Wearable Monitoring: a Project for the Unobtrusive Investigation of Sleep Physiology Aboard the International Space Station

Marco Di Rienzo, Emanuele Vaini, Prospero Lombardi

Dept. of Biomedical Technology, Fondazione Don Carlo Gnocchi ONLUS, Milano, Italy

Abstract

Several aspects of sleep physiology in microgravity are still unclear, including the determinants of the poor sleep quality often reported by the astronauts during space missions. In addition, simple and unobtrusive monitoring devices for the data collection are needed for sleep studies in microgravity to facilitate the experiment setup, and to interfere as less as possible with the sleep comfort.

The Wearable Monitoring experiment is part of the Futura Mission of the Italian Space Agency and aims to 1) validate the applicability of a new smart garment (MagIC-Space) for the monitoring of vital signs during spaceflights; and 2) by using this device, monitor astronaut's autonomic nervous control, heart electrical and mechanical activity, skin temperature and breathing patterns during sleep in microgravity.

One astronaut was recruited and seven inflight sleep recordings were made aboard the International Space Station from January till June 2015. Two preflight and two postflight reference sleep recordings were also done on Earth.

The first objective of the project has been successfully achieved, in that the smart garment allowed all recordings to be made as planned and provided signals of good quality (~98% of the recorded data is available for the subsequent analyses). With regard to the second objective, the data analysis is in progress.

1. Introduction

Several aspects of sleep physiology in microgravity are still unclear, including the determinants of the poor sleep quality often reported by the astronauts during space flights [1]. In addition, innovative technologies are required for an easy and unobtrusive assessment of the crewmembers' vital signs during long term space missions. Simplified monitoring approaches may ease the frequent control of the astronauts' health status and facilitate the investigation of the mechanisms underlying the human adaptation to microgravity. The Wearable Monitoring (WM) Project aims to focus on both the technological and biological issues mentioned above. In the following we provide a description of the project and a report on the preliminary results we obtained so far.

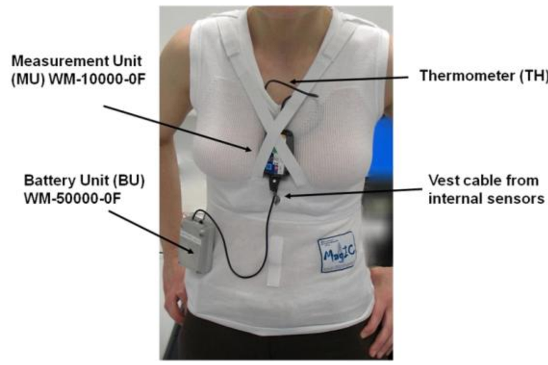

Figure 1 - Model wearing the MagIC-Space mockup. Arrows indicate the system components.

2. The Project

WM is an experimental project part of the Futura Mission, a research programme aboard the International Space Station (ISS) organized by the Italian Space Agency. The activities of the programme were carried out during the ISS Expedition 42/43 from November 2014 to June 2015.

WM had two objectives.

- The first objective has a technological nature and is aimed to validate a new textile-based system (MagIC-Space) for the assessment during sleep in microgravity of ECG, respiration, skin temperature, and the thorax vibrations produced by the beating heart (i.e. the seismocardiogram, see section 4).

- The second objective has a biological focus and is aimed to collect data on different facets of sleep physiology in space by using the above-mentioned device. Among them, (a) the beat-to-beat behavior of cardiac mechanics; and (b) the occurrence of non-rhythmic spontaneous activations of the sympathetic nervous system.

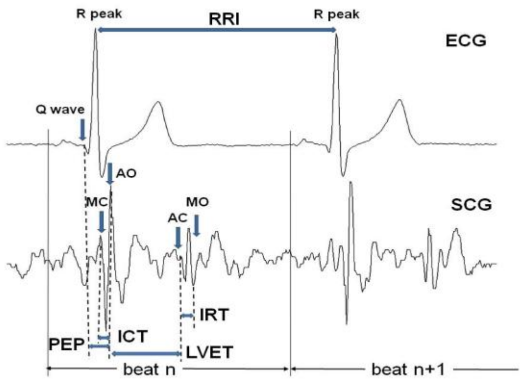

Figure 2. *Upper panel:* ECG complex. *Lower panel:* SCG waveform and fiducial points considered for the parameter extraction (see methods). MC= Mitral valve Closure, AO= Aortic valve Opening, AC= Aortic valve Closure, MO= Mitral valve Opening. Redrawn from [2], by permission.

3. The MagIC-Space device

The device developed for this project is derived from a smart garment previously designed in our lab (MagIC system [2]). The original device has been enhanced to meet the space qualification requirements and simplify the experiment setup and execution. A mockup of the final device is illustrated in fig. 1. The system is composed of 1) a cotton vest embedding textile sensors for ECG and respiratory assessment; 2) a miniaturized electronic module (the Measurement Unit, MU) for the signal conditioning and storage; this unit also contains a triaxial MEMS accelerometer (Freescale MMA8451Q) for the detection of the precordial vibrations generated by the beating heart from which indexes of cardiac mechanics are estimated; 3) a thermometric probe integrated into the vest for the measure of the skin temperature on the thorax; and 4) the battery pack, containing two AA 1.5v Lithium batteries.

Given the structure of the device, no sensor has to be placed on the body and this feature drastically reduced time and complexity of the experiment setup.

All signals are sampled at 200 Hz. In the subsequent analyses, the time position of the R peaks in the ECG and of the fiducial points in the seismocardiogram (see next sections) was determined after parabolic interpolation of the peaks to increase the temporal resolution of the localization.

4. The seismocardiogram

The seismocardiogram (SCG) is the measure of the precordial vibrations produced at every heartbeat by the cardiac contraction and relaxation and by the blood ejection from the ventricles into the vascular tree.

The typical SCG waveform is illustrated in fig. 2 together with the fiducial points associated with the opening and closure of the aortic and mitral valves. The correspondence between those SCG fiducial points and the real cardiac events was previously verified by simultaneous measurements with ultrasound techniques [3].

SCG may be assessed by placing an accelerometer in contact with the sternum of the subject and considering the dorso-ventral acceleration component. As detailed in section 6, from the joint analysis of SCG and ECG, indexes of cardiac mechanics are derived.

In the MagIC-Space device, the accelerometer is contained in the MU and this unit is kept in contact with the subject's sternum by elastic straps (see fig.1) to guarantee the SCG measure.

5. Experiment schedule and protocol

One female crewmember was recruited for the experiment. Seven inflight sleep recordings were made from January till June 2015 at mission days 53, 55, 56, 80, 116, 142 and 192.

In each experimental session the astronaut (a) worn the MagIC-Space system and activated the data recording before going to sleep; (b) free floated for 5 minutes to obtain baseline pre-sleep values; (c) went to sleep; and (d) on the awakening the following morning, stopped the recording, and by a USB cable transferred data from the MU to a laptop aboard the ISS for the data downlink to Earth.

Two preflight and two postflight reference sleep recordings were also performed on October 2014 and July 2015 in Cologne on the same crewmember.

6. Preliminary results

6.1. Technological Objective

The activities related to this objective terminated on

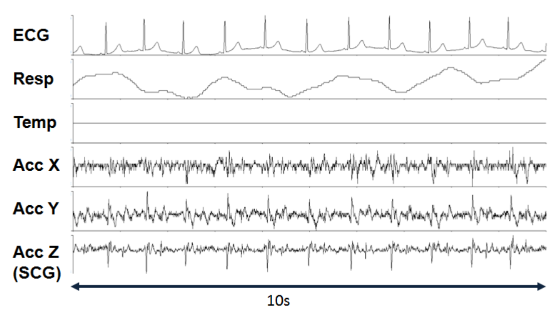

Figure 3 - Example of signals collected during the first inflight sleep recording. *From top to bottom*: ECG; Respiration; Skin Temperature; X, Y and Z acceleration components. SCG is the Z (dorso-ventral) component of acceleration.

July 2015 with the last two postflight sleep recordings.

The smart garment provided good quality recordings for all the planned experimental sessions and ~98% of the data are available for the subsequent analyses. A segment of data recorded during sleep aboard the ISS is shown in fig.3.

No issue was reported on the cleanliness or odor of the smart garment after 5 months of use in space.

Thus the first objective of the project has been successfully achieved.

6.2. Biological Objective

The data collection has recently finished and the analyses have just started. The following are some details of the two analyses we are carrying out at this moment.

ESTIMATION OF THE INDEXES OF CARDIAC MECHANICS - From each sleep recording we are now computing beat-to-beat indexes of heart contractility (Pre Ejection Period, PEP, Isovolumic Contraction Time, ICT, Left Ventricular Ejection Time, LVET) and relaxation (Isovolumic Relaxation Time, IRT) from the timings among the Q wave in the ECG and the instants of opening and closure of the aortic and mitral valves detected by the AO, AC, MO and MC fiducial points in the SCG (see fig. 2).

A segment of the time profiles of these indexes derived from the first inflight sleep recording is shown in fig. 4. To the best of our knowledge this is the first representation of the beat-to-beat behavior of cardiac mechanical variables during sleep in microgravity. The spectra of these variables estimated over a 60s data segment are illustrated in fig. 5. It is apparent the influence of respiration in the spectra of most variables, while the power in the Low Frequency band (0.04-0.15 Hz) is predominantly present only in the RRI spectrum. A similar spectral pattern is also observed during sleep on ground.

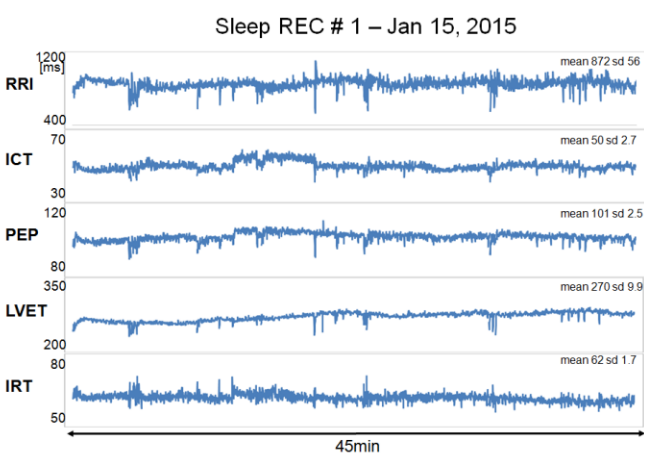

Fig.4 - Segment of beat-to-beat profiles of RRI, ICT, PEP, LVET and IRT estimated from the first inflight sleep recording.

ANALYSIS OF AUTONOMIC ACTIVATIONS - Currently, we are also investigating the presence of non-rhythmic sympathetic activations by the analysis of the RRI profiles during sleep. The rationale behind this activity is that these activations might be associated with autonomic subcortical arousals and their possible abnormal occurrence might be a co-factor responsible for the poor sleep quality in space.

In literature, these sympathetic activations are associated with RRI pattern characterized by a first profound tachycardic phase, lasting several tens of beats, followed by a relatively shorter bradycardic phase that brings the RRI values back to baseline. An example of this pattern is reported in fig. 6. The search for this pattern in the ground and inflights sleep recordings is in progress.

7. Applicability on earth

On Earth, about 25% of western population is affected by sleep disorders which are commonly studied using complex devices that require specialized operators and long time for the instrument setup. The ground version of the payload and the software procedures specifically developed for the data analysis might simplify the patients' monitoring during sleep on Earth and allow the assessment of indexes of autonomic neural control, and of cardiac mechanics in addition to the traditional vital signs. This methodology might be also easily integrated

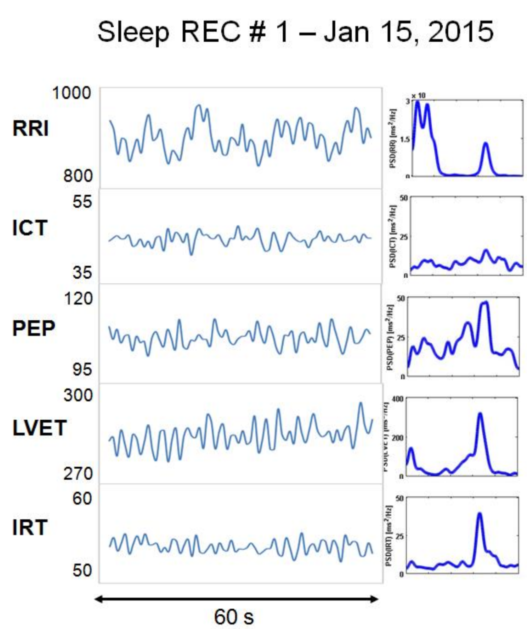

Figure 5 - Detail of a 60s data segment derived from the profiles reported in fig.4 with respective spectra.

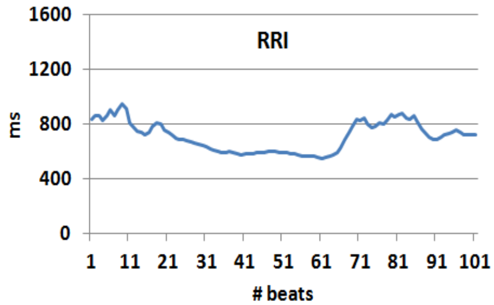

Figure 6 - Typical RRI pattern reported to be associated with autonomic activations during sleep.

in telemedicine platforms for the remote surveillance of patients at risk and as part of continuity of care programmes.

Acknowledgements

This research is supported by the Agenzia Spaziale Italiana contract 2013- 061-I.O, and for the signal analysis by the Agenzia Spaziale Italiana contract 2013-079-R.0

References

[1] Dijk DJ, Neri DF, Wyatt JK, Ronda JM, Riel E, Ritz-De Cecco A, Hughes RJ, Elliott AR, Prisk GK, West JB, Czeisler CA. Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights. Am J Physiol, 2001, 281: R1647-R1663.

[2] Di Rienzo M, Vaini E, Castiglioni P, Lombardi P, Parati G, Lombardi C, Meriggi P, Rizzo F. Wearable seismocardiography for the beat-to-beat assessment of cardiac intervals during sleep. Conf Proc IEEE Eng Med Biol Soc. 2014;2014:6089-91.

[3] Crow R, Hannan P, Jacobs D, Hedquist L, Salerno D. Relationship between seismocardiogram and echocardiogram for events in the cardiac cycle. Am J Noninvas Cardiol, 1994, 8:39-46.

Address for correspondence.

Marco Di Rienzo
Dept. of Biomedical Technology
Fondazione Don Carlo Gnocchi ONLUS
Via Capecelatro 66
20148 Milano (I)
mdirienzo@dongnocchi.it