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L. Fritzsche


M. Fritzsche


D. Majoe

OPTIMI (Online Predicative Tools for Intervention in Mental Illness) OPTIMI ECG sensor as a measurement tool for signs of stress and poor coping in high risk individuals

L. Fritzsche[1, 2], M. Fritzsche[1, 2], D. Majoe[1]
[1] ETH Zürich, Department of Computer Science Institute of Computer Systems
[2] Practice of Internal Medicine, Switzerland

Summary. Many researchers believe that depression is the outcome of a pathogenic combination between external stress and poor coping. Based on this hypothesis, the OPTIMI project is aimed to develop automated tools for the detection and characterization of poor coping. The current article is focused on the ECG sensor. The article will inform about the preliminary conclusions and results the experts have extracted from the data collected in the calibration trial in order to identify patterns and indicators related to stress and coping.

Key words: ECG sensor, HR, HRV, stress, high risk, coping.

The use of technology for the promotion of self-driven psychological wellbeing has grown exponentially in recent years, and the Internet can be used for the delivery of psycho-education and therapies such as cognitive behaviour therapy (CBT) to promote mental health and wellbeing [1] It has been established that so-called 'e-therapies' can be effective and acceptable [2; 3] and cost effective [4] in the treatment of a wide variety of psychological problems, including stress among otherwise healthy individuals [5; 6]. Attention is turning to the future research agenda in e-mental health [7; 8], where issues such as how to personalise and promote engagement with e-therapy programs, have been highlighted as requiring attention [9].

Self-tracking is the practice of recording and monitoring aspects of oneself (e.g. sleep quality, management of a chronic condition, mood states, etc.), for the purposes of learning, noticing patterns, and effecting change [10]. The appeal of 'self-tracking' or the 'quantified self' movement has grown rapidly since the inception of smartphones, which makes data capture and representation available to the masses. The inherent curiosity humans have about themselves makes self-tracking an engaging activity with a potential for clinical benefit.

In the current study, we examine the potential of wearable sensors for periodic monitoring of biological variables.

The ECG Sensor was developed to be much more wearable than conventional holster systems (Figure 1). In addition, the requirements for the system specified that the sensor should perform onboard analysis of data. In brief, what was required was a device that would be very small and highly complex and yet still be fashionable.

The OPTIMI ECG sensor system comprises the following entities

– Network-based Home PC application;
– USB Dongle;
– ECG sensor

The ECG sensor performs its function over a 24 hour period, in which it has no connection to the Home PC application. During Home PC sessions, stored data is downloaded to the netbook from where it is transmitted to the central server. During the same session, the application asks users to place their sensors on the charger and to replace them with a second set of sensors, which has been charging in the meantime. The Home PC application then activates the second sensor.

The ECG sensor provides heart rate (HR) and heart rate variability (HRV) readings every 18 minutes as long as the subject is wearing the device correctly and the upper chest muscles are relatively relaxed. Additionally, the sensor gives an estimation of the person's physical activity and verticality.

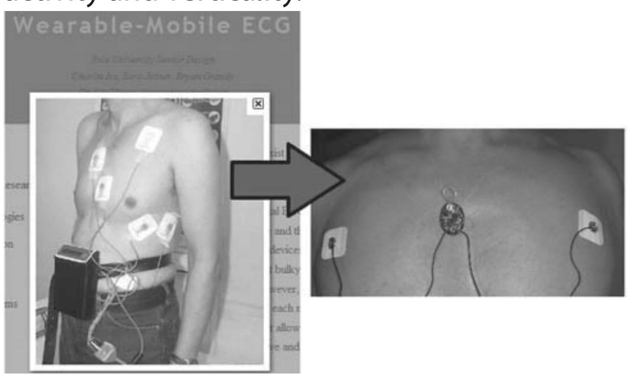

Figure 1. The difference between a holster ECG and the smaller OPTIMI ECG sensor

The final design sensor (Figure 2) has been subjected to several cycles of testing, including extensive user trials each lasting several days. All design requirements have been fully satisfied.

Figure 2. Multiple views of the final ECG sensor

The ECG sensor has been tested with a fairly high number of volunteers (over 90). The objectives of the tests were (i) to ensure that the sensor could capture a good ECG signal regardless of individual differences among subjects; (ii) .to ensure that the HR and HRV measures were consistent and accurately reflected the physiology of the Autonomic Nervous System (ANS); and (iii) to guarantee that the sensor could be worn without discomfort.

The ECG sensor has been designed and developed by partner MAS. The task will commence with a review of user related issues addressing ergonomics, usability and participant acceptability. Mock up models will be made and tested with users to find appropriate fixing methods that suit day-to-day usage. Processor oriented hardware will be designed based on the Nordic nRF24LE1 range of microcontrollers and will include a proprietary low energy Body Area Network protocol from ETH. Aiming at extreme miniaturization, the typical sizes will be below 200mm2 in plan area, 3mm in profile.

In OPTIMI, the subject's heart rate variability (HRV) is in the time domain (SDNN parameter) and in the frequency domain (LF and HF parameters).

To understand the meaning of these parameters it is necessary to understanding the working of the human autonomic nervous system. This comprises two subsystems: the sympathetic system (SS), which prepares the body for conflict and challenge and the parasympathetic system which is there to help the body relax. Current thinking suggests that when a person is stressed mentally, the SS causes the heart beat to become stronger and the rate more regular. If the person deals with the problem quickly the PS system will bring about a change such that the heart beat lightens and the rate becomes more varied. The PS system is coupled to the respiratory system. Deep breathing is thus associated with the PS attaining relaxation. During stress, breathing becomes lighter and more erratic. If the SS dominates the heart rate tends to a fixed rate and LF tends towards a very high value, since all power is at the Direct Current (DC) frequency. When the PS dominates, HR varies strongly changing by as much as 15 % over periods of 8 to 15 seconds. This results in a high HF value.

We can thus summarize our assumptions on LF, HF and LF/HF ratio behaviors as follows:

– The LF/HF ratio will tend to rise during stress as LF increases and HF decreases.

– The HF value may be used as an indicator of vagal tone and could be preferable to the SDNN HRV value, which combines all frequencies of variation. Vagal tone indicates how well the parasympathetic system is performing. People whose average vagal tone is low or poor vagal tone is unlikely improve it, from one day to the next.

The OPTIMI team expects to build up personal baselines for each subject and use them to identify physiological markers or events of interest.

The analysis is still ongoing.

Pre-processing and data cleaning

To date, we have focused our analysis on daily recordings of approximately 3 weeks of data from 23 early subjects.

In order to clean the data we applied the following simple rules:

– Subject must show continuous, non-interrupted sleep data of 5 or more hours.

– Subject must have continuous day time data between 9 AM and 5 PM.

By applying these rules we were able to calculate a rank for each subject.

Analysis

Daytime — Nighttime analysis

For each subject, we selected samples that provided eight hour contiguous sampling (9.00AM to 5:00PM), where possible using samples that included two weekend days and five week days. Data with a high deviation due to extraordinary or inconsistent behavior was removed.

Comparison of Sleep time and Daytime data

In order to test the basic methodology we compared the subjects' average heart rate during sleep and daytime. In the following figures (from 4 to 11) the users are represented on the x axis, 1 to 10.

Figure 3 shows clearly that HR is 30 % higher during the day time. This is evidence that data collection systems worked as planned.

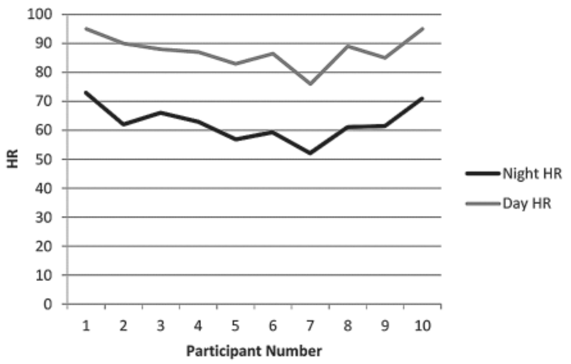

Figure 3. Sleep and day time average heart rates for the top 10 subjects

HRV measures

Figure 4 shows SDNN values for the top 10 subjects.

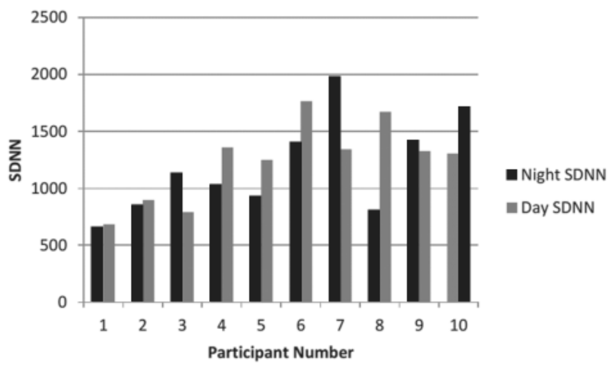

Figure 4. SDNN values for the top 10 subjects

In 7/10 cases, SDNN is higher in the daytime than at night. This confirms our general expectations.

Figure 5 compares HF during sleep and during the day.

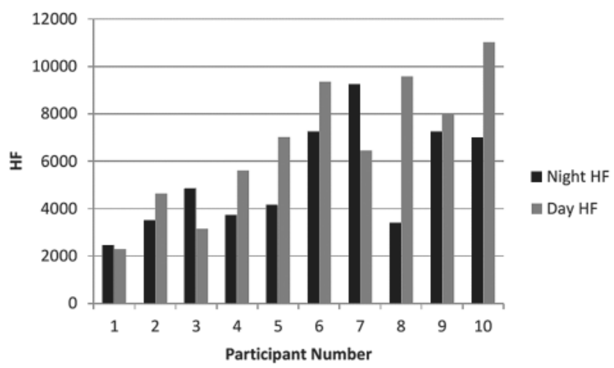

Figure 5. Comparison of HF between Sleep and Day times

In this comparison, 3 subjects have higher HRV at nighttime than during the day. However the differences are smaller than in the case of SDNN.

In the case of the SDNN figure, differences between sleep and daytime averages may be an indicator of negative mood. Smaller differences could imply a reduced ability to relax, with sluggish changes in HR, insufficient parasympathetic responses and possible poor coping. As far concerns HF, the data shows that HF is generally higher during the day. However, due to the way the HF is calculated, this data is probably better suited to dynamic analysis comparing vagal tone and the parasympathetic system over shorter periods of time.

ECG combined with self-reported stress

To analyze these effects we combined the data just described with data for self-reported stress. The nature of this data varied between subjects. Some subjects would simply block off long periods of time and assign them a stress score. Others took more care and seemed to provide more precise timings for stressful events. Most rated themselves as only suffering mild to medium stress. Very few subjects rated themselves with very high or very low stress scores.

To match this data to the HR and HRV data, we estimated each subject's average level of self-reported stress during day time hours. We then compared this data to average daily deviations in HR (Figures 6 and 7).

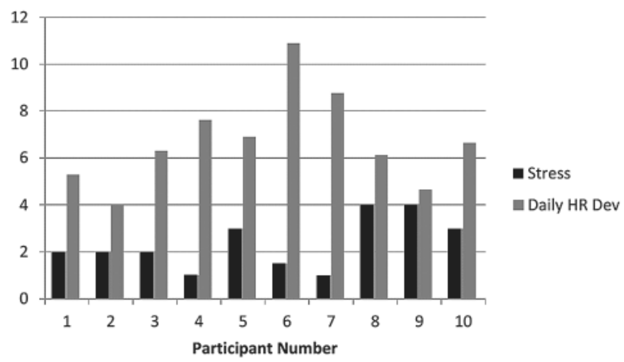

Figure 6. Self-reported stress vs daily HR deviation

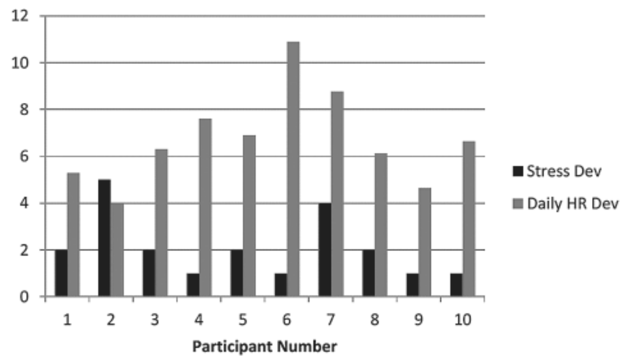

Figure 7. Deviation in self-reported stress vs Daily HR deviation

Since stress levels can rise and fall during the daytime, we also estimated the average deviation in self-reported stress over the day and compared it against the average deviation in HR. The data shows that subjects 8 and 9 reported relatively high stress, while subjects 5 and 10 reported moderate stress and subjects 1, 2, 3, 4, 6, 7 reported low stress.

Even if self-reports of stress are not completely accurate they can provide important evidence for our study.

Having carried out this broad analysis, it is useful to look at the daily life of these subjects in more detail.

Daily life analysis

Consider subject 8

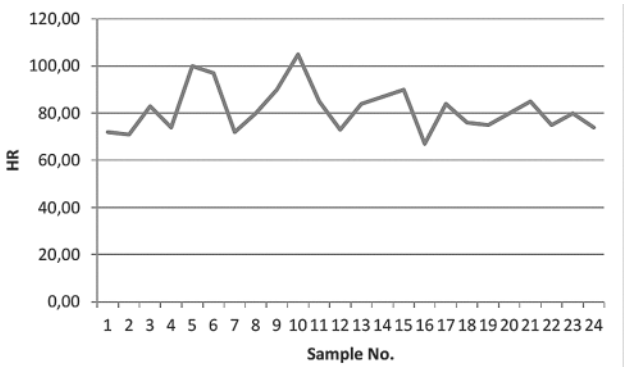

Figure 8. HR of the subject 8 during the day 9AM to 4:40 PM

Figure 8 plots the 24 acquisitions of HR (each sample on the x axis is at 18 minute intervals), starting at 9AM and ending around 4:40 PM. The graph shows that during the morning the subject has a relatively high heart, especially compared to the afternoon. This suggests that the subject is emotionally aroused and potentially stressed during the morning

However, before drawing conclusions, it is necessary to ensure that this is not due to physical activity. Figure 9 provides a plot of physical activity where each sample on the x axis is at 9 minute intervals.

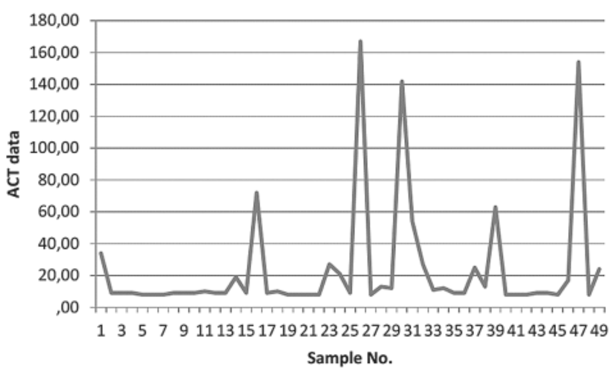

Figure 9. ACT of subject 8 during the day

The data suggests that the subject did relatively little during the morning and may indeed has been seated for the whole period. Nonetheless HR was rather high. If the subject was stressed during those first few hours at work, this should cause the LF/HF ratio to rise due to a lower parasympathetic response (HF) and higher sympathetic response (LF).

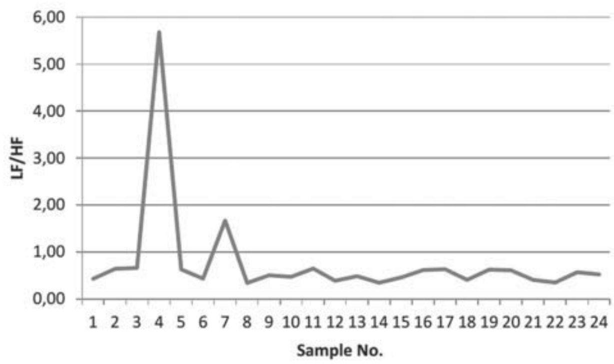

Figure 10. LF/HF ratio of the subject 8 during the day

Figure 10 shows the LF/HF ratio over the day. As predicted, it is high during the morning hours. So this is looking quite convincing.

Notice that on the activity plot at 13 and 16 on the y axis, there are some small peaks. This may correspond to the subject deciding to get up and move around a short while. For example maybe the subject may go and drink a coffee or get some fresh air. Of course we cannot know this, but it is one way to interpret the facts. Around the same time, the LF/HF ratio see at x axis 13 for activity and 8 for the HRV.

Note that there is more movement activity around lunch time and that HR is lower despite this activity.

If we have a look at the SDNN and HF values we obtain the following plots:

The SDNN (Figure 11) tells us that during the day this subjects HRV is on average around 1500. From the small study conducted so far this is high. This suggests that the subject person is unlikely to be suffering from long term negative mood or mild depression. The SDNN (Figure 11) and HF curves (Figure 12) are similar in shape but the HF is very low during the morning and usually becomes high after lunch. Since the HF is an indicator of vagal tone and parasympathetic response, the data suggests that the subject struggled during the morning and coped better towards the later part of the day.

Stress at work or home is unavoidable. However, the speed and depth of recovery from stress provides interesting information on a subject's coping capabilities.

Given the clear signs of stress followed by recovery and overall high average HF, one may conclude that despite a high risk, stressful lifestyle, the subject is unlikely to fall into depression.

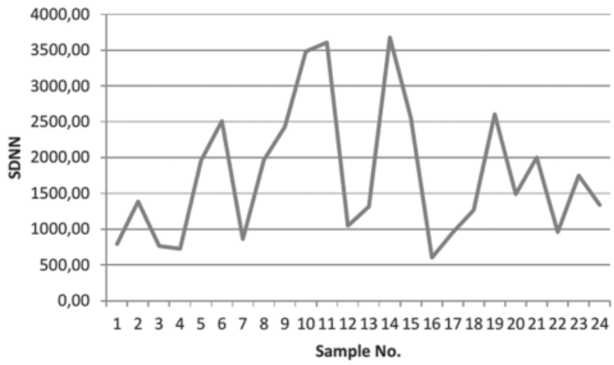

Figure 11. SDNN of the subject 8 during the day

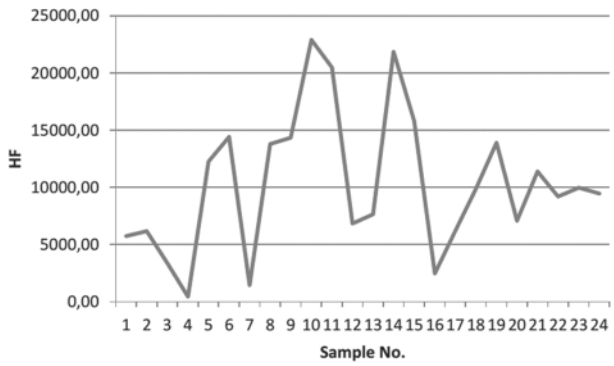

Figure 12. HF of the subject 8 during the day

Figure 13 provides a plot of self-reported stress which suggests that the subject began to feel stress early in the morning and recovered later in the mid afternoon. Independently of possible miss timing in the self-report this data confirms our interpretation of the subject's day went.

Summary

To date our analysis has served two purposes. On the one hand the team has been able to create methods that can be tested against the data. On the other hand it helps to create methods that can predict subjects' tendency towards depression. What follows is a summary of the methods we have used so far.

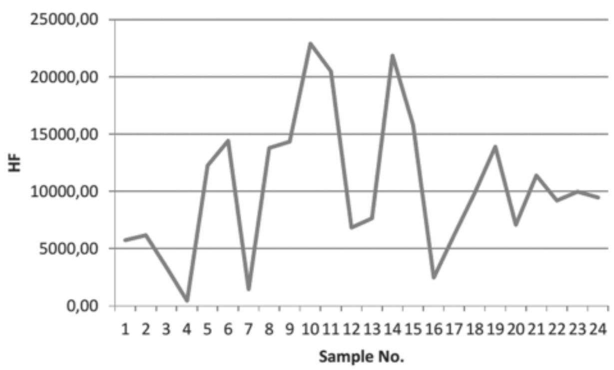

Figure 13. Self-Reported stress

Logical analysis

– Overview: identification of subjects of interest.

– Comparison of average sleep HR against day time HR as a validity check.

– Test for high HR variation during the work day as an indicator of stress.

– Identification of cases where this coincides with low levels of physical activity.

– Test for generally elevated LF/HF ratio comparing night and day.

– Compare HF figure for the day time work hours against the average during sleep.

– IF the average HF value for work time is equal to or higher than the nighttime value we draw no conclusions.

– If the average HF for working hours is approximately 10.0 % lower than the average nighttime value then this is normal (value to be checked).

– If the average HF for the working hours is approximately 20.0 % lower than the average nighttime value, the subject is subject to pressure (value to be checked).

– If the average HF for working hours is approximately 30.0 % lower than the nighttime value then the subject is not coping well (value to be checked).

– Check that the SDNN for different subjects is in the range 700 to 1300.

– IF The SDNN (during the day) for a subject is within 20.0 % of the night time value AND the average SDNN is less than a value X , to be defined after deeper analysis, then the subject is a subject of interest .

Daily: analysis of specific daily activity

– Check variation in daily HR and identify periods where it is above 120.0 % of baseline for periods exceeding 1 hour.

– Confirm no associated strenuous activity.

– Check that LF/HF ratio is below 0.6 (provisional value).

– If high LF/HF and high HR without activity check HF progression for the following 5 hours.

– If HF rises above the weekly average score the subject is coping well; if not he/she is coping badly.

Results and conclusions

Applying these rules, we obtain meaningful correlations between subjects' physiological data and their self-reports. This is reassuring evidence that the sensors are working well and that they are providing data in sufficient quantity and with sufficient quality for the teams to work with. Although the correlations between the HRV and HR data and user reports of stress are not yet statistically significant, we are confident that with more data it will be possible to identify significance. We observed, furthermore, that the periods of contiguous data necessary to draw meaningful inferences are shorter than we initially expected: in many cases 5 to 8 hours of data are enough. In brief, our work has already made a useful contribution to developing the final OPTIMI rule base.

Future work is planned.

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OPTIMI (ПРЕДИКАТИВНІ ІНСТРУМЕНТИ В РЕЖИМІ ON-LINE ДЛЯ ВПЛИВУ НА ПСИХІЧНЕ ЗДОРОВ'Я) OPTIMI ЕКГ СЕНСОР В ЯКОСТІ ВИМІРЮВАЛЬНОГО ІНСТРУМЕНТА ДЛЯ ОЗНАК СТРЕСА ТА НЕЗАДОВІЛЬНОГО КОПІНГУ У ОСІБ З ВИСОКИМ РИЗИКОМ

Л. Фріцше[1, 2], М. Фріцше[1, 2], Д. Маджо[1]

[1]Інженерно-технічна вища школа (ІТВШ), Відділення комп'ютерних наук при Інституті комп'ютерних систем, Швейцарія

[2]Клініка внутрішніх хвороб, Швейцарія

Багато дослідників вважають, що депресія є результом патологічної комбінації надмірного стресу та поганого копінгу. Ґрунтуючись на цій гіпотезі, метою проекту OPTIMI є розробка автоматизованих інструментів для встановлення та характеристики поганого копінгу. Ця стаття описує ЕКГ сенсор. Стаття містить попередні узагальнення та результати, отримані експертами на підставі даних калібрувального дослідження, з метою встановлення патернів та маркерів, пов'язаних з стресом та копінгом.

Ключові слова: ЕКГ сенсор, ЧС, ВСР, стрес, високий ризик, копінг.

OPTIMI (ПРЕДИКАТИВНЫЕ ИНСТРУМЕНТЫ В РЕЖИМЕ ONLINE ДЛЯ ВОЗДЕЙСТВИЯ НА ПСИХИЧЕСКОЕ ЗДОРОВЬЕ) OPTIMI ЭКГ СЕНСОР В КАЧЕСТВЕ ИЗМЕРИТЕЛЬНОГО ИНСТРУМЕНТА ДЛЯ ПРИЗНАКОВ СТРЕССА И ПЛОХОГО КОПИНГА У ЛИЦ С ВЫСОКИМ РИСКОМ

Л. Фрицше[1, 2], М. Фрицше[1, 2], Д. Маджо[1]

[1]Инженерно-техническая высшая школа (ИТВШ), Отделение компьютерных наук при Институте компьютерных систем, Швейцария

[2]Клиника внутренних болезней, Швейцария

Многие исследователи считают, что депрессия является результатом патологической комбинации чрезмерного стресса и плохого копинга. Основываясь на этой гипотезе, целью проекта OPTIMI является разработка автоматизированных инструментов для определения и характеристики плохого копинга. Данная статья описывает ЭКГ сенсор. Статья содержит предварительные заключения и результаты, полученные экспертами на основе данных калибровочного исследования, с целью определения паттернов и маркеров, связанных со стрессом и копингом.

Ключевые слова: ЭКГ сенсор, ЧС, ВСР, стресс, высокий риск, копинг.