34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Seismocardiography While Sleeping at High Altitude

Paolo Castiglioni, Paolo Meriggi, Francesco Rizzo, Emanuele Vaini, Andrea Faini, Gianfranco Parati and Marco Di Rienzo, *Member, IEEE*

***Abstract*— Current advancements in sensor technology allow the prolonged assessment of the seismocadiogram (SCG) out of the laboratory setting. Aim of this study is to evaluate whether SCG, as measured by a recently proposed wearable device, can detect cardio-respiratory alterations during sleep in healthy subjects exposed to high altitude hypoxia.**

Sternal SCG, ECG, respiration and oxygen saturation were recorded by a smart garment (the MagIC-SCG system) in 6 volunteers at 4554 m asl during night sleep. Recordings were repeated at sea level in two subjects. Periods with and without sleep apneas (known to occur at high altitude) were selected for the analysis. SCG components associated to the first (S1) and second (S2) heart sound and the swing of low-frequency SCG were assessed in each segment.

As compared with sea level data, SCG waves showed a larger S1 component and a larger low-frequency swing at high altitude. The magnitude of these features did not differ in data segments with and without sleep apneas.

The recordings showed that our smart garment can assess SCG during sleep in extreme environment. Results suggest that 1) hypobaric hypoxia during sleep induces alterations in SCG parameters related to cardiac mechanics and 2) these alterations are not related to the occurrence of sleep apneas.

I. Introduction

The seismocardiogram, SCG, belongs to a "family" of physiological signals (including the ballistocardiogram, the kinetocardiogram and the apexcardiogram) which measures the mechanical effects of cardiac activity on the body in terms of vibrations, displacements, velocities or accelerations [1;2]. In particular, the SCG consists in the assessment of precordial vibrations induced by the beating heart as detected by an accelerometer usually placed on the sternum [3]. This field is living a renovated interest [4] thanks to advancements in sensors technology. Recently, a smart garment (the MagIC system) was modified by our group for the prolonged and unobtrusive assessments of SCG out of the laboratory setting [5-7].

Aim of the present study is to evaluate whether seismocardiography, as assessed by our device, allows detecting possible alterations in cardiac mechanics occurring during sleep at high altitude. In fact, high altitude with its low oxygen pressure represents a hostile environment for human beings. This environmental context may become particularly critical during sleep because of the frequent occurrence of central sleep apneas that further reduce the already low blood oxygen content [8].

P. Castiglioni, P. Meriggi, F. Rizzo, E. Vaini and M. Di Rienzo are with Biomedical technology Dept., Don C. Gnocchi Foundation, via Capecelatro 66, I 20148 Milan, Italy (e-mail: pcastiglioni@dongnocchi.it).

G. Parati and A. Faini are with San Luca Research Hospital, Istituto Auxologico Italiano, Milan, Italy.

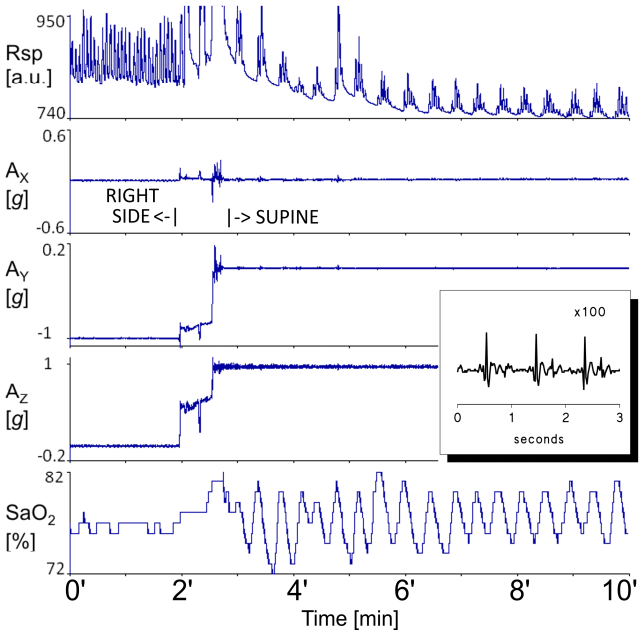

Figure 1. 10-minute segment of respiratory movements (upper tracing), acceleration components on the three axes (mid tracings) and oxygen saturation (lower tracing) in one subject while sleeping at high altitude, with identification of a posture change from right-side (A_X=0, A_Y=-1, A_Z=0) to supine (A_X=0, A_Y=0, A_Z=+1) position. The inset shows few seconds of A_Z magnified by a factor 100. Note the sequence of sleep apneas occurred after the change of posture.

II. Methods

A. The MagIC Wearable System for Sternal SCG

The wearable system for recording sternal SCG, named MagIC-SCG, is derived from a garment (the MagIC system) previously developed for monitoring cardiac patients. Details on the original garment have been previously reported [9]. MagIC-SCG consists in a polypropylene vest with textile sensors for recording one ECG lead and respiratory movements of the thorax [7]. Sensors are connected to an electronic board placed inside an elastic pocket of the vest at the sternum level. The sternal SCG vibrations are detected by a tri-axial accelerometer (ST LIS3LV02DL, ±2g, 12bit) located inside the electronic board. The accelerometer axes are oriented as follows: A_X (longitudinal) from head to foot; A_Y (lateral) from right to left; A_Z (sagittal) from front to rear. With this orientation, A_Z has the opposite direction of the mono-axial SCG first described by Salerno and Zanetti [3]. In this experiment an external finger pulseoximeter (Nonin Xpod®, Nonin Inc.) was connected to the electronic board for

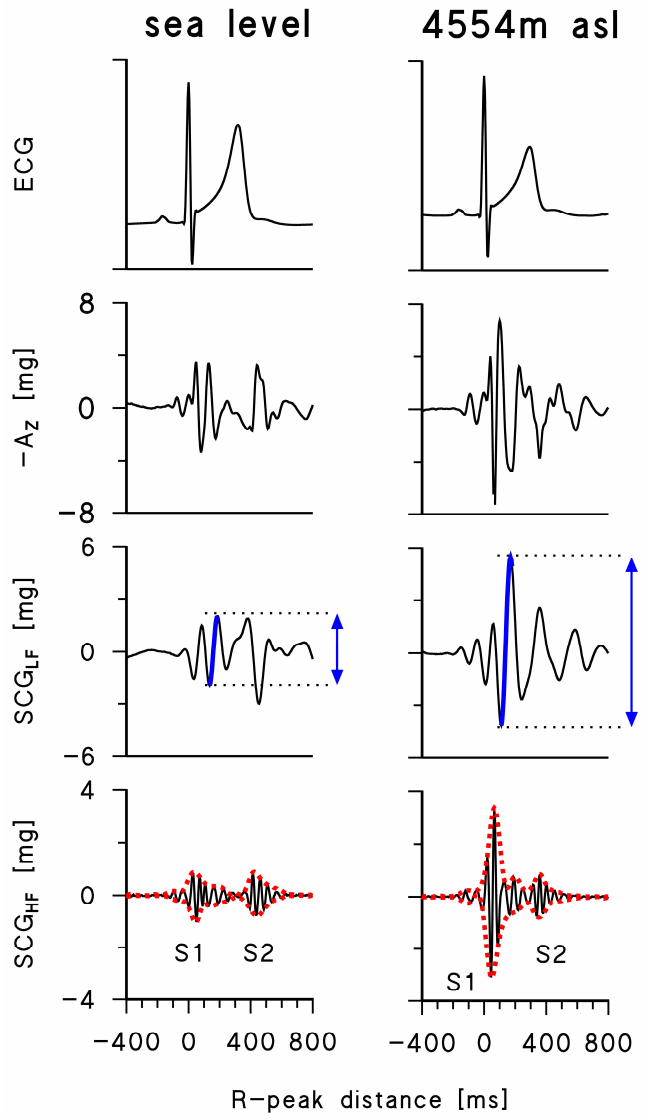

Figure 2. R-peak synchronized averages of ECG, -A_Z, SCG_{LF} and SCG_{HF} in the same subject sleeping supine at sea level and high altitude. Thick segments (blue line) indicate the "swing" component of SCG_{LF}; dotted lines (red) represent the envelope of SCG_{HF}.

the concomitant assessment of the blood oxygen saturation. Details on sampling rate and bit-resolution of each signal can be found in [10].

B. *Subjects and Data Recording.*

We considered recordings from six male healthy subjects participating in a scientific expedition on Monte Rosa (Italian Alps) in the summer of 2010. Experiments were aimed at evaluating different aspects of the physiological adaptation to high altitude and were performed on the Margherita hut (4554 m asl). Subjects reached destination after a two-day trekking from Alagna Valsesia (Vercelli, Italy), spending one night at the Gniffetti hut (3647 m asl). In each subject an overnight monitoring was performed with the MagIC-SCG system during the first night at the Margherita hut. Each recording lasted more than 8 hours. In two subjects an overnight recording was also performed at sea level few days before the expedition departure.

C. *Segments Selection.*

Effects of High Altitude. To evaluate the effects of adaptations to high altitude on SCG, sleep recordings available both at sea level and at 4554 m asl in two subjects were visually inspected to select stable periods in supine position. Supine position was identified from the 3 acceleration components (A_X and A_Y around 0*g*, A_Z around +1*g*, see figure 1). Each selected segment lasted more than 10 minutes.

Effects of Sleep Apneas. To understand whether possible SCG changes associated to high altitude are due to the occurrence of sleep apneas, recordings of the six subjects sleeping at the Margherita hut were visually inspected to identify two stable periods respectively characterized by presence and absence of sleep apneas. Sleep apneas were easily recognized by repeated cessations of breathing movements associated with falls of oxygen saturation (see the example in figure 1).

D. *Data Analysis.*

In each selected segment, the R-peak was identified from the ECG. Then, the infrasound components of SCG were extracted as described in [6]. Briefly, the high-frequency component of the sternal acceleration, SCG_{HF}, was obtained by high-pass filtering (cut-off frequency at 15 Hz) the modulus of the acceleration vector. Ensemble averaging synchronous with the R-peak was then applied to reduce noise. The envelope of the resulting wave was calculated by interpolating maxima and minima with spline functions (lower panels in figure 2). The SCG_{HF} envelope typically shows two components associated to the first (S1) and second

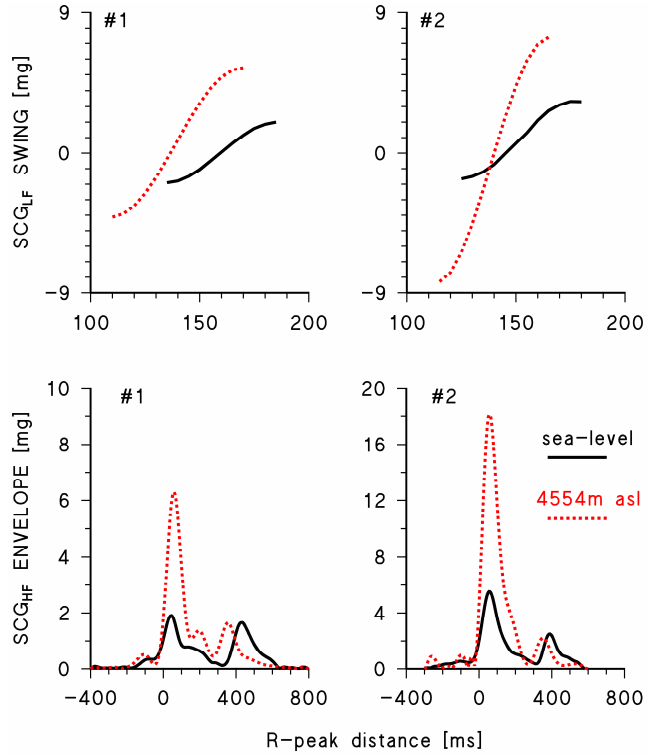

Figure 3. Swings of SCG_{LF} (upper panels) and amplitudes of SCG_{HF} envelopes (lower panels) at sea level (black continuous line) and high altitude (red dotted line) plotted separately in two subjects.

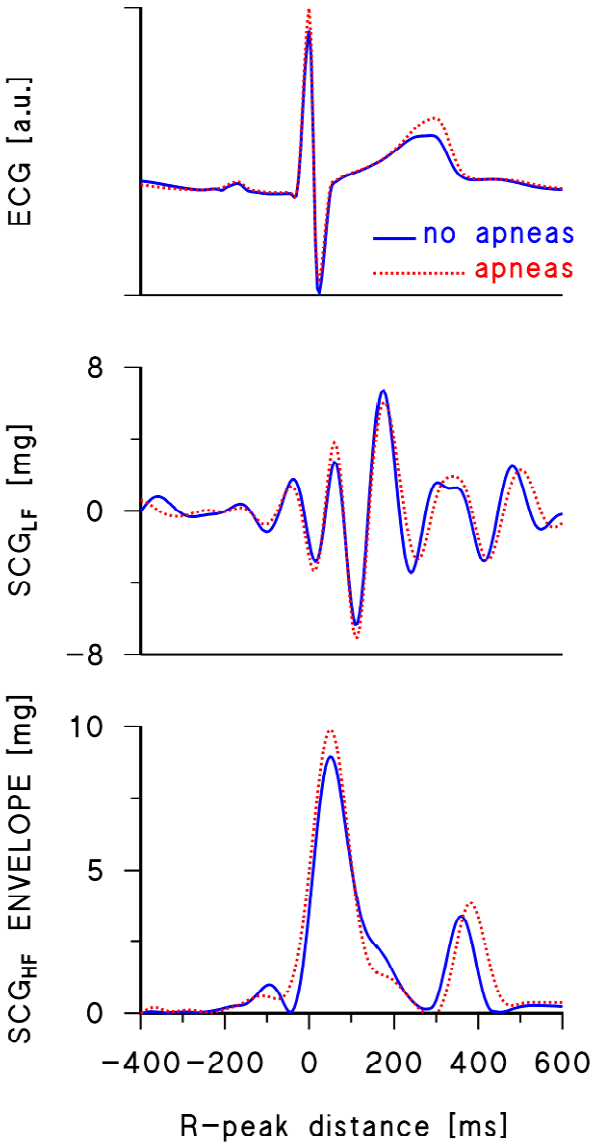

Figure 4. Comparison of ECG, SCG_{LF} and amplitude of SCG_{HF} envelopes in one subject while sleeping at high altitude in supine position with (red dotted line) and without (continuous blue line) apneas.

(S2) heart sound [6]. The envelope amplitude was calculated as difference between upper and lower splines; S1 and S2 components were derived from the amplitude maxima.

Similarly, the low-frequency component of the sternal acceleration, SCG_{LF}, was obtained by low-pass filtering the acceleration modulus (cut-off frequency at 15 Hz) and by applying an R-peak synchronized averaging with mean removal. The amplitude of the SCG_{LF} wave was quantified by the "SCG_{LF} swing", defined as the larger increase among SCG_{LF} oscillations occurring between S1 and S2 (see figure 2). In the following section, average data are presented as mean (SD).

III. Results

All subjects found the smart garment easy to wear, comfortable, and not interfering with the quality of sleep.

A. *Effects of High Altitude*

In the two volunteers monitored with the MagIC-SCG device during sleep both at sea level and at 4554 m, the R-R interval decreased sleeping at high altitude. On average, it decreased from 1121 (219) ms at sea level to 841 (242) ms at high altitude. Figure 2 shows the synchronized averages of the SCG components for one of the two subjects. The $-A_Z$ component was greater at high altitude than a sea level. The nature of the alteration appears more clearly by considering SCG_{LF} and SCG_{HF} separately. Sleep at high altitude was characterized by a larger swing of SCG_{LF} and by a larger amplitude of SCG_{HF} in correspondence of the first heart sound. Figure 3 compares SCG_{LF} swings and SCG_{HF} envelopes at sea level and high altitude in both the volunteers. SCG_{LF} swings and S1 component of SCG_{HF} envelopes were larger at high altitude. On average, swings increased from 4.4 (0.7) to 12.3 (4.6) mg, and the S1 component from 3.7 (2.6) to 12.2 (8.4) mg. By contrast, the amplitude of the S2 component of the envelope did not appear substantially altered at high altitude, being equal to 2.1 (0.6) at sea level, and to 1.9 (0.4) at 4554 m asl.

B. *Effects of Sleep Apneas*

For this analysis, it was possible to identify a stable period with and without sleep apneas of at least 150 s in all subjects. The mean R-R interval was only slightly longer in periods with apneas, 880 (130) ms, than in periods without apneas, 800 (70) ms. Figure 4 compares the R-peak synchronized averages of ECG, of SCG_{LF} and of the SCG_{HF} envelopes calculated over the segments with and without apneas in one subject sleeping at high altitude. Waveforms appear substantially similar in the two conditions.

Results over the whole group of N=6 subjects are shown in figure 5. Sleep apneas did not change substantially the SCG_{LF} swing and the S1 and S2 components of the SCG_{HF} envelope.

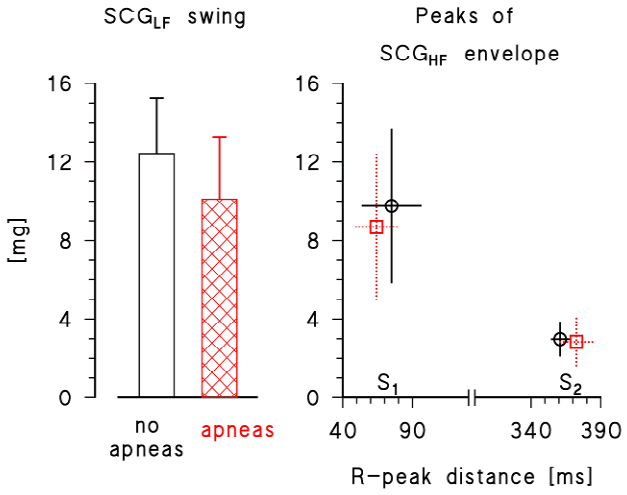

Figure 5. Effects of sleep apneas on SCG components: mean +SD. Left: SCG_{LF} swing without (open bar) and with (dashed bar) apneas. Right: amplitude and time distance from the R-peak of first (S1) and second (S2) component of SCG_{HF} envelopes without (black circle, continuous line) and with (red square, dotted line) sleep apneas.

IV. Conclusion

Our study demonstrated the feasibility of overnight monitoring of SCG during sleep even in the difficult conditions characterizing a high-altitude environment. In particular, the joint analysis of ECG, sternal accelerations, respiratory movements and oxygen saturations made possible by our system allowed us to extract SCG features in different postural and respiratory conditions. This finding supports the use of this device in future studies aimed at clarify aspects of cardiorespiratory adaptations to high altitude

Our analysis suggests the existence of SCG alterations associated to high altitude, although the small number of subjects considered in this study does not allow us to reach firm statistical conclusions. Results in fact suggest that acute exposure to high altitude increases the first heart-sound component and the following rise of sternal acceleration (SCG_{LF} swing), without substantially altering the second heart-sound component. We also observed that these changes were independent from the occurrence of sleep apneas.

Several physiological mechanisms may be involved in these alterations, including increased ventilation, pulmonary hypertension (with a possible risk for pulmonary edema), decreased oxygen saturation, increased sympathetic activity with increased heart rate [11]. All these factors might influence the cardiac mechanics and the cardio-respiratory coupling, thus leaving the biological interpretation of our findings an unresolved puzzle at the moment.

References

[1] K. Tavakolian, B. Ngai, A. P. Blaber, and B. Kaminska, "Infrasonic cardiac signals: Complementary windows to cardiovascular dynamics," *Conf. Proc. IEEE Eng Med Biol Soc.*, pp. 4275-4278, Aug.2011.

[2] I. Starr and A. Noordergraaf, *Ballistocardiography in cardiovascular research*. Amsterdam: North-Holland, 1967.

[3] D. M. Salerno and J. Zanetti, "Seismocardiography: A New Technique for Recording Cardiac Vibrations. Concept, Method, and Initial Observations," *J Cardiovasc Technol*, vol. 9, pp. 111-118, 1990.

[4] L. Giovangrandi, O. T. Inan, R. M. Wiard, M. Etemadi, and G. T. A. Kovacs, "Ballistocardiography: A method worth revisiting," *Conf. Proc. IEEE Eng Med Biol Soc.*, pp. 4279-4282, Aug.2011.

[5] P. Castiglioni, A. Faini, G. Parati, and M. Di Rienzo, "Wearable seismocardiography," *Conf. Proc. IEEE Eng Med Biol Soc.*, vol. 2007, pp. 3954-3957, 2007.

[6] P. Castiglioni, P. Meriggi, F. Rizzo, E. Vaini, A. Faini, G. Parati, G. Merati, and M. Di Rienzo, "Cardiac sounds from a wearable device for sternal seismocardiography," *Conf. Proc. IEEE Eng Med Biol Soc.*, pp. 4283-4286, Aug.2011.

[7] M. Di Rienzo, P. Meriggi, F. Rizzo, E. Vaini, A. Faini, G. Merati, G. Parati, and P. Castiglioni, "A wearable system for the seismocardiogram assessment in daily life conditions," *Conf. Proc. IEEE Eng Med Biol Soc.*, pp. 4263-4266, Aug.2011.

[8] U. Eichenberger, E. Weiss, D. Riemann, O. Oelz, and P. Bartsch, "Nocturnal periodic breathing and the development of acute high altitude illness," *Am. J. Respir. Crit Care Med.*, vol. 154, no. 6 Pt 1, pp. 1748-1754, Dec.1996.

[9] M. Di Rienzo, P. Meriggi, F. Rizzo, P. Castiglioni, C. Lombardi, M. Ferratini, and G. Parati, "Textile technology for the vital signs monitoring in telemedicine and extreme environments," *IEEE Trans Inf. Technol. Biomed*, vol. 14, no. 3, pp. 711-717, May2010.

[10] P. Meriggi, P. Castiglioni, C. Lombardi, F. Rizzo, P. Mazzoleni, A. Faini, M. Di Rienzo, and G. Parati, "Polysomnography in extreme environments: The MagIC wearable system for monitoring climbers at very-high altitude on Mt. Everest slopes," *Computing in Cardiology, 2010*, pp. 1087-1090, Sept.2010.

[11] J. S. Milledge, "Altitude medicine and physiology including heat and cold: a review," *Travel. Med. Infect. Dis.*, vol. 4, no. 3-4, pp. 223-237, May2006.