necessary to prompt the chronic state depends on individual characteristics [20]. Therefore, only constant control of the pshychophysiological well-being in high-stress jobs can assure that the personnel receives the support they need exactly when they need it. This way it is possible to administer an appropriate mental health intervention or debriefing before it is too late. Real-time monitoring and on-line management of everyday stress experienced upon real-life events may be key to addressing this issue, as a preventive tool [15][17][18][21]. Unfortunately, control of the subjective, psychological perception of stress appears insufficient, as discrepancies were reported between self-assessed distress and objective evidence of harm [6][22]. Therefore, when examining stress, it is important to consider both its psychological and physiological nature. Regrettably, much of the stress-related research concerning firefighters was based on questionnaire studies, yielding an incomplete picture. Such procedures are retrospective and mostly carried out in laboratory settings [23][24]. Acute stressors observed in the laboratory rarely represent real-world situations accurately [25]. Moreover, only single-dimension characteristics of stressful events can be investigated in a laboratory setting, while real-life situations are far more complex [25]. Furthermore, self-report is not always reliable; a phenomenon reflected in overestimation of physical activity level upon self-evaluation [26][27]. Additionally, self-assessment is influenced by recall biases reflecting individual levels of coping mechanisms, experiences and even mood fluctuations [28]. Therefore, results obtained in laboratory settings via self-report may suffer from decreased accuracy and reliability, and thus cannot be generalised. For this reason it is important to consider ecological validity and physiological reactions to stressors in stress studies. It is necessary to investigate individual psychophysiological reactions exhibited upon experiencing real-life stress. Psychophysiological monitoring would allow a better understanding and management of stress dynamics and result in health-care consequences at individual and organisational level.

2. Applications

Development of wearable sensors designed to measure basic physiological parameters enable data collection in the course of daily activities and situations that may be relevant to an individual’s well-being and the ability to perform certain tasks [29][30][31][32]. Wearable devices, due to their mobility, high flexibility and connectivity, receive a great deal of attention from health-care environment [32][33]. Moreover, they offer an ecologically valid method for assessing stress levels with much higher accuracy than laboratory measurements, and open new possibilities for stress management and rehabilitation [29][32][34]. Several indicators of autonomic stress response can be recorded by biosensors; however, heart rate variability (HRV) is most commonly used. This parameter reflects the cardiovascular response to regulatory impulses affecting heart rhythm [35][36]. Therefore, HRV may serve as an indicator of the autonomic nervous system’s reaction to stressors [37][38], including job-related ones [34][39][40][41]. Reduced HRV is associated with deteriorated physical and psychological health, for example, decreased performance on cognitive and physical tasks [26][42][43][44], cardiovascular diseases [35], psychological stress [45], or depression and anxiety [46][47]. Real-time HRV measurement provides a suitable, unobtrusive and continuous method for detecting psychophysiological stress [33], and allows for development of health-care solutions for stress monitoring, management and rehabilitation. Moreover, HRV-based sensors can be useful as personal protection equipment for workers employed in high-risk jobs, operating in dangerous and stressful conditions, such as soldiers, firefighters, or policemen [40].

Despite its undeniable merits, stress assessment based solely on HRV measures is not accurate enough, since several different factors affect HRV for example, circadian rhythms, physical activities, body position [48]. Heart responses depend on the type, volume and intensity of exercise [49]. Additionally, it is difficult to fully describe the relationship between stress, different kinds of physical activity and HRV without the knowledge of the normal, daily fluctuations in HRV [50]. Unfortunately, one cannot rely on self-reports of physical activity, as it was proved that there is no correlation between the alleged activity and HRV fluctuations [50]. Therefore, it is necessary to employ an objective measure of physical activity. Combining HRV measurements with data from other sensors could aid the explanation of differences in HRV levels upon various psychophysiological states. Inclusion of accelerometric data helps to control the influence of physical activity by assessing the type of motion. Furthermore, it allows for delineation of epochs in the cardiovascular signal that correspond to different types of physical activity. In this way, it is possible to pool together HRV metrics calculated from natural, ecological short epochs of real-life signal recorded during similar episodes of physical activity. In a subsequent step, these separately analysed subsets of data can be compared with each other in order to differentiate stressful and non-stressful epochs. Such approach is far more sensible than analysing full 24-h recordings, which are highly non-homogeneous with respect to other factors influencing HRV. A full day may consists of several different situations, characterised by varying levels of stress, physical strain imposed on the body, and so forth. The standard approach to computing HRV indices in a sliding window does not allow for comparative analysis. Additionally, long signal recordings create certain difficulties in data analysis, mostly concerning data quality and problems with signal stationarity.

Few studies attempt to assess stress based purely on accelerometric data [51]. Changes in movement are not necessarily correlated with variations in levels of stress. This could be true in certain occupations however firefighters tend to be physically active not only during emergency calls, but also in their free time. Physiological parameters, such as HRV, skin conductance, breathing, reflect the psychophysiological state of the body far better. However, accelerometry makes it possible to determine specific behaviour patterns and overall activity level. Combined information from both types of signal provides a much more complete picture of a current bodily state. Typical accelerometric sensors measure body acceleration in three physical dimensions at high temporal resolution (usually 100 Hz). A combination of parameters measured along these three axes over a given period of time can be used to describe and distinguish specific components of movement that comprises a single behaviour or a series of activities [52]. Machine learning allows to classify these activities with a high degree of accuracy [53][54]. Classification is based on two accelerometric variables—static acceleration (gravity-related body orientation and position), and dynamic acceleration (induced by changes in movement) [52]. Therefore, accelerometer data alone suffice to infer activity levels and distinguish different types of physical activity, eliminating any need for direct observation or self-assessment. Integration of accelerometric measurement with HRV recordings in human stress monitoring appears to be an interesting possibility.

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