QUANTITATIVE SEISMOCARDIOGRAPHY IN STRESS LEVEL EXAMINATION

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Abstract: The Q-SeimoCardio system is a noninvasive hardware-software device that works together with the computer and is based on the method of the quantitative seismocardiography. Main task of this apparatus is absolute noninvasive monitoring of the cardiovascular function. The equipment was tested on a group of children from Beslan. They were invited to the recondition stay in Karlovy Vary by the Czech Government as they suffered from trauma after the terrorist attack at school. Especially the stress index was examined. Normal values of the stress index (SI) are 50-150. It was found that at the beginning of their stay the values were very high, at the end of their stay the values were lowered but not yet normalized.

Introduction

In the last years there is emphasized the importance of the autonomic nervous system for the beginning and the course of hypertension etc. Methods of the HRV measurement are for this purpose suitable. Many parameters were so introduced and in last time the stress index (SI) was defined.

Ballistocardiography (BCG): In 1936, Starr took part in a conference held by the American Society of Physiology which dealt with methods of determining cardiac output. For this purpose, he used a bed with rigid springs, whereby by the movement against these springs increased the instrument's natural frequency to values higher than the heart rate. Thus began the era of high-frequency balistocardiography, which lasted approximately 15 years. Other types of instruments were developed, on which the displacement, velocity or acceleration of a body lying on a bed was measured. Later studies showed that there are difficulties when comparing records registered on different apparatuses.

This is mainly caused by two factors: (a) the instrument's natural frequency, (b) the instrument's damping.

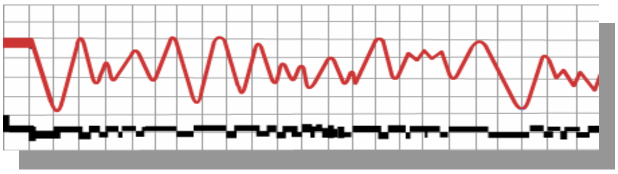

Figure. 1: Records registered using the BCG instrument with a frequency of 2Hz and critical damping. The lower curve depicts the effect of force applied, which is still of the same intensity but differs in the duration of its effect. The upper curve is a record, from which one cannot determine either size or duration of the acting force.

Quantitative ballistocardiography (QBCG): Following the critical evaluation of all these facts, we began in 1952 our own experiments related to the construction of an apparatus which would lack the aforementioned shortcomings. Thus, over the years, we constructed an apparatus whose advantages lie not only in the simplicity of its design, but also in its important functional qualities. To achieve a minimal distortion caused by the transmission from the origin of the force to the recorder it is necessary that the natural frequencies of the transmission systems lie as far as possible from the mentioned frequency range.

The cardiovascular activity is manifested by a force acting on the human body which represents a mechanical vibratory system transmitting the force to the balistocardiographic apparatus.

The basic part of our portable quantitative balistocardiograph is a very rigid piezoelectric force transducer [Trefný and Smetánka, 1956] resting on a rigid steel chair. The examined person sits (Figure 2) on

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the light seat placed on the transducer and the force caused by the cardiovascular activity is measured in this way. The output of the piezoelectric pick-up is fed into an operational amplifier.

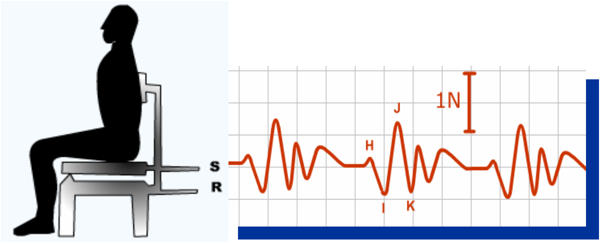

Figure 2: Position of the examined person during the QBCG session.

The advantage of the piezoelectric transducer is in very low compliance together with a very high natural frequency of the apparatus. Another advantage of the rigid pick-up is the fact that it can be preloaded with a substantial static force – the weight of the examined person, and it is still possible to measure the alternating forces of the magnitude of g+ (gram as weight). The simple push button is used to dispose of the static charge caused by the weight of the person. The measured force is registered (REG).

Dynamic calibration of the QBCG apparatus was carried out by an electrodynamic exciter (EXC) acting via a calibrated dynamometer (D), also of a piezoelectric type, on a pick-up (Q) of the QBCG (see Figure 3).

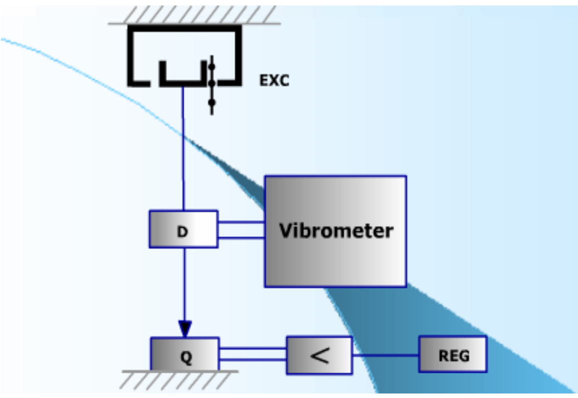

Figure 3: A set-up a dynamic calibration of the quantitative balistocardiographic apparatus.

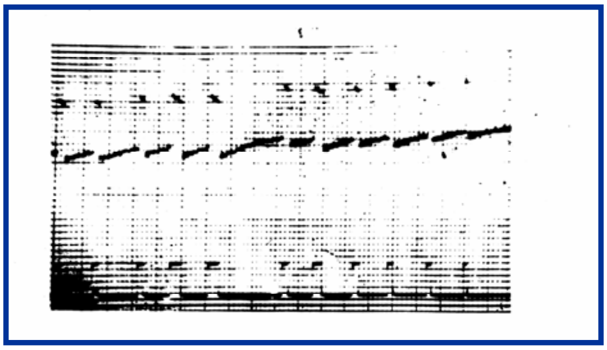

Figure 4: Records registered using the QBCG instrument. The lower curve depicts the effect of force applied. The upper curve is a record, from which we can determine size and duration of the acting force. Compare with BCG record on Figure 1.

Quantitative seismocardiography (QSCG: Our method enables the recording of force applied without phase or time deformation. Thus, heart rate may be monitored and analysed using the method of heart rate variability (statistical and autocorrelation analysis, spectral analysis, total effect of regulation, vegetative homeostasis, activity of subcortical centre, activity of the vasomotor centre and stress index). The method of QSCG was designated by the laboratory employees as an absolutely non-invasive, and the persons examined did not have any electrodes attached to the body surface and were not connected by cables to the registering instrument. This new field of monitoring heart activity, whereby we determine both amplitude-force and time-frequency relationships, is termed quantitative seismocardiography. Thus, one may determine the force-response of the cardiovascular system to changes in external stimuli, as well as the autonomous nervous system regulation of the circulation and the activity of the sympathetic and parasympathetic systems.

Methods

Experimental equipment: In terms of practical use, a new portable telemetric system has been created on Faculty of Biomedical Engineering, Czech Technical University in Prague. This system allows data to be acquired and assessed using quantitative seismocardiography (QSCG) and triaxial accelerometric measurements on the thorax of a patient. It is composed of the three HW modules that are telemetrically interconnected with the option of interconnecting through a metallic line. These are the seismocardiographic, the accelerometric modules and a module for the data transfer interconnected with the PC through the USB interface.

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Figure 5: Main sensor of she QSCG measuring equipment - detail of the solid-state accelerometer between measuring metal plates.

Sensing mechanical body reactions, which are induced in response to the cardiovascular dynamics, is provided by the seismocardiographic module, which reads the strain coming from the mechanical deformation of the piezo-electric plate. This sensing module is mounted on a special device, which works by transmitting the mechanical body reactions onto the piezo-electric recorder. The accelerometric module is applied for measuring thorax acceleration as induced by movements from the heart activity, this measurement is made on the three basic orthogonal axes. The core of the module is the sensing device composed of the two biaxial monolithic semiconductor accelerometers. The data transfer module is designed to transmit the data from the radio-module into the PC through the USB interface.

Figure 6: Measuring plates of the proposed QSCG device.

Algorithms: The target is to monitor the heart rate and carry out an analysis of heart rhythm variability. We have developed algorithms for preprocessing, segmentation and interactive analysis of the QSCG signal. The system contains the statistical and autocorrelation analysis, spectral analysis, assessment of the aggregated effect of the regulation of autonomous functions of vegetative homeostasis, activity of the vasomotor centre, activities of the sympathetic cardiovascular centre and the stress index (SI). Our experimental software allows also automatic extraction of classical QSCG hemodynamical parameters, especially so called systolic force (SF). The current version of the system is designed for OS Windows XP and has user-friendly interface.

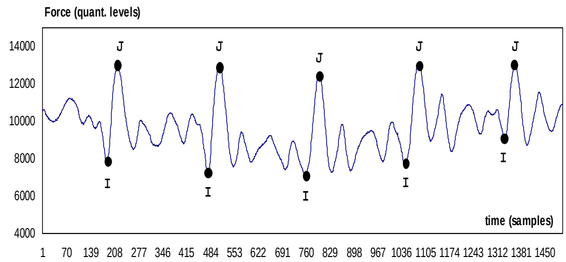

Figure 7: Automatic detection of reference points in QSCG signal – typical situation. Instead of RR-intervals (well-known from classical ECG analysis) so called JJ-intervals are calculated. J-waves are dominant graphical elements on QSCG curve, they correspond with heart action.

Experiment: Stress index (SI) in 76 children from Beslan was tested during 2 sessions. These children were invited to the recondtition stay after the terrorist attack at their school. The first session was acquired at the begin of their recondition stay in bath Karlovy Vary (Czech Republic), the second session was acquired before the end of this recondition stay. The goal of this experiment was examination of the ability of proposed system to detect/quantify specific information about functional changes of cardiovascular system regulation concerning its coincidence with increased level of the mental stress.

The QSCG signal was measured in sitting position, the length of each record was 5 minutes. The sampling frequency was 500 Hz, used resolution of the AD converter was 16 bits. Then the preprocessing (normalization, filtration) and automatic segmentation of the QSCG signal was performed. Finally, the methods of the HRV analysis were applied to obtained heart beat to beat series. We focused our attention on examination of so called stress index (SI).

Results

Mean values of SI in mentioned 2 sessions were compared. Graphical presentation of results is on Figure 8. Obtained results were statistically tested (pair test for two dependent choices, n=76). The differences between mentioned 2 sessions were significant ($p<0.05$).

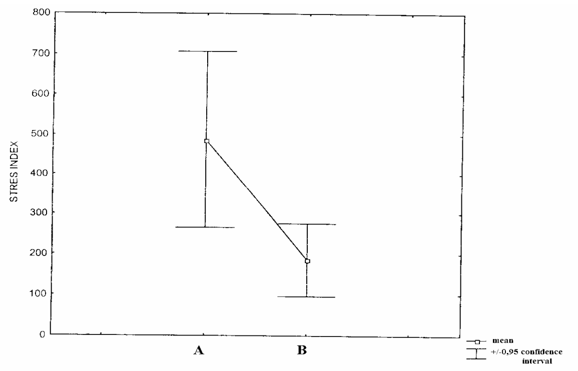

Figure 8: Discrimination between means of the group (A) before recondition stay. (B) after recondition stay. The difference is visually apparent.

The equipment was tested on a group of children from Beslan. They were invited to the recondition stay in Karlovy Vary by the Czech Government as they suffered from trauma after the terrorist attack at their school. Especially the stress index was examined and it was found that at the beginning of their stay the values were very high, at the end of their stay the values signifitiantly lowered but were not yet normalized. It was proved that the stress index is a very sensitive parameter and that the Q-SeismoCardio system offers specific information about functional changes of cardiovascular system regulation which preceed the structural changes coming later.

Discussion

There is probably a big potential in absolutely noninvasive QSCG methodology; we can access not only parameters of the cardiovascular system, but also parameters of the autonomic nervous system – continuously, in real-time. In the near future we will try to use this methodology/equipment in many practical situations, where the continuous monitoring of the stress level is useful. However, not all problems (especially technical) concerning the QSCG scanning and analysis are solved. The QSCG signal is very sensitive to motion artifacts and high-frequency noise; many practical problems must be solved and both device and algorithms are still under the development.

The exactitude and reliability of the above methods must be experimentally verified in relation to the current monitoring of persons during their conventional working activities. This absolutely non-invasive method can be used to monitor the operators within their examination. We can also mention, in addition to other applications, the continuous monitoring of staff to prevent diseases, to determine breaks during the working process, and to estimate the potential capabilities for performing duties (monitoring the mental load, fatigue, inadvertence etc.).

Conclusions

It was proved that the Q-SeismoCardio system offers specific information about functional changes of the cardiovascular system regulation which preceded the structural changes coming later. It was shown that the stress index is a very sensitive parameter for recognition of the autonomic nervous system dysfunction and disturbances. The equipment is ready for use, algorithms for automatic analysis of the QSCG signal are prepared.

Quantitative seismocardiography probably offers a more complex view of both inotropic and chronotropic heart function. It will be suitable for: examining operators exposed to stress; for assessing the effect of work, fatigue, mental stress; for monitoring persons as part of disease prevention; for determining a person's ability to carry out their duties both on the ground and in the air.

Acknowledgement

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