SYSTEM FOR CONTACTLESS REGISTRATION OF PHYSIOLOGICAL SIGNALS DURING A SLEEP

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Abstract: Contactless methods for physiological signal registration are known to be perspective ones for functional diagnostic and functional state control. In 1990-th years, the contactless method was applied on the orbital station "Mir" during several long term space flights. In this connection, the work was begun for the contactless method to be realized on the Earth. The new contactless devices have been developed for using the contactless registration of physiological signals during a night sleep. These devices have several advantages against traditional ones. It is no differences between usual sleep and sleep in the examination. Long term monitoring is possible to control cardiovascular system, breath and movement activity. With the devices it is possible to reveal the first sign of the emergency state, as cardiac arrest, apnoea and so on. Autonomous regulation sleep is under control during the night. Dynamic quality control of the night sleep is possible.

Introduction

In 1990-th years, a contactless method, which was based on balistocardiogram registration by sensor attached to a cosmonaut's sleeping-bag, was developed for functional state estimation in the space medicine [9]. The contactless method was applied on the orbital station "Mir" during several long term space flights [1, 3, 4]. Equipped data showed strong correlation between cosmonaut's functional state and parameters of the recorded contactless balistocardiogram. In this connection, the work was begun for the contactless method to be realized on the Earth [2]. The interest to search noninvasive and relatively simple methods for study and monitoring of night sleep without complex polysomnographic instrumentation increases at the last years. The results of many studies made clear that cardiac autonomous activity varies with sleep stage [6, 8, 5]. The previous joint research in Moscow Center of Sleep had demonstrated possibilities of the use contactless method in hospital practice for study of autonomic regulation in the sleep and for identification of sleep stages by the contactless cardiac activity monitoring [7].

Contactless methods for physiological signal registration are known to be perspective ones for functional diagnostic and functional state control. These methods have several advantages in comparison with contact methods. Some of the advantages of such methods are: no discomfort, because there are no electrodes and sensors on the body; long term monitoring of functional state.

Researches be conducting with contactless sensor located on the bed give a lot of information about functional state during the night sleep. Advantages of night sleep examinations are: a) The absence of differences between comfortable during the usual night sleep and comfortable during the night sleep examination; b) Examiner has a continuous monitoring of cardiorespiratory system and movement activity; c) The possibility of control and diagnostic of autonomous regulation disturbances during the night sleep; d) The method fulfills the efficient diagnostic of emergency states (apnoea, arrhythmia, etc); e) Dynamic evaluation of quality of the night sleep;

Materials and Methods

During developing a system for contactless registration of physiological signals during the night sleep it is very important to choose a proper sensor type. The acceleration sensor used in the space flight has a low noise protection. That is why we have selected a torsion sensor type that recognizes only angular accelerations in three dimensions (3D-sensor). The torsion 3D-sensor "METR-03" has developed and is produced by ANO SC MIPT (Autonomic nongovernmental organization Scientific centre of Moscow Institute of Physics and Technology). It is a question of applying a torsion balistocardiography method to register body's pulse rotation micro movements around three axis: longitudinal, frontal, transverse. The 3D-torsion sensor attached on the bed can get 3-D balistocardiotram (Figure 1). The torsion sensor is insensitive for lineal vibration, that reduce noise level. Heavy torsion movements can distort a

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signal in one of the channels, but the signal in the other channels is noise free.

There were developed two types of devices for contactless baslistocardiogram. The first type is on-line device for real time monitoring and analysis. The second type is home-use off-line device for autonomic recording and postpone analysis. The first type device is named "CardioSleep-1", the second – "CardioSleep-2".

On the Figure 2 the schemes of devices "CardioSleep-1" and "CardioSleep-2" are presented.

The differences between devices are the one dimension torsion sensor "METR-01" (1D) and Flash-memory of device "CardioSleep-2" (Figure 2b). These differences allow to diminish size, weight, power consumption and flash-memory size of the device "CardioSleep-2".

Main task for signal processing had been to recognize heart rate, respiration frequency and movement activity. The three type of signal patterns without additional processing are presented on Figure 3. Special software for signal processing and analysis was developed on Borland Delphi 7.0 for MS Windows 2000/XP.

The software recognizes key points and builds trends of cardiointervalogram, amplitude of balistocardiogram at the key points, duration of respiration, movement activity. Statistical and spectral parameters are calculated for the trends and are output on the display as average for every 5, 15 or 30 minutes. Each parameter has own norm (green zone), above or below norm (yellow zone) and pathological (red zone) values. All results for a whole night are saved into database for following analysis and detail overview.

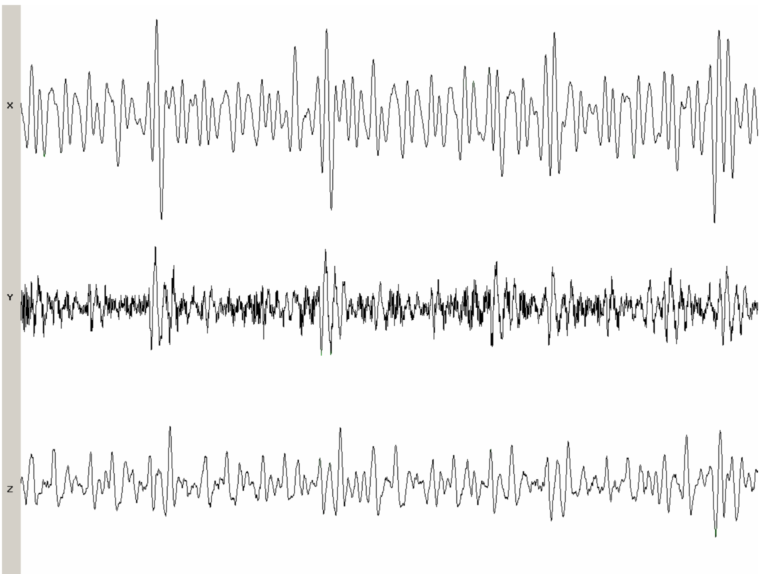

Figure 1: The example of the 3D-balistocardiogram (X – longitudinal axis; Y–transverse axis; Z–frontal axis).

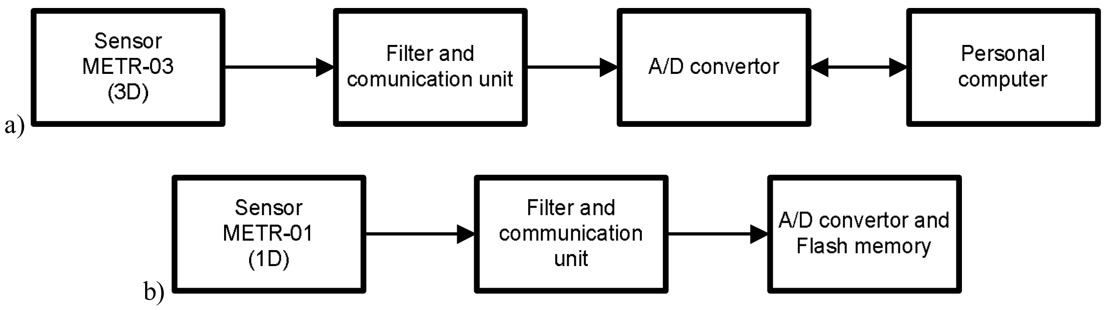

Figure 2: Schemes of the devices "CardioSleep-1" (a) and "CardioSleep-2" (b)

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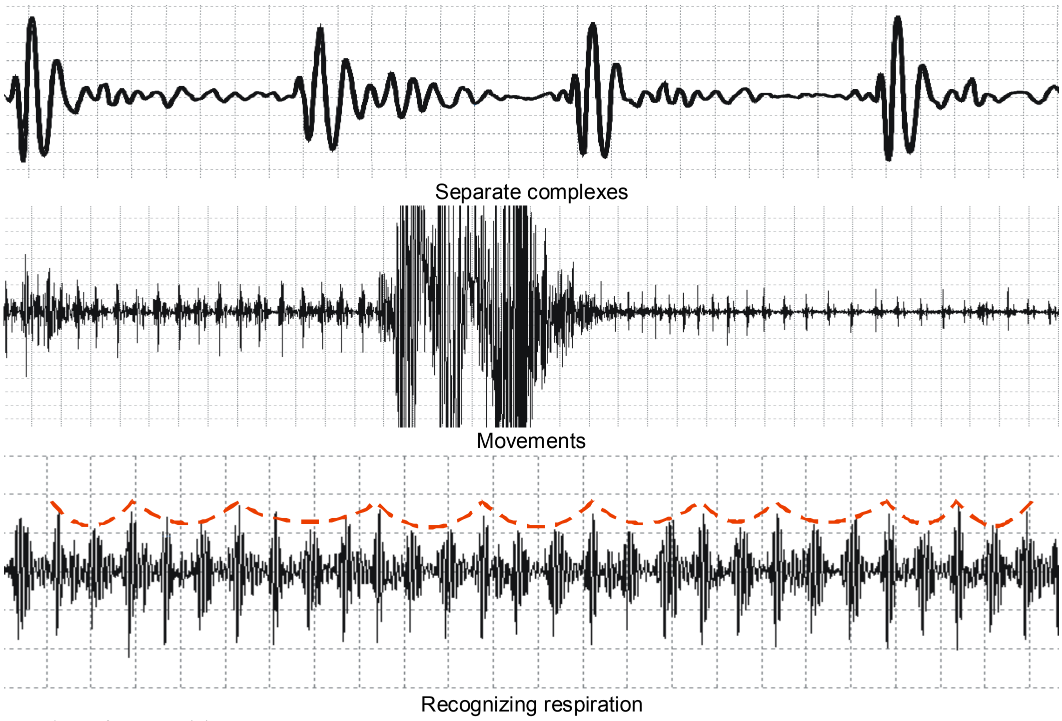
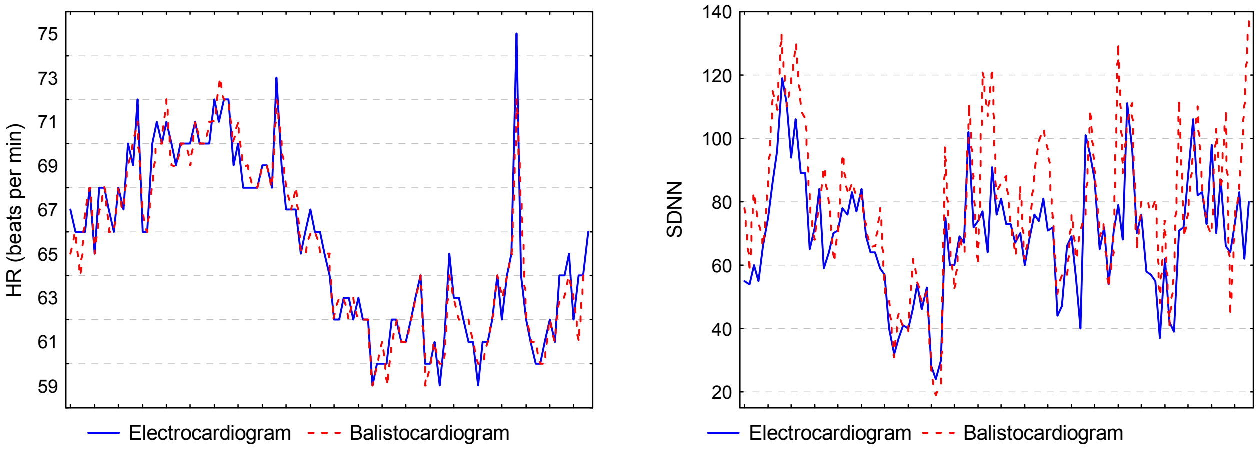


Figure 3: Examples of recognition patterns.



a) b)

Figure 4: Average heart rate 5-minute intervals of contact (ECG) and contactless (balistocardiogram) methods.

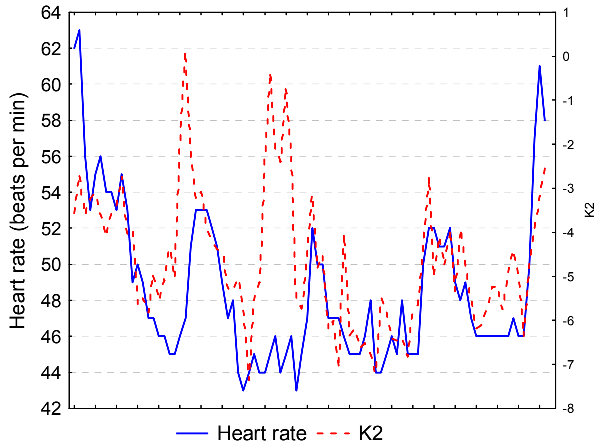


Figure 5: Dynamic of the heart rate and K2 of the healthy man during a sleep

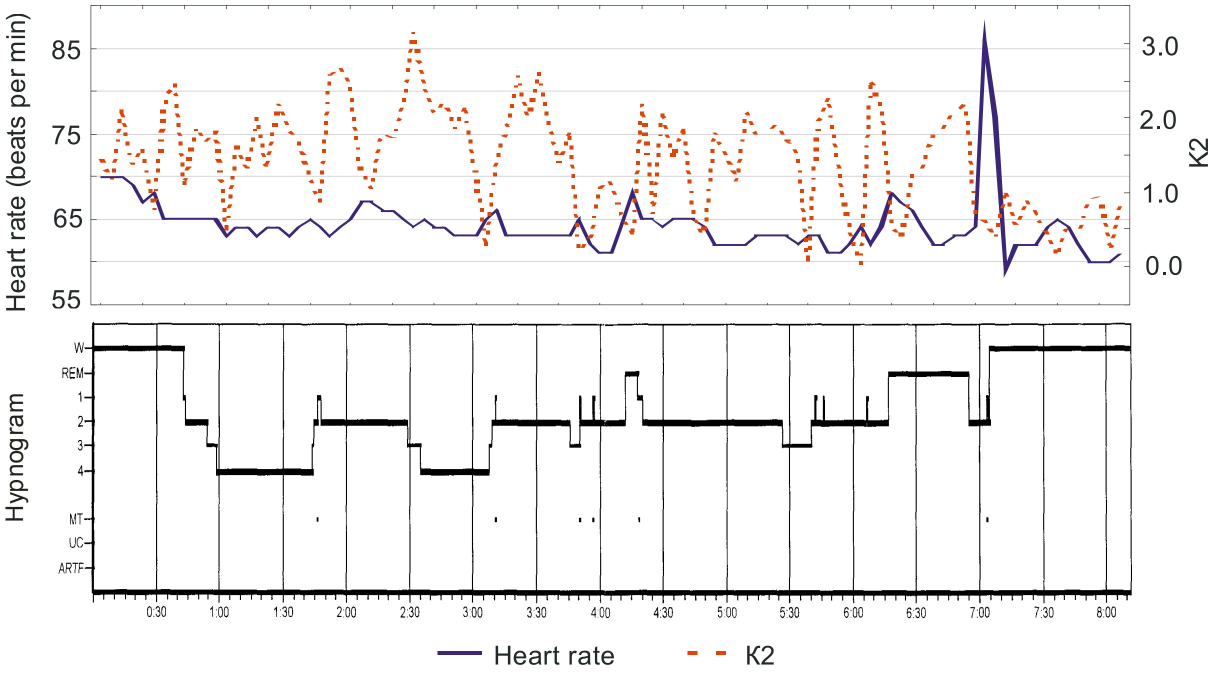


Figure 6: Dynamic of the heart rate and K2 of the patient with sleep disorders during a sleep.

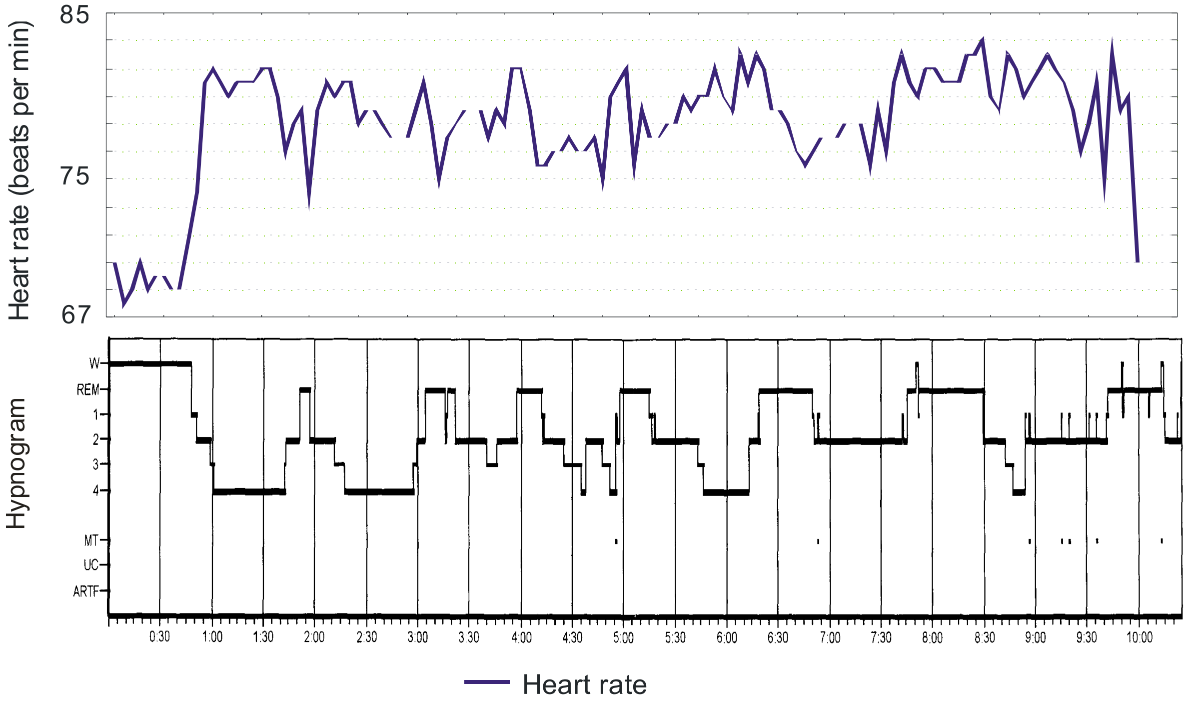


Figure 7: Dynamic of the heart rate and hypnogram of the health children of 5 years old.

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Results

The simultaneous recording was performed by both "CardioSleep-1" and traditional electrocardiogram (ECG) during 8 hours to evaluate a reliable and precision of signal processing. Graphs of consecutive 5-minute average heart rate recorded by contact (ECG) and contactless (balistocardiogram) methods are presented on Figure 4a. The both graphs look alike with insignificant differences due connected with recognition err during movements.

A standard deviation of heart rate variability of the same signals is presented on Figure 4b. These graphs look alike with little discrepancy, which can be eliminated by more reliable recognition algorithm.

The sleep disturbances are known to be a complex problem that needs special diagnostic equipments to resolve it. That is why, at first stage, the clinical testing of the "CardioSleep-1" was conducted in the Sleep centre of I.M. Sechenov Moscow Medical Academy. The clinical test included two methods:

– sleep polygraph with record an electroencephalogram (EEG – C3 and C4), electrooculogram, electromiogram, electrocardiogram;

– contactless balistocardiogram by torsion sensor attached on the bed (system "CardioSleep-1").

The 11 patients with sleep disorders and 5 healthy men (control group) were examined.

Comparing a data of polygraph and contactless balistocardiogram shows the nearly identical sleep cycles and heart rate variability in both cases. The hypnogram (by polysomnogramm), heart rate and K2 (overstrain index of adaptation process) of the healthy man are presented on Figure 5. Falling asleep and awakening processes, 3 full sleep cycles are here.

For reference, the data of patient with sleep disorders (insomnia) are located below (Figure 6). There are a long fall asleep process, early awakening and only two REM stages with latent time 209 minutes in 1-st cycle. Integrated analysis of heart rate variability and hypnogram shows a heavy disturbances of sleep's refreshment function and high level of sympathetic activity during whole night (K2 > 0). After examining the patient according with standard protocol, a chronic fatigue was detected among reasons of insomnia. High sympathetic activity in the night and sluggish heart rate dynamic are the signs of the overstrain of regulation process and depletion of adaptation reserves.

On Figure 7 the dynamic of the heart rate and hypnogram of the health children of 5 years old is presented as comparison with patient.

Discussion

The present investigation with device "CardioSleep-1" reveals a necessity of widely using the contactless registration of physiological signals during a night sleep. In many countries, there are resolved questions about treatment of sleep disorders, develop new services and technology, graduate a specialists. There are need complex solution of the problem of treatment a sleep disorders, because the sleep is a complicated physiological process with many unclear details. Sleep disorders cause a disturbances of refreshment process during the night sleep. The refreshment process helps to adapt to the changing environment, as consequence the disturbances of the process can deplete work efficiency, to worse mental facilities, increase morbidity and mortality.

Autonomous regulation disorders can be consequence of sleep disorders or as sign of illness without connecting with sleep quality. In addition, the normal hypnogram is not always normal refreshment process. These situations can be revealed with diagnostic device "CardioSleep" and by methods of heart rate variability and autonomous regulation examination. It is important for physicians, that "CardioSleep" software can help to diagnose night arrhythmia and apnoea. Control of the sleep quality and functional state can be useful at home, during vacations, for sportsmen to reveal an overtrain.

Conclusions

It is important to develop systems for contacless control of functional state during the sleep. These systems can be applied at home and everyone can buy it for himself.

The developed devices "CardioSleep-1" and "CardioSleep-2" have next advantages:

– It is no differences between usual sleep and sleep in the examination;

– Long term monitoring is possible to control cardiovascular system, breath and movement activity;

– With the devices "CardioSleep" it is possible to reveal the first sign of the emergency state, as cardiac arrest, apnoea and so on;

– Autonomous regulation sleep is under control during the night;

– Dynamic quality control of the night sleep is possible.

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