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An Approach to Evaluation of Clinically Healthy People by Preventive Cardio Control

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Abstract**:** *This article presents the main algorithms and the methodology for the development of the evaluation criteria and the results of the work of the program environment developed for evaluation and analysis of the electrocardiographic signals in the preventive control of clinically healthy people after emotional or physical stress for the purpose of diagnosing of current disorders in the cardiac activity. The presented structure combines a new approach to building an electronic system for assessing individual medical information from the real life of healthy people and a specific method for analyzing the results. The purpose of preventive control is to preserve human health through early and timely assessment of its current health status.*

Keywords**:** *ECG, algorithm, criteria, evaluation, analysis, preventive control.*

1. Introduction

The electronic processing and analysis of electrocardiographic signals are one of the most advanced computer procedures for diagnosing heart disease. Despite the considerable variety of mathematical, statistical, and computer-based methods for processing electrocardiographic information, search and improvement of methods of analysis and diagnostics remains a priority in the development of medical science.

Cardiovascular diseases are among the most common diseases leading to a letal outcome for the patient. Data published by the National Center for Health Information at the Ministry of Health reveal alarming statistical data on cardiovascular diseases in Bulgaria – 66% of the total mortality. Patients with heart problems represent the largest group of diseases in Bulgaria and this determines the focus of the study on this type of change and puts the need for preventive measures by developing methods for evaluation and diagnosis of electrocardiographic signals.

In healthy people in rest, heart rate is not a constant and there are uneven changes in the duration of individual fragments of the electrocardiographic curve. For this reason, the use of traditional algorithms to avert heart cycles in the temporal area results in blurring of the informative fragments, resulting in inaccuracies in their measurement meanings.

The morphological analysis of the electrocardiographic curve is limited to assessing the polarity, amplitude, duration, and shape of the characteristic electrocardiographic segments. Pre-hospital check-ups are carried out in outpatient care, but they are reduced to one or two examinations per year, which is extremely insufficient for prevention and does not give the general picture of the individual. There are risky situations in which people are undergoing severe stress as well as situations where the momentum out of the rhythm leads to serious health disorders and illnesses. At such times, the availability of a cross-sectional analysis system will provide a response and direction for subsequent treatment [6, 8].

Combining a new approach to building an electronic system for assessing individual medical information of healthy people and a specific method of analysis of results is the basis of the proposed preventive control algorithms to preserve health through early and timely assessment of their current status.

The aim of the article is to present the methodology for the evaluation criteria, the algorithms of the developed program system, the results of its work and the analysis of the electrocardiographic signals in the preventive control of clinically healthy people after emotional or physical exercise for determining of the current cardiac abnormalities.

2. Methodology

Most informative parameters for the study of people in preventive control are rhythm analysis on the ElectroCardioGram (ECG) and ElectroDermal Activity measurement (EDA). Rhythmic analysis consists of recognizing the heart abnormalities and distinguishing them from normal QRS complexes (a professional term concerning the readings of an ECG) and extrasystoles [1, 3].

The most common physiological processes are three: excessive excitement, muscle tension, and electrodermal activity. Electrodermal activity in the human body leads to a constant change in the electrical characteristics of the skin. The autonomic nervous system registers excitement, involuntary wobbling (sympathetic), then increases the sweat gland activity and this leads to an increase in skin conductivity – a measure of emotion and assessment of the sympathetic nervous system response. By registering signals through an electronic system, the relationship between emotional state and sympathetic activity is tracked without identifying specific types of emotion or stress.

The methods used for analysis [4, 5, 10] include: (i) *method by phase intervals* – the ECG signal processing in the frequency domain; (ii) *phase trajectory method* – the behavior of the dynamic systems by phase portrait is studied, the analysis is carried out in the phase plane and the shape and deviations of the individual fragments in the ECG signal which are usually not reflected in the temporal field; (iii) *detection of QRS complex* – this is done by the Docinsky method [2] by determining the first derivative of the selected ECG signal output, forming differences between discrete spaces separated apart and their comparison by character and amplitude versus standard deviation with a minimum value of 0.2 mV and maximum 1.6 mV; (iiii) *modeling an ECG signal* – the single period of each ECG signal is considered to be composed of triangular and sinusoidal waves, each function of the ECG signal being represented by shifted and scaled waves.

3. Algorithms

The analysis of the ECG curve of a healthy person is made from the physiology of his cardiac activity at various exertions to derive potential risks for pathological alterations. The developed algorithms and programming environment are the basis for building software to an electronic system for assessing the individual ECG information of healthy people from their daily lives to provide preventive control and analysis of results.

Algorithm 1. Graphics module for evaluation of ECG signal

Preventive control aims at early and timely assessment of the momentum of people. – Algorithm 1 depicted in Fig. 1 encompasses the graphical part of the program environment for analyzing ECG signals. The input parameter is a file record with current medical information.

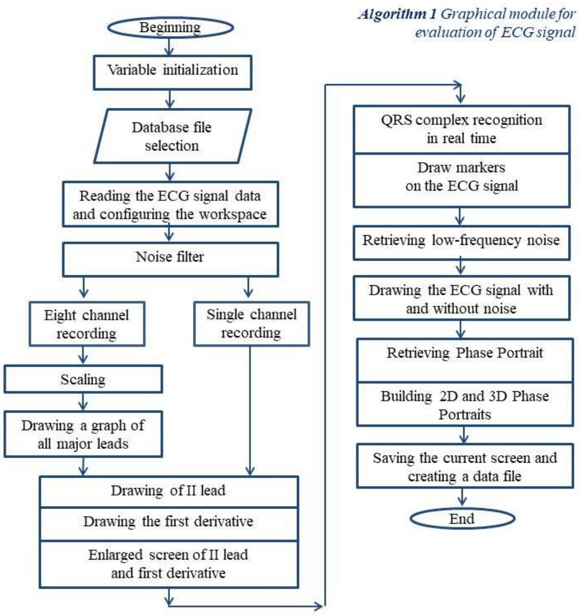


Fig. 1. Algorithm 1: Graphical module for evaluation of ECG signal

Recognition of the file system and the medical record is automated and the software module evaluates multi-channel recording (medical ECGs) and single-channel recording (from ECG signal or instantaneous ECG signal simulation).

After applying the operations described in the Methodology a phase portrait is drawn for the particular medical record, which allows with high precision to assess the shape of the individual fragments in the cardiogram and to eliminate the deviations that are not usually seen in the temporal area. Output data for the algorithm are screen windows after each analysis and file with signal parameters.

Algorithm 2. Analysis and evaluation of ECG signals

Algorithm 2 presented in Fig. 2 gives the basic structure of the program environment and the links to the individual substructures. It is possible to work with a database containing ECG signals of people subjected to different emotional or physical load for the diagnosis of heart disorders. Some keywords are assigned to recognize the load applied. An option for manual input or data correction is also provided for flexibility in research.

The ECG signal [10] is modeled on the obtained parameters and the type of cardiogram is plotted at the respective load. On the basis of the proposed Algorithm 4, the signal is analyzed according to the medical literature and the occurring momentary deviations from the norm, if available. After recording the received data, the ECG signal is analyzed and evaluated according to the established preventive control criteria in Algorithm 3. On the basis of the nine indicators, the current status or the temporary risk for change of single indicators from the cardiovascular system is evaluated. The evaluation of each of them individually or in a group gives the direction to analyze the possibility of future pathological changes.

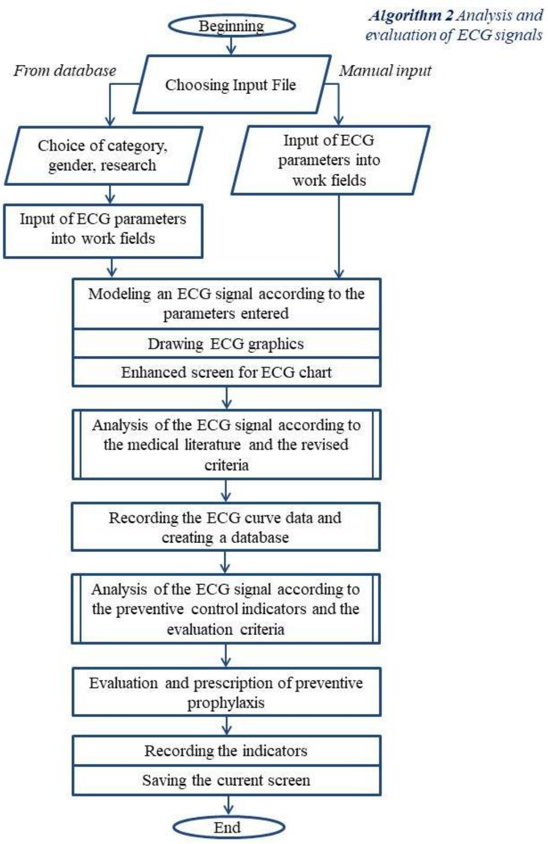
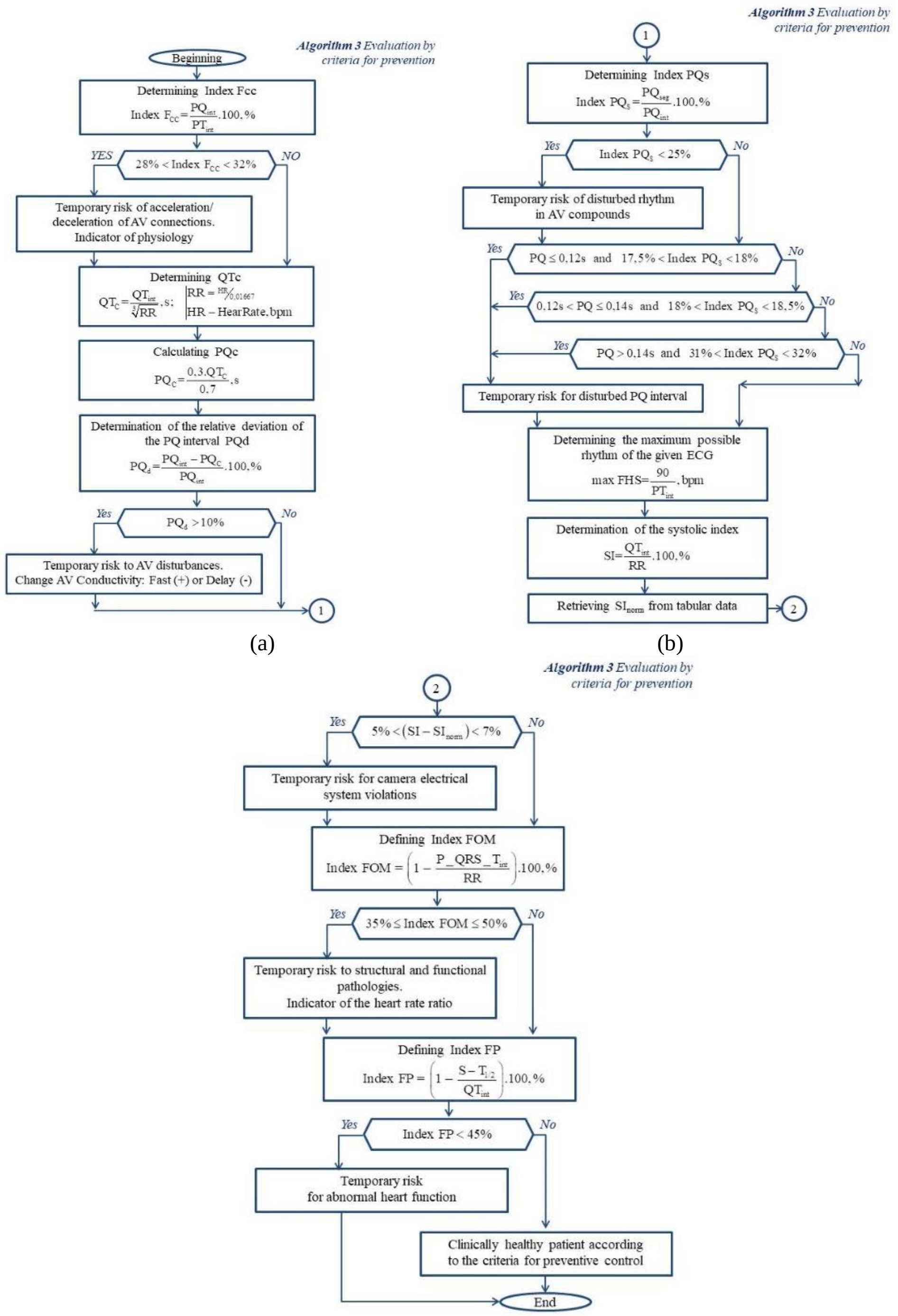


Fig. 2. Algorithm 2: Analysis and evaluation of ECG signals

Algorithm 3. Evaluation by criteria for prevention

Algorithm 3 presented in Fig. 3 contains the main nine criteria and indicators for evaluating the ECG signal.



(a) (b)

(c)

Fig. 3. Algorithm 3: Evaluation by criteria for prevention

The described indices evaluate in digital form the changes of the heart rhythm at different loads.

The mechanism of contraction of the heart is unique to every person. In the process of increasing the heart rate, the time of all components of the electrocardiogram ECG – intervals PQ, QT, PT, PQ, ST, TP segments, is shortened. With the increase in heart rate, the heart may fall into the risk zone of rhythm disturbance due to the hemodynamic conflict between the systoles of the atrium and the ventricles. This feature is associated primarily with the disruption of the AV connection itself and the most frequent cause of such is functional factors. To do this, it is necessary to diagnose the disruption of the AV connection, and to correct certain actions, prevent heart disorders [7, 9].

To judge the physiology of the processes of cardiac contraction and the work of AV compound, the Fcc index, which lies in the range of 28-32%, allows one to estimate. When the pulse is accelerated into the ventricles of the heart, the proportion of the PQ interval in the total systole of the heart decreases below 28%, and when the conduction slows down, the proportion of the PQ interval rises above 32% or more. The Fcc index is a sensitive tool for diagnosing this pathology and, above all, AV connection pathology. For differential diagnosis of localization and the nature of pathology, the comparison between the proper and actual intervals of PQ and QT is used.

The deviation of the proper PQ interval from the actual more than 10% indicates a violation of the AV connection and requires the prevention of such a violation. The significance of the relative PQ interval was comparable to the risk of tachycardia rhythm disturbances – up 15%.

Evaluate the severity of the risk of tachycardia rhythm disturbances by comparing the PQs index. Index PQs shows the criterion for evaluating the rightness of work and AV risks. Such ECG values characterize more the individual values of the normal ECG, when the frequency of the shortening of the PQ interval is high and, without using the PQs index, it is difficult to distinguish the norm from the pathology.

In the medical literature, it is recommended that the PQ interval to be within certain limits, and according to them, to display the status of healthy people under preventive control.

The Max FHS index gives the maximum possible heart rate at which the heart can develop without the individual's load for the given situation. The obligatory PQc interval is the individual standard of each PQ interval of the specific subject with specific cardiac rhythm needed to detect the initial disorders of AV compounds. The PQs index is an indicator characterizing the presence or absence of risk for rhythm disturbances during tachycardia.

The FP (plateau) index is an indicator allowing to identify the signs of a heart failure impairment. The FOM index (Phase I Myocardial Rest) is an indicator for assessing the physiology of the heartbeat phases – the systole/diastole. The Fsc index is an indicator of the physiology of the heart systole that characterizes the condition and performance of the AV node and myocardium.

The resulting heart rate information allows a qualitative, independent of the subjective factor assessment of heart performance, provides information to prevent future pathological abnormalities, provides control of the cardiac fitness for a healthy life of the average person.

Algorithm 4. Assessment by Medical Criteria

In the medical literature, S. Marchev [11] through an analytical approach, describes the practices and details of human electrocardiogram reading. The proposed Algorithm 4 (Fig. 4) follows these practices, and the individual stages of the study are arranged in the steps performed by medical professionals in the reading of an electrocardiogram.

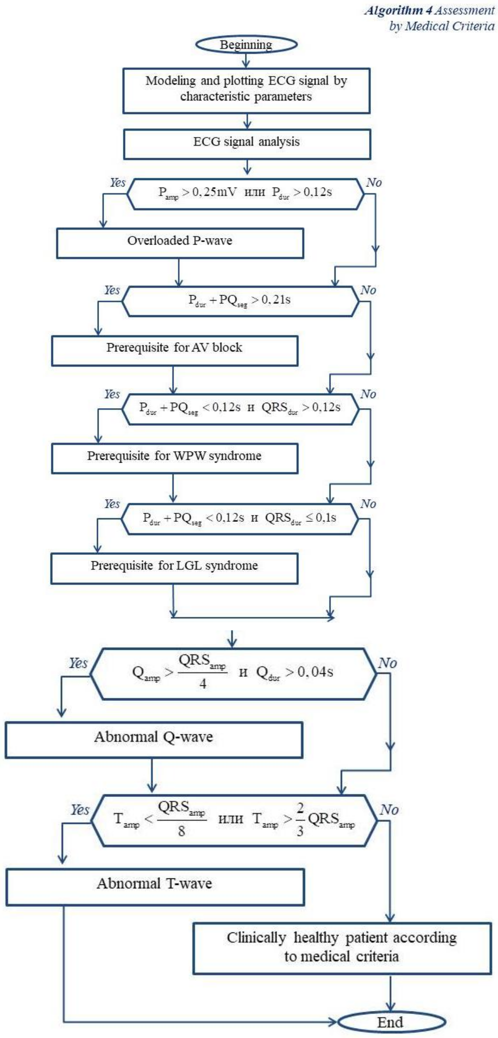


Fig. 4. Algorithm 4: Assessment by Medical Criteria

The sequence of steps tracks precisely the way a specialist's eye passes when reading an electrocardiogram. Of course, cardiologists include, in the analysis, “informal” subjective decisions, taking into account the overall clinical picture and relying on their accumulated experience.

The results of the implementation of Algorithm 4 give the control group parameters to perform the in-depth analysis of ECG signals as well as to compare the medical assessment and the prevention.

The analysis begins with the determination of one of the major waves in the cardiogram – the P wave. It is normally sinusoidal (positive or isoelectric) and has amplitude up to 0.25 mV and duration up to 0.12 s. Lower amplitude limits and duration are of no clinical significance.

The PQ interval is measured from the beginning of the P-wave to the beginning of the Q-tooth or, in the absence of one, to the beginning of the R-tooth. Therefore, the PR interval is determined due to the atrioventricular (AV) node, which slows down the procedure to shorten the atrium first and to fill the chambers, and then cut the chambers.

The AV node itself is too small (several millimeters), its excitation is not recorded on the usual electrocardiograms, and therefore, after the end of the P-wave, the ECG line goes up the zero line to the start of the QRS complex.

Typically, II is diagnosed and the algorithms are used in the analysis. Normally, the PQ interval ranges from 0.12 up to 0.2 s. If it is over 0.2 s, an AV block is suggested. When it is below 0.12 s, there are two possibilities: WPW syndrome or LGL syndrome, distinguishable by the duration of the QRS complex. If the QRS complex is wider than its standard of 0.1 s, it is a prerequisite for WPW syndrome and, if normal, its duration is LGL syndrome.The normal duration of the QRS complex is up to 0.1 s. Over a duration of 0.1 s, the QRS complex is pathologically expanded.

The T-wave should normally have a more sloping upward shoulder and more steeply downward, i.e., is not symmetrical. It becomes symmetrical in certain diseases. The normal amplitude of the T-wave is bound to the QRS complex and must be outside the range (0.125 ... 0.667)×QRS.4.

4. Results and discussion

4.1. Test studies on the ECG signal in the preventive control

Figs 5 and 6 show the developed HMI dialog interfaces of the simulation module and the ECG signal analysis module on individual medical data of a healthy person in preventive control. They are built on Algorithm 2, Algorithm 3 and Algorithm 4 in the developed programming environment.

The results show that the assessment of a clinically healthy person assessed on the medical criteria (Fig. 5) is not a sufficient factor for the analysis of the current state of the studies. According to the Preventive Control Criteria (Fig. 6), there is currently a prerequisite for tachycardia rhythm disturbances (PQs Index) and mismatch relaxation phase (FOM Index). These indices and evaluation should be refined for a longer interval of time at the same condition, and a cardiac assessment by a specialist.

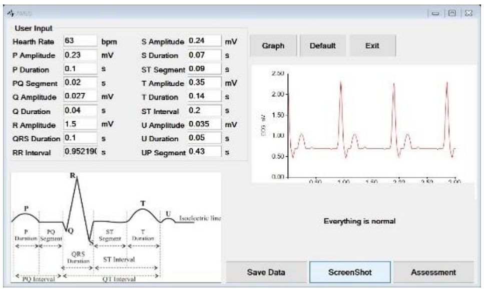


Fig. 5. ECG signal simulation program

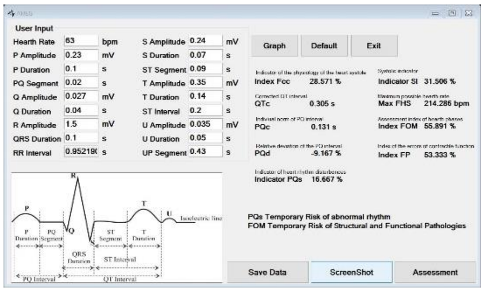


Fig. 6. ECG signal analysis program

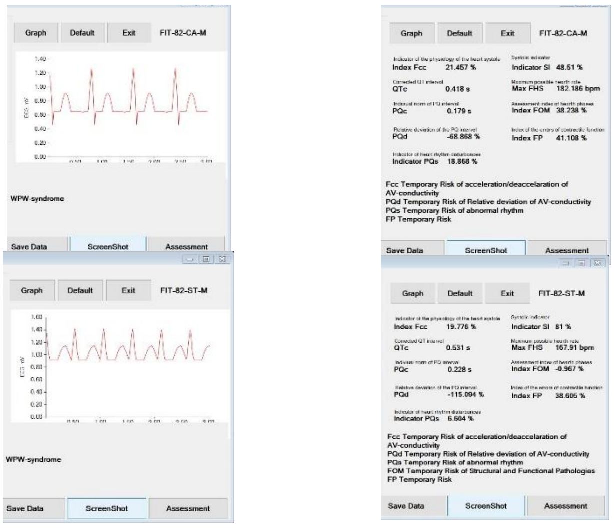
Table 1. Experimental results from field studies

№	Name	HR	RR Interval	P Duration	PQ Segment	PQ Interval	QRS Duration	ST Segment	T Duration	ST Interval	TP Segment	QT Interval	PT Interval	P Amplitude	Q Amplitude	R Amplitude	S Amplitude	T Amplitude
		bpm	s	s	s	s	s	s	s	s	s	s	s	mV	mV	mV	mV	mV
3	DAN-91-CA-F	97	0.629	0.126	0.013	0.132	0.113	0.086	0.232	0.278	0.046	0.377	0.517	0.07	0.06	0.39	0.08	0.14
4	DAN-91-ST-F	157	0.371	0.126	0.079	0.219	0.093	0.013	0.152	0.199	0.013	0.305	0.49	0.15	0.15	0.21	0.21	0.1
5	DAN-92-CA-F	87	0.801	0.099	0.02	0.166	0.132	0.04	0.172	0.258	0.066	0.391	0.497	0.06	-0.01	0.33	0.03	0.01
6	DAN-92-ST-F	111	0.51	0.146	0.007	0.146	0.166	0.046	0.152	0.225	0.033	0.331	0.477	0.04	0.03	0.23	0.15	0.17
7	EX-63-ST-M	80	0.715	0.126	0.007	0.159	0.146	0.093	0.166	0.212	0.06	0.391	0.543	0.06	0.01	0.53	0.01	0.26
8	EX-63-CA-M	79	0.768	0.126	0.046	0.185	0.106	0.026	0.225	0.331	0.06	0.49	0.543	0.05	0.01	0.31	0.07	0.23
9	EX-64-ST-F	101	0.616	0.093	0.02	0.086	0.093	0.06	0.119	0.252	0.073	0.338	0.337	0.01	0.01	0.15	0.03	0.1
10	EX-64-CA-F	84	0.682	0.106	0.053	0.159	0.086	0.04	0.219	0.272	0.073	0.391	0.51	0.04	-0.01	0.24	-0.02	0.08
13	FIT-82-CA-M	75	0.808	0.086	0.02	0.119	0.126	0.06	0.199	0.262	0.106	0.404	0.523	0.07	0.02	0.57	0.22	0.26
14	FIT-82-ST-M	113	0.543	0.099	0.007	0.139	0.139	0.04	0.252	0.291	0.06	0.417	0.55	0.08	-0.02	0.43	0.06	0.22
15	FIT-83-CA-F	83	0.722	0.106	0.007	0.106	0.152	0.046	0.199	0.252	0.119	0.384	0.45	0.04	-0.02	0.23	0.11	0.23
16	FIT-83-ST-F	135	0.464	0.066	0.04	0.172	0.093	0.026	0.238	0.285	0.033	0.391	0.503	0.06	-0.02	0.31	0.03	0.24
21	TIN-78-CA-F	78	0.728	0.093	0.007	0.106	0.113	0.046	0.291	0.384	0.033	0.497	0.556	0.03	0.02	0.04	0.15	0.15
22	TIN-78-ST-F	128	0.45	0.066	0.007	0.073	0.106	0.06	0.179	0.219	0.033	0.318	0.457	0.07	-0.02	0.16	0.17	0.15
23	TIN-79-CA-F	112	0.536	0.146	0.013	0.179	0.132	0.073	0.152	0.238	0.046	0.331	0.503	0.03	0.02	0.25	0.02	0.04
24	TIN-79-ST-F	64	0.894	0.079	0.026	0.086	0.132	0.06	0.192	0.219	0.026	0.384	0.57	0.06	-0.01	0.44	-0.04	0.16
25	AU-22-CA-M	87	0.788	0.086	0.007	0.106	0.146	0.04	0.192	0.278	0.026	0.391	0.497	0.05	0.05	0.39	0.25	0.23
26	AU-22-ST-M	75	0.715	0.106	0.013	0.1203	0.139	0.053	0.132	0.185	0.04	0.258	0.404	0.08	0.01	0.58	0.09	0.04
27	AU-23-CA-F	78	0.735	0.073	0.007	0.099	0.106	0.026	0.172	0.199	0.04	0.338	0.477	0.09	-0.03	0.54	0.18	0.29
28	AU-23-ST-F	88	0.810	0.086	0.007	0.099	0.146	0.066	0.225	0.291	0.046	0.377	0.503	0.01	0.15	0.58	0.23	0.21

In 2017 and 2018 on the territory of the University of Ruse (laboratories, terrains and fitness and sports hall) and the city swimming pool were conducted studies of healthy people in five different categories of physical stress and stress:

- AU Emotional driving when driving in extreme winter conditions. The study is done before and after crossing an icy stretch into a sharp turn. Age group – 18-45 years old. The test group was tested under the same initial conditions.
- DAN Physical workload for a professional folk dance group. The study was done before and after one hour of active workload. Age group – 16-60 years old. The test group was tested under the same initial conditions.
- EX Emotional workload for a group of students during the exam. The test is done before the test is set and after the exam is completed. Age group – 18-24 years old. The test group was tested under the same initial conditions.
- FIT Physical load in the gym in groups active and inactive athletes. Age group – 18 to 55 years old. The test group was tested under the same initial conditions.
- TIN Physical and emotional load during a swimming competition in an outdoor pool. Age group – 12-18 years old. The test group was tested under the same initial conditions.

The obtained data from the conducted studies are summarized in Table 1 by categories, in two states – normal and stress. For each category, there are two surveyed sites for different age groups (Fig. 7, Fig. 8).



Calm Stress Calm Stress

(a) (b)

Fig. 7. Experimental ECG data in Calm and Stress for FIT group studied: (a) analysis during medical criteria; (b) analysis during preventive control criteria

Calm Stress Calm Stress

(a) (b)

Fig. 8. Experimental ECG data in Calm and Stress for DAN group studied: (a) analysis during medical criteria; (b) analysis during preventive control criteria

4.2. Test graphical examinations of ECG signals

In the Laboratory of Medical Electronics of the Department of Electronics using CARDIOSIM II ECG Arrhythmia simulator and ECG Implementation of the TMS320C5515, Texas Instruments, research and analysis of the ECG signal of myocarditis with cardiac symptomatology was performed: premature ventricular contraction, ventricular fibrillation and normal pulse with premature ventricular contractions. The results obtained are analyzed and visualized through the developed AMEG graphical interface implemented under Algorithm 1.

Fig. 9. ECG signal myocardia

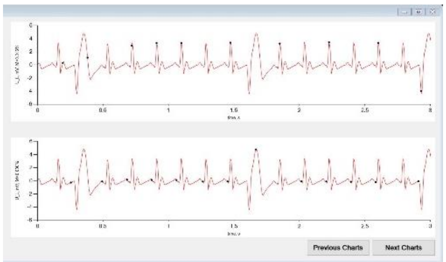


Fig. 10. ECG signal myocardia with recognized QRS complexes

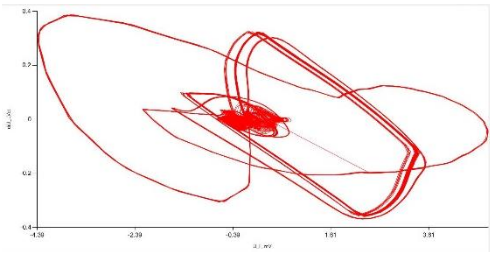


Fig. 11. Phase portrait of ECG signal myocardia

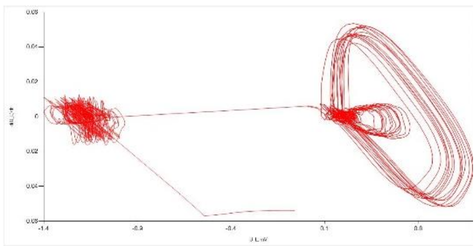
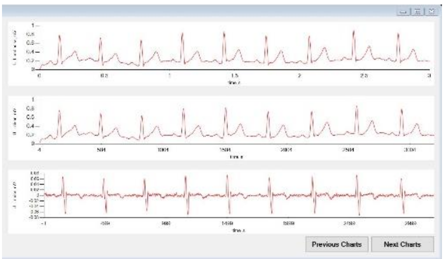
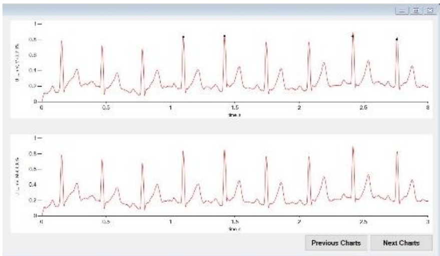


Fig. 12. Phase portrait of the ECG signal e0116



(a)



(b)

Fig. 13. ECG signal is 0116: First derivative and extracted noise (a);
with recognized QRS complexes (b)

The signals are tracked over a time interval with the purpose of repeatability of the individual symptom indicators and their localization. The sampling rate of the ADC is 500 Hz, the resolution is 4.88 μV. The analysis and study of the specificities of the individual parts of the ECG signal were taken into account in the changes made to the individual structures. The results are shown in Figs 9 and 10. Fig. 11 shows the phase portrait of the signal. The analysis clearly highlights the characteristic shake of the ECG fragments.

In the testing of the developed programming environment, we have also used Internet specialized databases – European ST-T Database, BIDMC Congestive Heart Failure Database and MIT-BIH Arrhythmia database. From the bases was selected patient e0116, age 47, sex M, resting angina, normal coronary arteries. Some of the results for e0116 are shown in Figs 12 and 13. The phase portrait of the signal outlines the apparent uniformity (of Fig. 13a) of the ECG fragments but at the same time gives the anomaly zone.

5. Conclusion

Criteria for evaluation of electrocardiographic signals in preventive control were developed to obtain an instant assessment of the condition of clinically healthy people.

The presented basic algorithms, a methodology for establishing criteria for assessment and analysis of electrocardiographic signals in preventive control, allow quantitative indicators to evaluate the emotional or physical load of clinically healthy people in order to diagnose current cardiac abnormalities.

The ability to develop a program environment is proven by the study of five different groups of healthy people who have not undergone medical treatment. The resulting quantification is a combination of nine indicators and shows the respective areas of cardiac load. This assessment should be used in a more detailed medical analysis by specialists.

The presented program structure combines a new approach to building an electronic system for assessing individual medical information from the daily life of healthy people and a specific method for analyzing the results.

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