Advances in Informatics, Management and Technology in Healthcare
J. Mantas et al. (Eds.)

doi:10.3233/SHTI220669

Beat to BEAT - Non-Invasive Investigation of Cardiac Function on the International Space Station

Urs-Vito ALBRECHT[a,1], Martin DROBCZYK[b], Christian STROWIK[b],
Andre LÜBKEN[b], Jan BERINGER[c], Jochen RUST[d] and Ulf KULAU[a,d,e]
[a]*Department of Digital Medicine, University of Bielefeld, Germany*
[b]*German Aerospace Center (DLR) Institute of Space Systems Department of Avionics Systems, Bremen, Germany*
[c]*Hohenstein Laboratories GmbH & Co. KG, Boenningheim, Germany*
[d]*DSI Aerospace Technologie GmbH, Bremen, Germany*
[e]*Smart Sensors Group, Hamburg University of Technology (TUHH), Hamburg, Germany*

Abstract. This paper describes the protocol of the microgravity experiment BEAT (Ballistocardiography for Extraterrestrial Applications and Long-Term Missions). The current study makes use of signal acquisition of cardiac parameters with a high-precision Ballistocardiography (BCG)/Seismocardiography (SCG) measurement system, which is integrated in a smart shirt (SmartTex). The goal is to evaluate the feasibility of this concept for continuous wearable monitoring and wireless data transfer. BEAT is part of the ”Wireless Compose-2” (WICO2) project deployed on the International Space Station (ISS) that will provide wireless network infrastructure for scientific, localization and medical experiments.

Keywords. Space health, seismocardiography, cardiac function, micro gravity

1. Introduction

Health is key for any successful mission, and space agencies are searching for reliable, durable, versatile, and non-complex health monitoring and diagnostic solutions. In manned space flight the cardiovascular system is especially at risk [1]. To offer a possible solution for the future, the authors developed a wearable sensor system that may provide low weight and low maintenance cardio-vascular monitoring which is nevertheless comfortable and continuous. The method of Seismocardiography (SCG) is utilized to achieve this goal. SCG as variant of the century old BCG follows the paradigm that the force of the beating heart and recoil of the blood flow in the vessels lead to characteristic vibrations that can be detected on the body’s surface [2]. These vibration patterns correlate with cardiac function and specific conditions. Decades of research have focused on improving the technology, but also on methods how to utilize the signals for

---

[1] Corresponding Author, Urs-Vito Albrecht, Department of Digital Medicine, Medical Faculty OWL, University of Bielefeld, Universitätsstraße 25, 33615 Bielefeld, Germany; E-mail: urs-vito.albrecht@uni-bielefeld.de.

determining the heart rate, heart rhythm, relative blood pressure and much more [3]. Accompanied by the correct methodology for evaluation, this technology is thus a powerful tool for health monitoring both in space and on earth.

In this paper, the authors present the design of an ongoing study BEAT (Ballistocardiography for Extraterrestrial Applications and Long-Term Missions) on the International Space Station (ISS). The goal of the study is to analyse the feasibility of such a sensor system for long distance space travel and explore further perspectives for its deployment.

2. Method

2.1. The BEAT Experiment

The BEAT Experiment is a feasibility study for a wireless communication network and its exemplary application for the fundamental measurability of acceleration properties to describe the cardiac physiology of a heart-healthy astronaut under conditions of weightlessness using body-worn sensor technology integrated into a T-Shirt (smart shirt). Our intent is the analysis of repetitive intra-individual measurements of accelerations at two measurement sites on the body under the long-term influence of gravity and in weightlessness. We measure and calculate basic cardiac parameters (heart rate, heart rate variability, pulse transit time) and explore whether other parameters, like the heart contraction interval, ejection and filling volumes, absolute and relative cardiac function event times (heart valve opening and closing) can be observed or calculated. Furthermore, we evaluate the overall feasibility of the system regarding its comfort and practicability.

Each astronaut will be examined both pre- and post-flight using basic physiological examinations and calibration of the SCG/BCG sensors. Simultaneously, an electrocardiograph is connected to obtain a reference signal. All measurements comprise a 3-by-3-minute reading with the subject in supine position. The sensors are positioned on the body surface. One sensor is placed on the carotid artery, while the other is attached with tape at the point above the apex of the heart or at the centre of the sternum. For the first and the last 3-minute intervals, the subject is at complete rest. The middle interval is divided into three parts of 1 minute duration. The subject is at rest during the first and last minute but will be performing 4 Valsalva pressing manoeuvres during the second interval. An electrocardiogram (ECG) is performed during the subjects' pre- and post-flight intervals, depending on time constraints. For this purpose, we developed an echocardiography protocol which focuses more on physiological and anatomical aspects of the heart actions than on the clinical condition. During flight, the astronauts are to be asked to put on the T-Shirt, check the sensor positions (and adjust them if necessary), and to start the measurements. They are to stay at rest for one minute, perform four Valsalva pressing manoeuvres and relax for another minute. Afterwards, they follow their activities for another seven minutes, and stop the measurements after the activity period. Finally, they are asked to fill out a questionnaire regarding their experience with the T-Shirt. The measurements are then encrypted and sent to earth to be analysed post-hoc.

The astronauts take part in the experiment on a voluntary basis, after giving their informed consent. The study was approved by the Ethics Committee of the Ärztekammer Westfalen-Lippe and WWU Münster, Germany, on the 15.02.2022 (2022-068-f-S; Chairman: Prof. Dr. W. E. Berdel).

2.2. The Technical Setup

The technical aspects of the Wireless Compose-2 (WICO-2) equipment have been explained in detail elsewhere [4]. For brevity, the current article only provides a brief summary of the key features of the system and its devices.

Two sensor patches are connected to a Pre-Processing Unit (PPU) that reads out the sensor data and performs signal processing in order to forward the data to a communication module that transmits all data wirelessly to a sink node via Ultra Wideband (UWB) link. All components are integrated in customized tailored T-shirts made from flight-certified Space-Tex fabric from former Space-Tex and Space-Tex2 ISS experiments that allows for ergonomic design and comfortable wearing in space. The fixation of the two sensor patches in the T-shirt was designed to be highly flexible to ensure best data quality. Thus, two variants of the T-shirt had to be designed to comply with female and male anatomy, respectively. To increase both the reliability and the signal quality of the SCG/BCG measurement, each sensor patch holds two Kionix-122 accelerometric sensors mounted in a differential orientation. Thus, the signal-to-noise-ratio is increased while dependability is achieved by inherent redundancy (relevant for space projects) [5]. The sensors' suitability for BCG was extensively analysed and tested beforehand [6,7]. In order to enable the differential sensing while keeping high temporal accuracy, the PPU was developed based on an ultra-low power (ULP) Field Programmable Gate Array (FPGA) (Lattice ICE40 UltraPlus). The Output Data Rate (ODR) of the sensors was set to 800Hz while the overall sample rate has been 1KHz leading to an oversampling of 20% which is again a fault tolerance scheme to reduce the risk of data losses. All data were transmitted via the comm module using UWB link. Evaluations showed a Packet Reception Ratio (PRR) of 99.88%, however, dual redundant SD-Cards are used as an additional backup.

2.3. The Software

Monitoring software has been developed for the ground-based measurements. The BCG data of all BCG fields and axes as well as the ECG signal are visualised in real time to allow adjustments of the general setup and sensor positions. Individual sessions can be recorded, and the binary data stream can be stored without loss of information for documentation purposes and post-hoc evaluations.

2.4. The Analysis

The collected data will be analysed in several iterative steps. Initially, the data sets will be visually checked for completeness, plausibility, and signal quality. As the measurements are collected continuously for each sitting, the data sets will be separated manually into two main parts, namely readings at rest (first three minutes) and readings during activity. In space, on-board video footage is taken during the experiments that will support the understanding of the type and extent of the activities conducted by the astronauts. This information will be added by making annotations to the measurements. The first three minutes of the experiment in space reflect an abridged protocol that follows the pre-and post-flight measurements. These measurements are valuable for two reasons. Firstly, they serve as a baseline for comparison with the activity data in micro-g environment, and secondly, they are used for comparison with the earthbound collected data. The system measures the other seven minutes during the astronauts' light activity, providing an insight into cardio-vascular conditions under light physical stress and changes in the course of the stay. The primary endpoint is heart rate variability (HRV). Secondary endpoints comprise the heart rate (HR), pulse transit time (PTT), cardiac valve timing and a questionnaire about comfort and experience with the T-shirt.

Statistical analysis is primarily performed descriptively for the primary and secondary endpoints. Comparative analysis will be conducted intra- and inter-individually regarding the setting (earthbound vs micro-g environment), time (begin, mid, end of mission), and level of activity (rest vs. activity), gender (female vs. male). Qualitative analysis of the questionnaire for the user experience will be performed separately.

2.5. The Schedule

BEAT and WICO-2 are meant to be conducted on the ISS expeditions (increments) 66 and 67 as a continuous scientific experiment of the Cosmic Kiss (Matthias Maurer) and Minerva (Samantha Cristoforetti) missions. The equipment was sent to the ISS in two deliveries (November 2021 and April 2022), and is thus already in orbit. The WICO-2 hardware with the wireless network components were installed in the Columbus Module in January 2022. Two astronauts will perform the experiments during their long-term stays. It is planned to conduct several measurements with the system, simultaneously with other experiments. Parts of the equipment will return to earth by the end of the year.

3. Results

The results of the BEAT experiment will be mostly descriptive and mainly used for generating hypotheses for future experiments. With the current experiment, we expect a knowledge gain for several aspects that comprise a) detailed information about the sensor system behaviour in micro-g environment and the interpretation of the collected data on ground, b) information about the physiological changes of the cardio-vascular system in long term stay in micro-g conditions (stratified for gender), and c) information on the feasibility of continuous measurements using the system.

4. Discussion

From the technical perspective, in context with physiological measurements, the results will allow to explore several aspects. Foremost, the influence of gravity on the sensor system itself as well as on the signals of the accelerometers are in the focus. By reducing the force of gravity on the sensor, the effects of using differential sensing for improving the signal-to-noise-ratio and thus signal quality can be evaluated. For the interpretation of the measurements, it is of great interest to see how the signal characteristics differ between the earthbound versus micro-g setting.

The obtained measurement data will be analysed and examined with regard to quality, completeness and plausibility. Signal changes over the course of time and number of experiments will vary, and bias will be discussed. According to this idea, it is necessary to determine whether and to what extent the measured values can be correlated with changes in the cardio-vascular state (anatomical and physiological).

The diagnostic key concept of the experiment is SCG [8]. Critical consideration must be given to the suitability of this variant of BCG for continuous screening, and limitations and possibilities for different settings will need to be identified. Lastly, the feasibility, usefulness and usability of overall system will be evaluated along with the results of several previous attempts of efficiently measuring cardio-vascular function under microg conditions. The transferability of the BEAT concept to earthbound settings will be reflected.

5. Conclusions

We expect that the physiological data will improve the hypothesis generating processes in the context of cardio-vascular changes in a micro gravity environment. Moreover, the results and experience are of high interest for further development of future health monitoring systems in space as well as on earth, specifically regarding BCG and SCG methods for prevention.

6. Acknowledgements

The authors thank the ESA astronauts S. Cristoforetti and M. Maurer for participating in the experiments. The project is funded by institutional funds of the University Bielefeld and Hamburg University of Technology and supported by DLR Space Research and DLR Space Administration, DSI Aerospace Technologie GmbH and Hohenstein Laboratories. The authors would like to thank the DLR Institute for Space and Aviation Medicine envihab, Köln, Germany for their continuous support and fruitful discussions.

References

[1] Jirak P, Mirna M, Rezar R, Motloch LJ, Lichtenauer M, Jordan J, et al. How spaceflight challenges human cardiovascular health. Eur J Prev Cardiol. 2022 Feb.

[2] Baevsky RM, Baranov VM, Funtova II, Diedrich A, Pashenko AV, Chernikova AG, et al. Autonomic cardiovascular and respiratory control during prolonged spaceflights aboard the International Space Station. Journal of Applied Physiology. 2007;103(1):156-61.

[3] Inan OT, Migeotte P, Park K, Etemadi M, Tavakolian K, Casanella R, et al. Ballistocardiography and Seismocardiography: A Review of Recent Advances. IEEE Journal of Biomedical and Health Informatics. 2015;19(4).

[4] Drobczyk M, Lübken A, Strowik C, Kulau U, Rust J, Beringer J, et al. Wireless Compose-2: A wireless communication network with a Ballistocardiography Smart-Shirt experiment in the ISS Columbus module. In: 2021 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE). IEEE; 2021. p. 103-8.

[5] Kulau U, Rust J, Szafranski D, Drobczyk M, Albrecht UV. Differential BCG Sensor System for Long Term Health Monitoring Experiment on the ISS. In: 2022 International Conference on Distributed Computing in Sensor Systems (DCOSS). IEEE; 2022. p. x-x. Accepted for Publication.

[6] Clausen T, Jura T, Jahne-Raden N, Wolf MC, Wolf L, Kulau U. A Precise, Parallel and Scalable Mea-¨ surement System for Ballistocardiographic Research. Smart Health. 2021;19:100169.

[7] Jähne-Raden N, Kulau U, Gütschleg H, Clausen T, Jura T, Sigg S, et al. How is your Heart Acceleration: The Collection of BCG Ground-Truth Data; 2019.

[8] Baevskii RM, Egorov AD, Kazarian LA. SEISMOCARDIOGRAPHY. Kardiologiia. 1964 Mar;4:87-9.