Workplace Stress Estimation from Physiological Indices in Real Situation

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Abstract. We have developed a new method to estimate no only stress occurrence, but also various workplace stress types. The method relies on adaptive selection of physiological indices integrated into an intelligent multi-steps discrimination process. Preliminary results revealed the method promising to improve estimation accuracy of workplace stress types. The study reported here, has two purposes: investigate if it is effectively possible to estimate stress type independently from individual differences, and validate the performances of proposed method in real situation. Four subjects that were not part of the preliminary study were assigned whether a tape dictation task or a presentation task as real situation tasks. The occurrence of various types of harmful stress could be correctly discriminated, confirming proposed method as an effective solution to estimate stress type regardless individual differences.

Keywords: Multivariate analysis · Stress monitoring · Virtual healthcare · Wearable sensors · Workplace stress

1 Introduction

1.1 Background and Definition of Stress

Nowadays, most developed countries are facing a serious problem with the increasing number of diseases caused by excessive stress. This includes not only mental disorder diseases (depression, etc.), but also lifestyle-related diseases such as hypertension, metabolic syndrome, etc. Current stress detection methods, when not afterwards conclusions, rely on inquiry sheets or interviews with a medical specialist. However, stress is so pervasive in our social activities. There is an inherent need to monitor it continuously in daily life over extended periods. It is important to propose a personal and seamless system for regular screening of stressful experiences an individual is exposed during his daily life activities. Such system will enable prevention of serious stress-related health disorders. It will also benefit both individuals by providing regular

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feedback about their stress, and physicians by supporting patient status monitoring and evaluation with quantitative and in context information.

Taber's Cyclopedic Medical Dictionary defines stress as "the result produced when a structure, system or organism is acted upon by forces that disrupt equilibrium or produce strain". When it occurs in amounts that cannot be handled, both mental and physical changes may occur. In our study, we focus on "Workplace stress." We define it as the physiological responses that can happen when there is a conflict between job demands on the person and the amount of control this person has over meeting these demands. In general, the combination of high demands in a job and a low amount of control over the situation can lead to stress. The Canadian Mental Health Association stated stress in the workplace can have many origins: fear of job redundancy, pressure to perform, increased demands for overtime, layoffs due to an uncertain economy act as negative stressors. Among these origins we focus on the following three non-economical categories of workplace stress.

- Monotonous stress: stress due to a tedious feeling when repeating a work with little content changes for a long continuous time (redundancy, frequent overtimes, etc.).
- Nervous stress: stress due to a feeling of tension when performing a work that cannot afford any miss (speech, meeting with hierarchical superiors, etc.).
- Normal stress: stress accompanied by any feeling different from above described, when performing a basic work (that does not generate extra stress).

1.2 Current Technological Solutions and Their Issues

Traditionally, personal medical monitors have been used only to perform data acquisition. Typical examples are Holter monitors that are routinely used for electrocardiogram (ECG) monitoring. Recently, with the miniaturization and improved performances of micro-sensors, wearable computing, and wireless communication technologies, a new generation of wearable intelligent sensors have been developed. We can classify prior research related to stress study using wearable physiological sensing into the following three categories.

1. Studies that demonstrate the causal relationship between stress and changes in physiological indices [5, 10].
2. Studies that evaluate qualitatively and/or quantitatively the stress issued by an external stimulus [6, 14].
3. Studies that estimate the occurrence or not of stress based on the observation of changes in physiological indices [1, 4].

Aiming at stress monitoring during daily life activities, our research corresponds to the third category. This category have four big issues that need to be addressed.

1. As physiological indices are strongly influenced by individual differences, their values on stress occurrence are different depending on each individual [8].
2. Depending on the type of stress (in other words the type of emotion), reacting physiological indices are different, so that it is difficult to estimate stress in detail from a single physiological index [9, 10].

3. Stress status output models application is often limited to only one specific individual, and cannot output stress status correctly for a different person [12].
4. Models are often limited to an output of having or not stress, and do not estimate stress status in details (i.e. stress type) [11, 13].

To address above described issues, we have established a general stress types' estimation method using physiological indices less prone to individual differences.

2 Physiological Information Useful to Stress Estimation

For monitoring stress, we focus on autonomic nervous system activity, though we don't use electroencephalogram (EEG) due to its difficult processing that makes it difficult to use for a real-time stress monitoring solution. It is known that the autonomic nervous system influences the activity of the heart, the breath, the lung, and the skin activities. Typical studies of the autonomic nervous system activity monitoring consist in ECG's heart beats R peak time interval variations (RRV: R-R interval variations) frequencies analysis [2]. Strength of low frequencies zone (LF) reflects sympathetic nervous system's activity, and strength of high frequencies zone (HF) reflects parasympathetic nervous system's activity. Though studies reported that LF/HF ratio analysis was effective to evaluate the physical and mental loads by quantifying respectively the activity level of sympathetic and parasympathetic nervous system, this index is known to be different according to the age, sex and the individual variation [9]. Thus, selected physiological indices should meet the following two conditions.

1. They can reflect the categories of stress.
2. Individual differences are not large.

In this study, we decided to measure simultaneously ECG, pulse wave by photoelectric plethysmography (PPG), breath, and temperature of finger's skin. From these four physiological signals, we extracted the following nine physiological indices, which we adopted as the basic information for stress type estimation.

- From finger's skin temperature: T_F (average temperature of the finger's skin)
- From breath: f_G (respiratory central frequency), $|f_G\text{-}f_P|$ (absolute difference between f_G and peak frequency f_P), te (breath time), $stdt_T$ (derivation of breath time)
- From ECG: HR (Heart rate), RRV, LF/RF (ratio between RRV low frequencies and $f_G \pm 0.05$ Hz)
- From PPG: t_{PAT} (pulse arrival time)

We have defined an original procedure composed of three steps to gradually estimate stress status corresponding to input physiological signals as shown in Fig. 1 [3]. The first step aim at discriminating with high accuracy the presence of any workplace stress. If stress presence is detected, the second step consists in identifying the harmfulness of the stress. If harmful stress is identified, the final step consists in discriminating the nervous and monotonous stress.

A large amount of physiological data-sets were collected under different stress types' exposure in laboratory settings from 39 participants different in age and sex.

We used leave-one-out cross validation to compare the stress types' estimation performances of proposed procedure with conventional methods. Self-assessment of stress status during experiments was used as the reference. The results showed that selection of best fit physiological indices has a great impact on stress presence estimation accuracy, while the multi-steps discrimination process is essential to improve the accuracy of stress type estimation (Table 1).

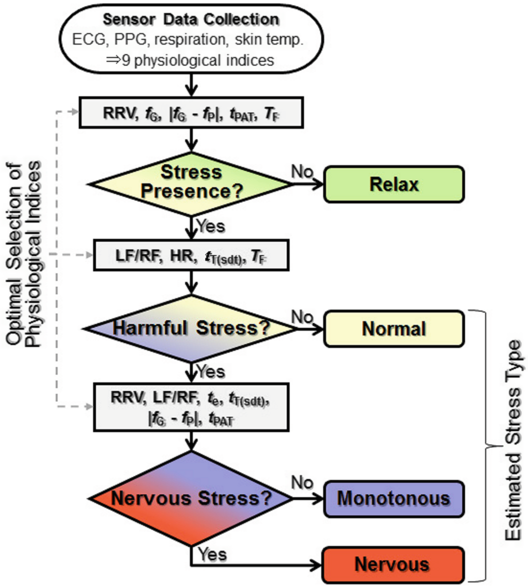

Fig. 1. Proposed multi-step estimation procedure with indices selected for method A.

Table 1. Discrimination accuracy for stress presence and type depending on the method used

Physiological indices used	LF/HF only	All indices	Selected indices	Selected indices and multi-steps method
Stress types	26 % ± 2 %	48 % ± 8 %	56 % ± 3 %	64 % ± 5 %
Stress presence	63 % ± 1	83 % ± 7 %	89 % ± 3 %	–

3 Estimation of Stress Types in Real Situation

3.1 Real Situation Task Content and Environment

To validated laboratory settings results, proposed multi-steps procedure have been evaluated in real workplace stress conditions. Tape dictation work can been identified as monotonous stress real situation. Tape dictation is a task that consists in typewriting the text of dictated speech sound tape. Two volunteers accepted to measure their physiological signals during tape dictation of speech issued from a meeting. Presentation of a new product to clients by sales people can be identified as nervous stress real situation. Two volunteers accepted to measure their physiological signals before, during, and after the presentation of new medicine to physicians.

3.2 Task Protocol and Data Collection Timing

Tape dictation work was performed sat. The subjects rested for five minutes, performed there tape dictation work continuously during 60 min, and finally rested again for five minutes. To capture the situation of monotonous stress occurrence, self-assessment had to be performed at the end of each period of rest, and every 5 min during the tape dictation assignment. In order to avoid that the tedious feeling of the subject declines due to the self-assessment interrupting the task, we used a limited questionnaire sheet as shown in Fig. 2 (left). The index "fed up, bored" is representative of the presence or not of monotonous stress.

In presentation work, each salesman had to wait for some minutes before entering the presentation room. After entering the salesman was imparted five minutes to prepare the document in front of the audience. The presentation document's materials were available, though it has to be arranged efficiently to respond to client's request. Then, the prepared document is presented during five minutes. Next, a question and answer (Q&A) session were carried out during five minutes. Finally, they rested again in the waiting room. Salesmen were sitting during document preparation session, and standing during presentation and Q&A sessions. However, the duration of presentation and Q&A sessions differed slightly between the two subjects since it was an uncontrolled real situation. To capture the situation of nervous stress occurrence, self-assessment had to be performed at the end of each period of rest, to keep the conditions as natural as possible. The questionnaire used for the self-assessments was also based on conventional stress evaluation questionnaire, from which we extracted the indices related to the feeling of tension and tedious feeling as shown in Fig. 2 (right).

For each situation, physiological signals listed in Sect. 2 were measured continuously during the whole task duration using a multi-channels biological amplifier. Volunteers were not part of our former experiments, classification schemes trained for proposed multi-steps procedure were not calibrated for their physiological reactions.

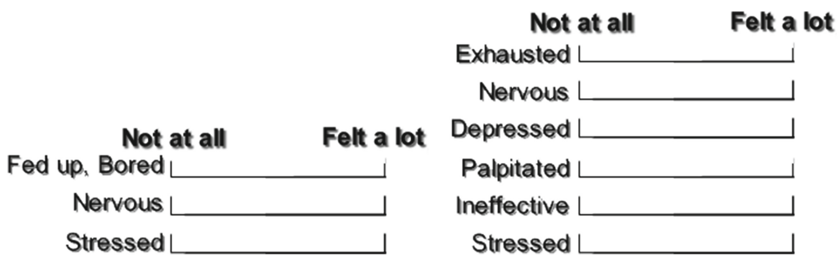

Fig. 2. Example of self-assessment sheet for tape dictation (left) and presentation (right) tasks

4 Harmful Workplace Stress Estimation

4.1 Stress Estimation Method, and Results Validation Methodology

As shown in Table 2, the maximum accuracy for stress types' estimation could be reached with various classification schemes [3]. The reliability criterion U proposed in Eq. 1 should help to choose the classification scheme that provides both high accuracy and high independence to individual differences. In Eq. 1, x_{1i}, x_{2i}, and x_{3i}, are respectively the average accuracy, the standard deviation of the accuracy, and the database dependency of the adopted stress classification schemes (i = 1, 2, 72), which should result in positive values of U index for reliable classification schemes, and small or negative values of U index for unreliable schemes. Such, we propose to compare the analysis of data collected in real situation using classification schemes with the high U and the low U values.

$$U_i = \frac{x_{1i} - \overline{x_1}}{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_{1i} - \overline{x_1})^2}} - \frac{x_{2i} - \overline{x_2}}{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_{2i} - \overline{x_2})^2}} - \frac{x_{3i} - \overline{x_3}}{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_{3i} - \overline{x_3})^2}} \quad (1)$$

Table 2. Stress types' estimation performances of selected classification methods

	Scheme A (highest U)	Scheme B (lowest U)
Classification scheme	Gaussian kernel Support Vector Machine (σ = 2.75)	Fuzzy logic
Stress presence detection	RRV, f_G, $\lvert f_G\text{-}f_P \rvert$, t_{PAT}, T_F	RRV, LF/RF, f_G, t_e, t_{PAT}
Stress harmfulness detection	LF/RF, HR, $stdt_T$, T_F	HR, $stdt_T$, t_{PAT}, T_F
Stress type detection	RRV, LF/RF, $stdt_T$, te, $\lvert f_G\text{-}f_P \rvert$, t_{PAT}	HR, f_G, $\lvert f_G\text{-}f_P \rvert$, t_e
Accuracy	64 %	64 %
Standard deviation	28 %	36 %
Reliability criterion (U)	3.08	−2.8

We can notice that though they use different classification algorithms and different physiological indices, both classification schemes achieved an accuracy of 64 % for the estimation of workplace stress types, but with different standard deviation, and respectively positive and negative U values. Also, 64 % may not be sufficient for accurate stress estimation from real situation sensor data. Such, we decided to leverage each estimation result obtained from one minute data set, using the majority rule on a five minutes time window with one minute forward step. With accuracy greater than 60 %, the majority rule should return a correct estimation result.

4.2 Monotonous Stress Estimation Result

Self-assessment's result for tape dictation task performed by subject 1 and 2 are shown in Fig. 3. The boredom score and nervous score of the self-assessment reflect respectively the responses to the questionnaire for the index "fed up, bored" and "nervous," using a scale from 0 to 100 from left to right. In the case of subject 1, we can observe an elevation in the boredom score since the beginning of the tape dictation task. Although the boredom score has been decreasing temporarily, we can assume that

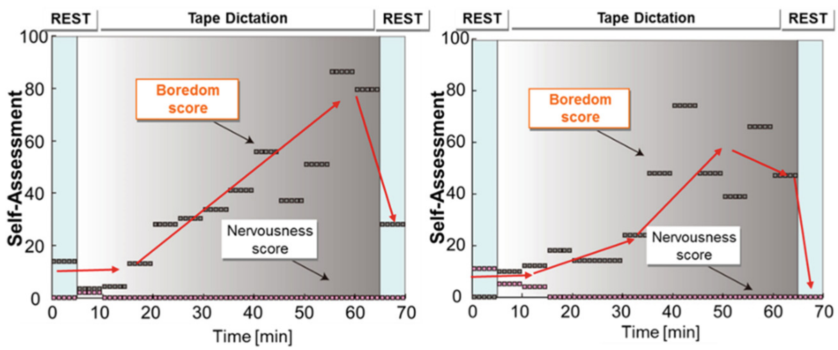

Fig. 3. Self-assessment by subject 1 (left) and subject 2 (right) for tape dictation task

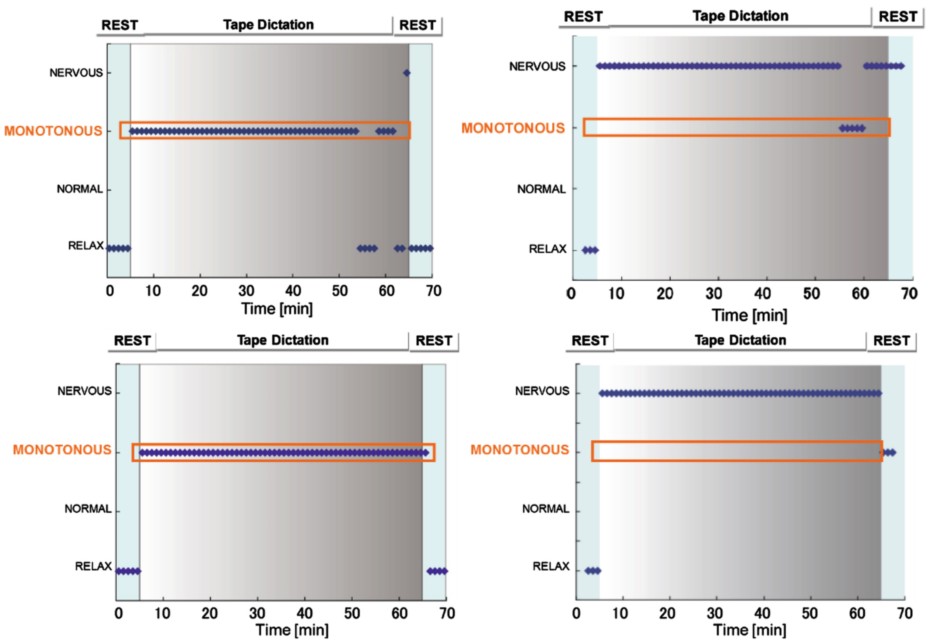

Fig. 4. Stress type estimation result for tape dictation task using classification schemes A (left) and B (right), subject 1 (top) and subject 2 (bottom)

monotonous task stress occurred during the tape dictation task. Considering the very low nervous score we can assume that nervous task stress did not occurred.

Regarding the estimation results shown in Fig. 4, we can observe that reliable scheme succeeded in correctly estimating the rest status during both periods of rest, and monotonous stress type occurrence during the whole tape dictation period.

Although monotonous stress occurrence was not obvious at the beginning of tape dictation task when boredom score was low, we can assume that we could capture correctly the characteristic of assigned task. On the contrary, the unreliable scheme was not able to estimate properly stress type. Concerning subject 2, though boredom score was not as high as for subject 1, it increased a lot during tape dictation task period compared to rest periods, while nervousness score was almost null. Such we assumed monotonous stress also occurred for subject 2. Stress type estimation using reliable scheme also resulted in monotonous stress estimation during the whole tape dictation.

Summing up the results from both subjects, using proposed highly reliable method we could estimate correctly monotonous stress occurrence in uncontrolled conditions similar to real life's ones, even for subjects that were not part of the formerly build database.

4.3 Nervous Stress Estimation Result

Self-assessment's result for presentation task performed by subject 3 is shown in Fig. 5. The boredom score and nervous score of the self-assessment reflect respectively the responses to the questionnaire for the index "exhausted, ineffective" and "nervous, palpitated" using a scale from 0 to 100 from left to right. Subject 3, we can observe a large elevation in the nervous score during the document preparation, the oral presentation, and the Q&A session, compared with the two periods of rest. From these results, we can assume that nervous task stress occurred during the presentation task. Although boredom score increased a little at the second rest period, it globally stayed very low, such we can assume that boredom stress did not occurred. The nervous score of subject 4 was not as high as for subject 3. It increased for the documents preparation and the oral presentation periods. However, it decreased for the Q&A period and went null for the second rest period. Such, we can assume that an obvious nervous task stress

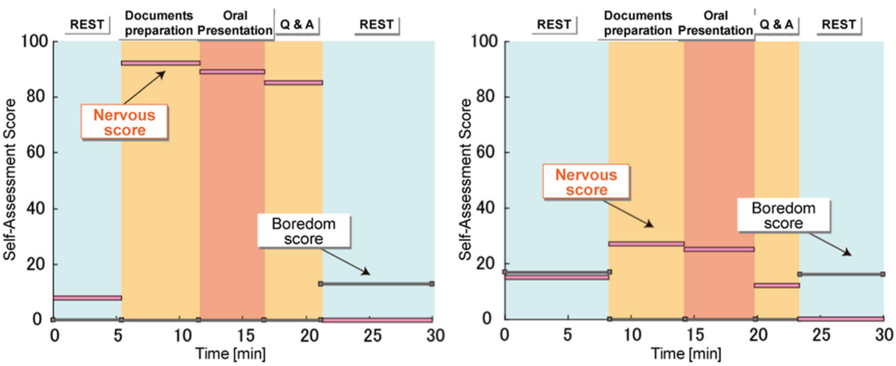

Fig. 5. Self-assessment by subject 3 (left) and subject 4 (right) for presentation task

did not occurred with subject 4. The boredom score was similar to subject 3, increasing slightly during the second rest period.

Regarding the estimation results for subject 3 (Fig. 6 top), we can observe that both reliable and unreliable schemes estimation results are detecting the occurrence of nervous stress. However, reliable scheme also succeeded in detecting correctly the periods of rest, while unreliable scheme always detects some kind of harmful stress. Concerning subject 4 (Fig. 6 bottom), we can observe that reliable scheme detected nervous task stress occurrence during the documents preparation period, and relax status during all other periods. The document preparation period corresponded to the highest nervous stress score from self-assessment, such we may consider this was the most nervous period in subject 4 relatively low nervous stress status. Unreliable scheme could not detect successfully the relax status during rest periods, as for subject 3.

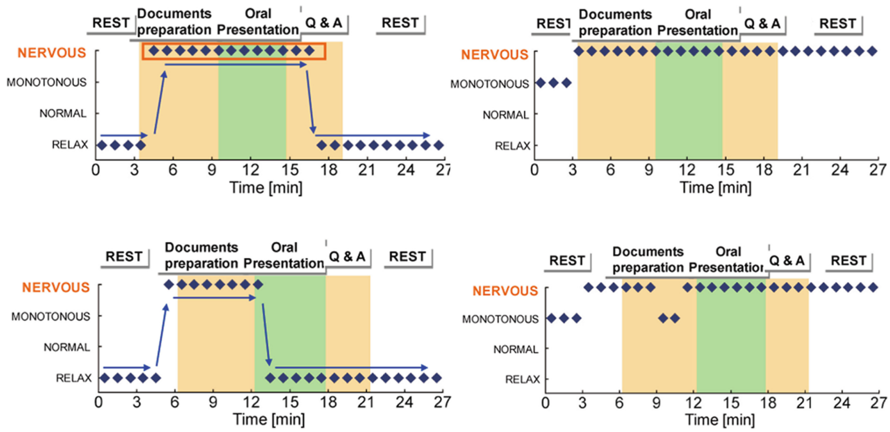

Fig. 6. Stress type estimation result for presentation task after majority rule application for subject 3 (top) and subject 4 (bottom): scheme A (left), and scheme B (right)

5 Discussion and Future Works

The results of real situation workplace stress study presented here confirmed that we could correctly discriminate relax situation and the occurrence of various types of harmful stress using proposed method. The importance of not only the accuracy but also the reliability of implemented method were demonstrated by comparing two methods with both high accuracy, but respectively high and low reliability criterion U. Moreover, since the subjects participating in this study were different that the subject used to build the model, we could demonstrate that proposed procedure implementing a method with high U is not prone to individual differences. However, to achieve our goal of a system as shown on for personal continuous stress monitoring in daily life [7], we still have to tackle following issues.

- Evaluate in detail the relation between U and methods' robustness to be able to define the minimum U value a method should obtain to be reliable.

- Continue improving stress type discrimination accuracy while limiting at best the number of sensors worn.
- Investigate the possibility to discriminate more types of stress.
- Investigate a method that enables to evaluate quantitatively stress level.

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