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

24h Seismocardiogram Monitoring in Ambulant Subjects

M. Di Rienzo, *Member, IEEE*, P. Meriggi, E. Vaini, P. Castiglioni, F. Rizzo

Abstract— **Sternal seismocardiogram (SCG) is the assessment of microvibrations produced by the beating heart as detected by an accelerometer positioned on the sternum. This signal reflects mechanical events of the heart contraction, including the opening and closure of mitral and aortic valves and maximal blood flow acceleration. Traditionally, SCG has been detected in a laboratory setting with the subject lying at rest in supine position. Aims of this study were 1) to investigate the feasibility of a SCG monitoring over the 24 hours in ambulant subjects, and 2) to calculate number and time distribution of the SCG estimates obtainable over the 24 hours.**

In 5 healthy subjects ECG, respiration, body accelerations and sternal SCG were recorded for 24 hours in a workday by a smart garment recently developed in our laboratory, the MagIC-SCG system. Each recording was split into a series of contiguous 5-s data segments and SCG was estimated in each segment where the magnitude of the acceleration vector was <4 milli-g (this condition indicates that the subject was not moving).

All the 24-h recordings were found of good quality and could be entirely analyzed. A large number of SCG estimates could be obtained over the 24 hours. In particular, more than 100 estimates per hour were available during the day; at night this rate was three times higher.

Thus our study indicates that not only the 24h SCG monitoring in daily life is feasible but also that possible changes over time in SCG and its derived parameters may be tracked with an extreme temporal detail.

I. Introduction

Sternal seismocardiogram (SCG) is the assessment of microvibrations produced by the beating heart as detected by an accelerometer positioned on the sternum. For each heart beat an SCG waveform is produced with a repetitive structure including several peaks and valleys that reflect mechanical events of the heart contraction, including the opening and closure of mitral and aortic valves and the instant of maximal blood flow acceleration [1]. Thus the analysis of this signal may provide insights into mechanical aspects of the heart function (or dysfunction). Since the first measurements made in the early '60s, SCG has been detected in a laboratory setting with the subject lying at rest in supine position. The subsequent availability of echocardiography made the laboratory evaluation of cardiac mechanics more comprehensive and the interest in the SCG progressively dropped. However, advancements in sensor technology make now conceivable the unobtrusive self-assessment of SCG out of the laboratory environment and open the unique opportunity to investigate features of cardiac mechanics over the 24 hours.

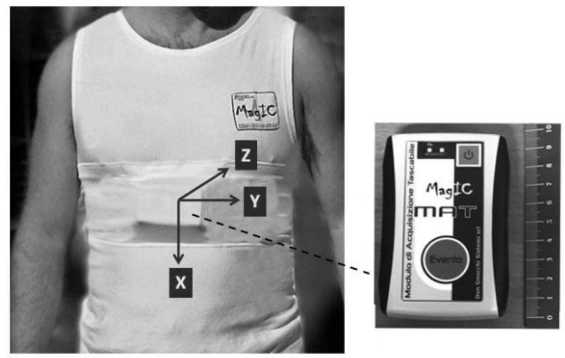

Fig.1 - *Left panel:* the MagIC-SCG garment with orientation of the accelerometric axes: x (longitudinal: head-foot), y (lateral: right-left), z (sagittal, front-back). *Right panel:* the electronic board, to be located into the vest pocket at the sternum level.

In this context, we recently proposed a smart garment (MagIC-SCG) able to monitor body acceleration, sternal SCG, ECG and respiration during spontaneous behavior [2, 3]. So far the system has been used to collect biological data out of the laboratory setting for a limited number of hours during sleep at high altitude [4] and during parabolic flights. These recordings made it clear that in unrestrained conditions the SCG can be detected only when the subject is not moving. Indeed, major body accelerations occurring during walking, running, or while performing physical activity completely mask the weak SCG signal that has a magnitude in the order of few milli-gs. This means that in daily life we can expect to get a series of intermittent SCG estimates over time, each obtained whenever the subject is spontaneously still.

In this study we extend our exploration of the potentialities of the SCG measurement in unrestrained conditions, and address, for the first time, methodological aspects related to the SCG assessment over the 24 hours. In particular, we 1) investigated the feasibility of a 24h SCG monitoring by the MagIC-SCG garment, and 2) computed number and time distribution of the SCG estimates obtainable over the 24 hours.

II. Methods

A. The MagIC-SCG system

Details on the MagIC-SCG garment used in this study to collect biological data can be found in [2]. In summary, this

M. Di Rienzo (corresponding author), P. Meriggi, E. Vaini, P. Castiglioni and F. Rizzo are with the Department of Biomedical Technology, Fondazione Don Carlo Gnocchi, ONLUS, Milano, Italy (Phone: +39-02-40308305; fax: +39-02-4048919; mdirienzo@dongnocchi.it).

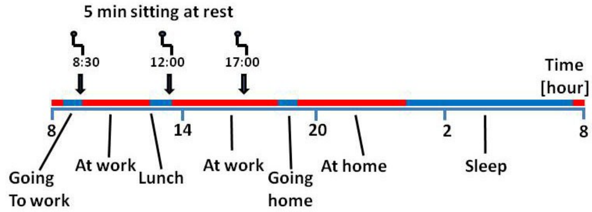

Fig.2 - Average activity schedule of the five subjects during the 24h recording

system is composed of a textile vest and an electronic board (see fig.1). The vest, made of cotton and elastan, embeds textile electrodes for the assessment of one-lead ECG and respiratory thorax movements. The biological signals detected by the sensors reach the electronic board, having size and weight of a cellular phone, through connections made of conductive textile fibers. The electronic board includes a triaxial accelerometer (ST LIS3LV02DL, ±2g, 12 bit), and is inserted into a vest pocket so to be in contact with the sternum. All data are sampled at 200Hz and locally stored on a memory card or transmitted to external devices via a Bluetooth connection.

As shown in fig.1 the original orientation of the A_Z component of our accelerometer is opposite to the dorso-ventral direction proposed by Salerno and Zanetti [1]. To facilitate the comparison with available literature, our SCG data are shown after the change in direction.

B. *Subjects and experimental protocol.*

Five healthy subjects (age range: 25-58 yrs) where recruited for the study. They worn the MagIC-SCG garment for 24 hours in a workday starting from 8 a.m. During the recording they were asked to follow their usual habits as to the work, meals and sleep times. All subjects were researchers and thus their work activity included a mix of work at the computer and experimental activity in the research laboratory. Additionally, during the monitoring they were asked to sit and stay still for 5 minutes at three different times (8:30 a.m., 12:00 a.m., 5:00 p.m.). The average activity schedule is schematized in fig. 2.

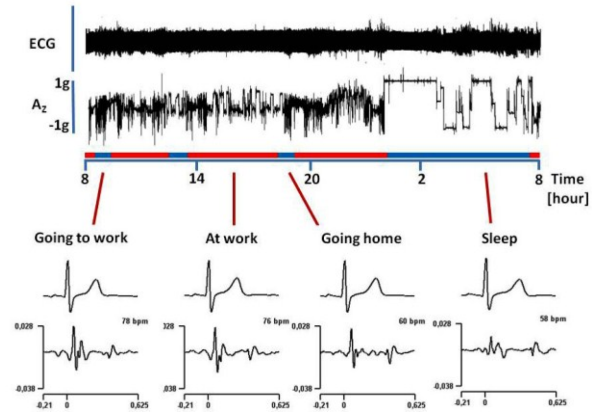

Fig. 4 - Example of a 24-h recording (here only ECG and A_Z are represented to improve readability) and samples of average SCG estimates obtained going to work, at work, going home and during sleep).

Two subjects also underwent two additional 8-min recordings performed after 10 and 12 days from the 24h recording, indicated as T_0+10 and T_0+12, respectively. This was done to explore the repeatability over time of the SCG assessment by the MagIC-SCG garment. During these short recordings, the subjects were asked to remain still for two minutes in each of the following controlled conditions: sitting, lying supine, lying on the left side, lying on the right side.

Although all the three orthogonal acceleration component of SCG have been recorded, in this study we only consider the sagittal component, A_Z, to estimate the SCG waveform, as in common practice.

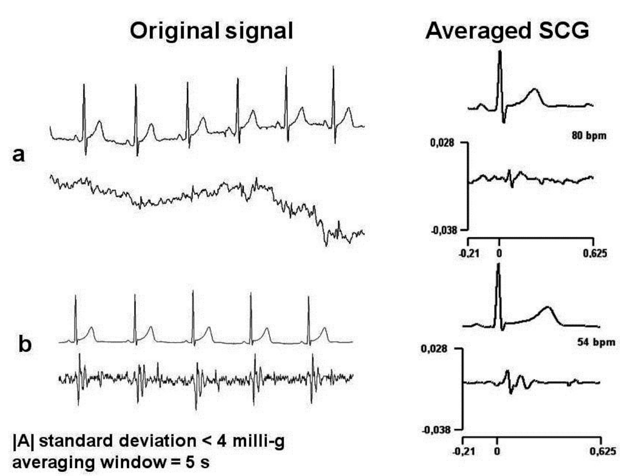

Fig. 3 -Typical range in SCG quality observed in the 5s motionless data segments as identified by our algorithm with a standard deviation of |A| <4milli-g. *Left panels*: (a) worst case, (b) best case. *Right panels:* Corresponding averaged SCG waveforms.

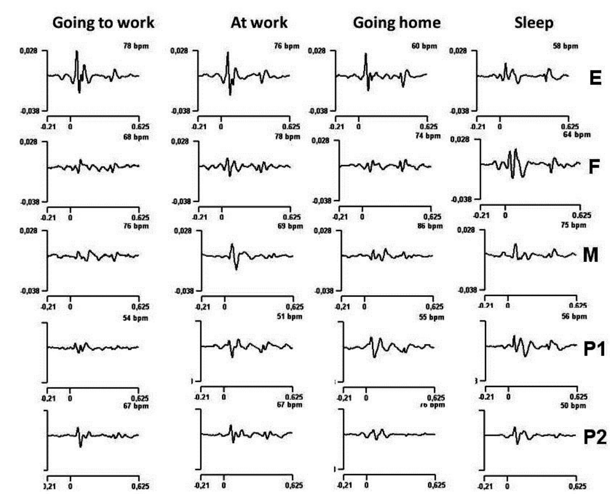

Fig. 5 - Individual samples of SCG estimates obtained from the 24h recordings at different times of the day. The abscissa refers to the time, in ms, with respect to the R peak of the ECG (0 is the time of occurrence of the R peak). All vertical axes have the same scale to allow a comparison of signal amplitude among subjects.

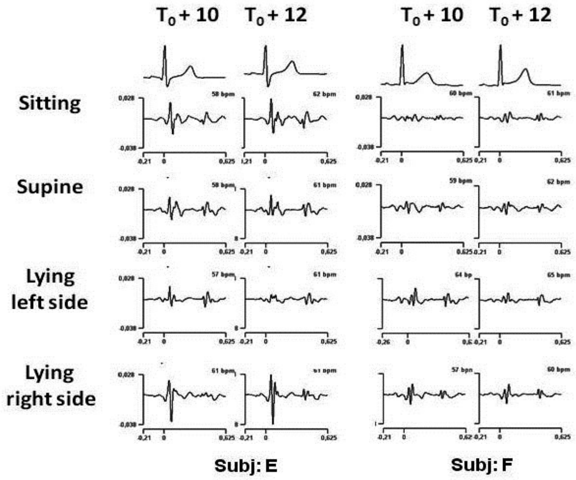

Fig. 6 - Repeatability of individual SCG waveforms over time in two subjects in different postures.

C. *Data analysis*

As a first step, each 24h recording was split into a series of consecutive 5-second data segments. Then we identified the data segments where the subject was still. This was done by verifying that the standard deviation of the magnitude of the acceleration vector was < 4 milli-g. The threshold value was empirically determined by ensuring that the quality of the A_Z component of SCG in the under-threshold segments was adequate to be further analyzed as indicated in the following paragraphs. From now on these segments will be referred to as "motionless data segments". An example of the range in the quality of SCG obtainable by a 4 milli-g threshold is illustrated in fig. 3. It is worth noting that with this threshold value the average SCG waveform can be estimated even in the worst case shown in the upper panels.

For each recording, the time location of each motionless segment was stored in a table and the hourly distribution of these segments was computed for each subject and averaged over the group.

As mentioned, the sternal SCG was estimated from the sagittal accelerometric component A_Z. Low frequency oscillations of the baseline induced by respiration were preliminarily removed from this component. This was done by performing a wavelet decomposition (based on the db4 mother wavelet) of the whole 24h A_Z series and removing the level 6 approximation component, a_6, from the original signal. For each 5-second motionless segment, the average SCG waveform was estimated from the detrended A_Z series as follows: 1) the R peak was identified from the ECG, 2) the detrended A_Z included in the data segment was subdivided into individual heart beats; 3) the average SCG waveform was then estimated by the ensemble averaging, synchronized with the R-peak. The above procedure was also used to estimate SCG in the 8-minute recordings performed at T_0+10 and T_0+12.

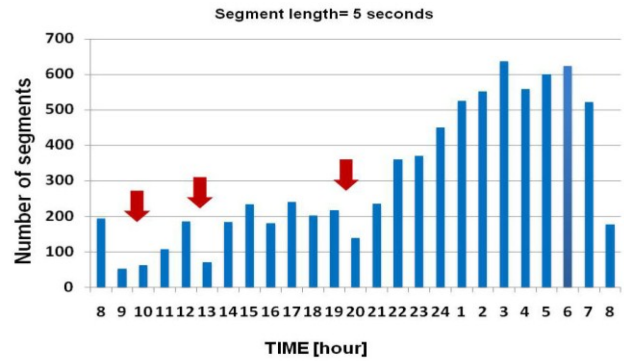

Fig. 7 - Hourly distribution of 5-second motionless data segments. Data are averaged over the whole group of 5 subjects. Arrows point at moments of the day characterized by an expected increased signal instability (*from left to right*: going to work, lunch-time, and going home).

III. Results

A. *Feasibility of a 24h SCG monitoring by MagIC-SCG*

All the 24h recordings were found of good quality and could be entirely analyzed. In particular for the acceleration data, no fault was observed and it has been always possible to indentify the level of movement, the subject posture and, whenever the subject was still, the SCG. A 24h recording with samples of the SCG estimates obtained while going to work, at work, while going home and during sleep is reported in fig. 4. It can be noted that the typical structure of the SCG waveform is preserved at any time. Samples of the average SCG in the same above conditions for all the five subjects are shown in fig. 5. The detailed analysis of the SCG morphology over the 24h is out of the purposes of this study, however it is apparent a large inter-subject variability in the amplitude and shape of the signal. In each subject the SCG morphology may change over time, although to a lesser extent.

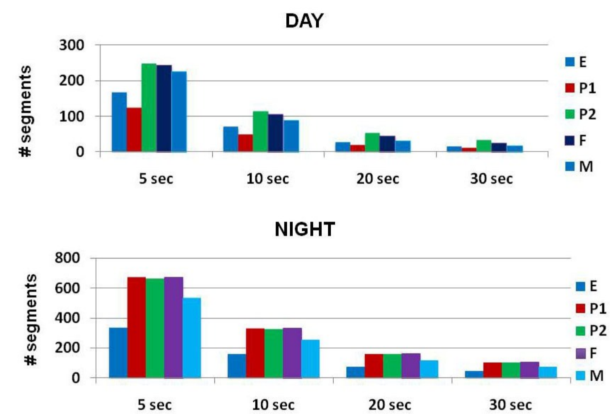

Fig. 8 - Individual hourly rate of the motionless segments averaged over day (upper panel) and night (lower panel). Data are shown as a function of the segment length (estimated by considering consecutive under-threshold 5-s segments).

A first indication on the repeatability of the SCG assessment by the MagIC-SCG garment is given in fig. 6. These data refer to the short recordings performed two days apart while the subjects were in different controlled postures. For each subject it is evident a substantial similarity in the SCG waveforms obtained from the two recordings.

B. Distribution of motionless data segments

The hourly distribution of the 5-s motionless segments over the 24 hours for the whole group of subjects is shown in fig. 7. As expected the larger number of motionless segments was observed at night with more than 400 segments/h. However, an important number of segments was observed also during the day. In this case the minimum number was observed while going to work, at lunch and while going home in the evening, as shown in the figure by the arrows. Still, even in these conditions more than 50 motionless segments/h were on average available to estimate SCG.

The hourly rate of the motionless segment observed in each subject and separately grouped over day and night is reported in fig. 8. It is worth noting that during the awake activity in each subject more that 100 5-s segments/h can be observed on average. In the same figure also the individual distribution of longer motionless segments are shown.

IV. Discussion and Conclusion

For the first time, this study demonstrated the feasibility of a 24h monitoring of SCG in freely moving subjects. This finding makes now conceivable the dynamical assessment of features of cardiac mechanics over day and night, and the investigation on their modulations in response to the different challenges imposed by the everyday living. A key role in this positive outcome was played by the textile system we used for the data collection. The use of this device has largely simplified the measurement procedures and increased the comfort of the subject, because all sensors, including the accelerometer, were embedded in the vest. Thus, once the garment was worn, all sensors were (and remained) in the right position with no need of additional interventions on the subject's body. Moreover the absence of floating cables and adhesive electrodes -that might detach over time- improved the signal quality.

The second novelty of the study refers to the finding that a large number of SCG estimates can be obtained over the 24 hours. Indeed we observed that on average more than 100 motionless data segments are available in each hour of the day for the SCG assessment. At night this number was more than three times greater. These data indicates that possible changes over time in SCG and its derived parameters may be tracked with an extreme temporal detail.

Finally, the observed good quality of the SCG estimates supports the splitting of the whole recording in segments lasting 5 seconds and the threshold for identifying motionless segments to 4 milli-g. Both these values may be not optimal but they worked fine, and may thus represent a good start point for further refinements.

Obviously all the above findings are based on data collected in a limited number of subjects. Further investigations on a larger population of healthy subjects and cardiac patients are in progress to confirm these preliminary observations.

References

[1] 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.

[2] 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.

[3] 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

[4] 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.