Nonlinear Phenomena in Complex Systems, vol. **18**, no. 1 (2015), pp. 38 - 43

Mental Stress Testing Using Classification and Regression Tree

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(Received 17 December, 2014)

The Classification and Regression Tree has been used for decision taking process and diagnostics of the hemodynamic response to mental stress testing. Using ambulatory blood pressure monitoring signal, Data Mining algorithm determined the five types of hemodynamic reactions, including hyperactivity, hypertensive and atypical reaction, accompanied by a significant decrease in pulse pressure has been offered. The proposed classification of the hemodynamics can be used to detect abnormalities of hemodynamics and cardiovascular system, as well as increased risk of arterial hypertension.

PACS numbers: 47.63.Cb, 87.19.ug, 87.19.uj
Keywords: Data Mining, Classification and Regression Tree, mental stress testing, '7±2' test, Stroop color test, information test, ambulatory blood pressure monitoring

1. Introduction

The blood pressure levels and the heart rate are directly affected by psychological stress during daily routine activity. Alterations of the cardiac autonomic response to stress may therefore have a cardiovascular prognostic value. Psycho-emotional or mental stress testing in clinical practice provides the possibility to investigate the stress reaction of the patients, because such reaction is able to identify a number of cardiovascular diseases [1, 2], psychopathic diseases [3], and early functional hemodynamic disturbances, including increased risk of the arterial hypertension (AH) [4]. The prospective clinical studies showed, that the patients with the cardiovascular hyperactivity (overlarge increment of blood pressure in a stressful situation) have high risk of developing hypertension compared to patients with normal reactivity [4]. Psycho-emotional stress causes an increase in blood pressure (BP) and changes in QT-interval on the electrocardiogram [1] in patients with myocardial infarction and ventricular fibrillation, also it causes the increasing the concentration of a number of stress hormones [5].

Systolic blood pressure (SBP) is the pressure in the arteries at the systole phase (contraction of the heart), and its value depends of the myocardium state. Diastolic blood pressure (DBP) is the pressure at the time of heart relaxation (diastole), and DBP is determined by the tone and elasticity of the vessels. The difference between SBP and DBP is called the pulse pressure, which increase or decrease is an important and reliable predictor of cardiovascular diseases.

There are many mental stress tests used in laboratory setting: a mental arithmetic in front of an audience [3], interviewing or free speech, modeling an exam situation [4, 5], and tests with the use of special tables and computer equipment. Last of them are information test [6], '7±2' test [7, 8] or Stroop color test [9], which use the videogame challenges to create a psycho-emotional stress, denoted by increased BP level

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and heart rate. Information test evokes the mental stress by directive to intercept the mobile tags in the interactive videogame [6], Stroop test induces the stress in laboratory routine, where a subject is presented the words, which font color does not coincide with the color, defined by the word [9]. The protocol of '7±2' test implies a presentation to the subjects the visual information in the form of simple graphic elements [7, 8]. Participants were asked to remember and repeat as much as possible of 10 graphic elements during 5 min task, then the patients rested for 5 min in a quiet room.

The aim of a mental stress testing is to estimate the increment of patient's BP during and after the standardized tasks of perception and processing of visual information. The sustained psychological stress resulting in sympathetic activation and parasympathetic inhibition, that manifest the alterations in heart rate and BP level. These alterations are compared with baseline values in accordance with a stress disorder scale for SBP and DBP.

According to the patient's BP dynamics during the mental stress test, 3 classes of the cardiac response to mental stress in patient are defined: 1st class (normal reaction) – increased BP values during the tasks (no more than 15 $mmHg$ for SBP and 10 $mmHg$ for DBP), then BP parameters return to their initial values at recovery time; 2nd class (hyperactivity) – increased BP values during the tasks (more than 15-20 $mmHg$ for SBP and 10–15 $mmHg$ for DBP), BP parameters return to their initial values at recovery time; 3rd class (hypertensive reaction) – increased BP values (more than 20 $mmHg$ for SBP and 15 $mmHg$ for DBP), no return to initial BP values at recovery time.

Thus, according to the results of the provoked stress it is possible to detect early occurrence of the hypertension (2nd class) or hypertension of I or II degree (3rd class). It should be noted that another studies determine hyperactive or hypertensive reactions at 35/21 $mmHg$ threshold of SBP/DBP increment [4].

Nowadays numerous of the traditional mathematical and statistical methods can be used for the medical data processing. These methods provide useful clinical information based on the preformulated hypotheses, but the tools are time-consuming and require an assistance of the trained medical expert. There are new scientific methods and specialized tools, such as Data Mining, that analyze the medical data more accurately and efficiently [11–13]. Data Mining, an interdisciplinary computer science, is the computational process of analysis, discovering information and conclusions on the basis of data set, it can be used for decision support in medicine, post-processing of discovered structures, visualization, and online updating.

In the presented article we employed Classification and Regression Tree for automatic diagnostics of the hemodynamic response to mental stress using BP recordings of 165 healthy individuals and patients with arterial hypertension (AH) performed the '7±2' test. Classification and Regression Tree is one of the most popular classification algorithm in Data Mining and Machine Learning [14, 15]. It is based on Boolean logic rules, can be combined with other statistical tests and effective even with little or raw data.

2. Materials and methods

The mental stress testing is consisted of the measuring the baseline BP and heart rate during the stress testing and recovery time period. Thus, a time series of 7 pairs of the systolic and diastolic BP was obtained, wherein the first pair of values is the initial measurement of SBP and DBP, 2-4 pairs are the BP measurements during the stress testing at 1, 3, 5th min and 5-7 pairs in the time series are the BP at the 1, 3, 5th min of the stress-test recovery time.

120 healthy young adults (normal, first group) and 45 untreated mildly hypertensive participants with grade I or II arterial hypertension (AH, second group) were enrolled in the '7±2' stress testing. Using the database of the 165 subjects, we have created

a Classification and Regression Tree-based classifier for functional classification of the patient's circulatory reactivity.

In addition, we have analyzed the database of the control group of 37 healthy participants, which performed sequentially in different days three protocol-identical psycho-emotional tests - information test, Stroop color test, and '7±2' test.

3. Analysis of the cardiovascular response using Classification and Regression Tree

The goal of Classification and Regression Tree is to create a model that predicts the target variables by learning decision rules inferred from the data features. Classification and Regression Tree builds classification in the form of a tree structure with decision node of few branches and leaf nodes, represented a classification or decision. Decision node is a set of attributes that distinguish the subjects for classification (in our case, a subject is a time series of 7 pairs of the consecutive BP measurements according to the protocol of the stress test). Leaf nodes are the categorical data for estimation the cardiovascular response of a patient. To classify the results of the patient's mental stress test of 14 BP measurements, it is necessary to down from the decision node to the leaf nodes (three known functional classes of the cardiovascular response to stress).

Classification problem was solved in two stages: first, creating a set of decision rules of Classification Tree, trained on the set of labeled BP records; second, once trained, the tree automatically assigns a class label, when presented with the unknown ambulatory BP record, thus providing a hemodynamic diagnosis (Fig.1). During the training process the Classification Tree algorithm finds the most efficient splitting into child nodes with the largest reduction in the Gini Index, evaluated the "distance" between the classes of the cardiac response to mental stress.

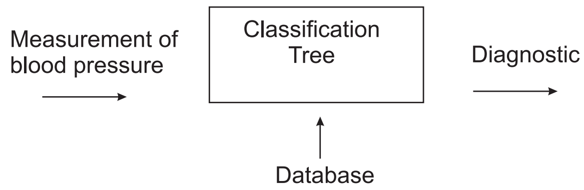

FIG. 1. Diagnostics of the cardiovascular response of the patient.

Statistics for database of 165 patients was as follows. 35 of the 165 patients had increased baseline BP (systolic $BP > 140$ $mmHg$ or diastolic $BP > 90$ $mmHg$), including 4 subjects among 120 healthy patients. 14 of 45 patients with untreated AH had normal initial values of BP, 26 of them also demonstrated a normal reaction on the mental stress, including 2 subjects, which had a negative growth of BP during the stress testing (see Table 1). Similarly for the 120 healthy patients: 97 subjects had a normal reaction to stress test, 20 of them demonstrated a negative increment of BP, and 23 had a hyperactive response to stress. Hypertensive relaxation (heightened BP during recovery time period) was in 19 and 17 patients of the healthy group or hypertensive group, respectively.

To classify the BP recordings, it is necessary to answer some questions that describe the different nodes of the Classification Tree. The first node is the representation for normal baseline BP or hypertensive BP (SBP>140 $mmHg$ and/or DBP>90 $mmHg$). Another nodes are defined by the rules, imposed on measurements of BP during psycho-emotional testing on 1st, 3rd and 5th minutes (2-4 pairs of patient's BP measurements in our database): "Mild and fast increment of the BP" (less than 15 $mmHg$ for SBP and less than 10 $mmHg$ for DBP), "Atypical increment of the BP (reduction of the SBP, but increment of the DBP during testing), "Moderate and fast increment of the BP" (15-20/10-15 $mmHg$ increment of the SBP/DBP), and "Delayed and large-scale increment of the SBP/DBP".

Table 1. Increment and recovery of the BP level in groups 1 and 2 (n is a number of patients) for '7±2' stress test.

Group	Baseline BP, n		BP reaction on stress, n		BP at recovery period, n	
	normal	hypertensive	normal	hypertensive	normal	hypertensive
1, $n = 120$	116	4	97	23	101	19
2, $n = 45$	14	31	26	19	28	17

Thus we can define a reaction on psycho-emotional stress: normal reaction, hyperactive or hypertensive reaction.

The further top-down induction at Classification Tree is accompanied by logical conditions for BP measurements during recovery time period at 1st, 3rd and 5th min of relaxation (5-7 pairs of patient's BP measurements in our database): "Return of the BP to baseline values" and "No decrease of the BP during recovery time period". As protocols of BP measurements suppose the 3-fold or 2-fold measurements of the BP during 5-min period, it is convenient to use the average value of SBP and DBP during recovery time. This assumption allows to define the BP dynamics and to minimize the natural fluctuations of the BP. As a result of Classification Tree discrimination for the BP records, we create a model that predicts the classes of the cardiac response to mental stress based on input BP measurement: 1st class corresponds to normal reaction to psycho-emotional loading, 2nd class associates with the boundary hypertension or neurocirculatory dystonia, and 3rd class is characterized by hypertensive reaction, corresponded to hypertension of I or II degrees.

4. Results

Proposed Classification Tree divides the patients into five classes of cardiac response to psycho-emotional stress, three of them are known classes (normal reaction, hyperactivity, hypertensive reaction). As a result of Classification Tree optimizing by reduced error pruning, two additional classes of functional reactivity has been defined. 4th class represents patients with normal hemodynamic reaction on mental stress, but with hypertensive relaxation (average increment of SBP and/or $DBP > 5$ $mmHg$), and 5th class consists of patients with atypical response to stress defining the decrease in SBP, but increase in DBP. This class is characterized by minimization of the cardiac output and a slight change in the patient's heart rate during stress test. The detail description of classification in first and second groups is given in Table 2.

As noted above, 1st class means a normal reaction to mental stress, 2nd class corresponds to the border hypertension, and 3rd class is characterized by a hypertensive reaction. Proposed 4th class with a normal reaction on stress and hypertensive relaxation is also a manifestation of neurocirculatory dystonia due to a patient's lack of adaptation to the stress. This particular reaction may cause the persistent changes in the pressure level in the next years [4]. We identified patients with a significant reduction (more than 20 $mmHg$) of the pulse pressure W in separate 5th class due to an atypical response to mental stress. The difference between systolic and diastolic pressure is called pulse pressure W (by the definition: $W = SBP - DBP$). The normal pulse pressure is about 30–40 $mmHg$, so the reduction of W indicates on decrease in stroke volume and it is representative in a number of cardiovascular diseases.

As training set method was used as the test mode, the confusion matrix of Classification Tree tells that there were 5 samples in 5th class, but

Table 2. Classification of cardiac response to mental stress in 1, 2 groups (n is a number of patients), '7±2' test.

Group	hemodynamic reaction				
	normal	hypertensive	hypertensive	hypertensive relaxation	atypical
1, $n = 120$	59	13	30	14	4
2, $n = 45$	7	5	24	8	1

Table 3: Classification of cardiac response to mental stress in control group ($n = 37$ patients), three tests.

Group n=37, test	hemodynamic reaction				
	normal	hypertensive	hypertensive	hypertensive relaxation	atypical
information	18	1	3	13	2
Stroop	14	0	2	21	0
'7 ± 2'	17	3	6	11	0

only one BP record was classified incorrectly as atypical response instead of normal reaction on mental stress. Such misclassification is explained by small sampling of the training set (5 samples of 165). Other samples were classified correctly.

Proposed classifier based on the Classification Tree was tested in a control group of 37 healthy subjects performed three protocol-identical tests: information test, Stroop and '7±2' tests (Table 3).

The results of these tests showed the comparable results, taking into account the variability of BP parameters of the patients at different days. Three samples were misclassified in 2nd, 3rd and 5th classes. Thus, we can assume the universality of Classification Tree for psycho-emotional tests with the similar protocols (5 min series of BP measurements during the testing and resting periods).

5. Conclusion

In the paper we present new Classification and Regression Tree algorithm for the real medical problem of correlation between the mental stress and the monitored BP signals. Decision about the hemodynamic response to mental stress is made on the base of features extracted from the BP time series and general information only. During the training process, the Classification Tree algorithm finds the most efficient splitting into nodes with the largest reduction in the Gini Index evaluated the difference between the classes of the cardiovascular response. Classification Tree cocnstructed is able to distinguish five classes of circulation reactivity of the patients, which include normal response to mental stress, hyperactivity and hypertensive reaction, as well as normal response to stress with hypertensive relaxation, and atypical reaction with decreasing SBP and increasing DBP level. We assume that normal stress reaction and hypertensive relaxation is a manifestation of neurocirculatory dystonia due to a patient's lack of adaptation to stress, and atypical response to stress is a symptom of latent circulatory problems or cardiovascular diseases.

Therefore, this work confirms the potential of signal processing and machine learning algorithms to differentiate pathological reactions in hemodynamics, ascertainment of early functional disorders, including increased risk of hypertension. Classification and Regression Tree achieved the highest level of success in identifying the cardiovascular response to mental stress.

Advantages of the proposed method make it attractive for a wide range of applications in clinical medicine, which might significantly improve the quality of treatment that the clinician can provide the patients.

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