Wearable Seismocardiography for the Beat-to-Beat Assessment of Cardiac Intervals During Sleep

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Abstract— **Seismocardiogram (SCG) can be detected during sleep by a textile-based wearable system. This pilot study preliminarily explores the feasibility of a beat-to-beat estimation of cardiac mechanical features (RR interval, RRI, Pre-Ejection Period, PEP, Isovolumic Contraction Time, ICT, Left Ventricular Ejection Time, LVET, Isovolumic Relaxation Time, IRT) from the joint ECG and SCG assessment during sleep. The analysis of two 30-min sleep data segments from one healthy subject, indicated that 1) respiration largely influence the dynamics of most of the parameters; 2) variability of cardiac intervals is only marginally influenced by the RRI variability; 3) appreciable spectral power at frequencies ≤0.1 is only observed in the RRI spectrum and not in the spectra of the other indexes; 4) IRT has a broadband variability, that is clearly different from the dynamics of the other indexes.**

These findings represent the very first description of the beat-to-beat variability of cardiac mechanical indexes. Further investigations on a larger population are in progress to confirm the present results.

I. Introduction

Seismocardiogram (SCG) is the time profile of thorax vibrations produced by the beating heart and can be detected by placing an accelerometer on the chest of the subject. From this signal we may obtain information on aspects of cardiac mechanics, including the opening and closure of mitral and aortic valves, the point of maximal acceleration of the blood in aorta, the isovolumic contraction and relaxation times. Each of the above events corresponds to specific displacements of the SCG waveform as shown in fig. 1.

In 2012 we demonstrated that SCG could be recorded, together with electrocardiogram (ECG) and respiration, in ambulant subjects by a smart garment, the MagIC-SCG system [2]. From the analyses of 24h recordings obtained by this system, we observed that at night, SCG could be estimated almost continuously.

On the above premise, this pilot study aims at exploring on whether indices of cardiac mechanics can be derived on a beat-to-beat basis from SCG recordings performed during sleep.

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II. Methods

In this paper we report on data collected in one healthy subject (age: 26 yrs). ECG, respiration and SCG were recorded during sleep by the MagIC-SCG system. In short, this device is composed of a sensorized vest and an electronic unit. The vest is mainly made of cotton, and incorporates textile sensors for the ECG and respiratory detection obtained from conductive textile fibers. The vest also includes textile conductive pathways to link sensors to the external electronic unit. The electronic module has size and weight of a cell phone and is placed in a pocket on the vest so to be in mechanical contact with the sternum of the subject. The electronics includes a three-axial accelerometer able to detect the SCG vibrations. Data originating from the textile sensors and accelerometer are sampled at 200Hz and locally stored on a memory card. They can also be transmitted in real time to an external device through a Bluetooth connection. Further details on the structure of the system can be found in [2, 3].

The whole sleep recording lasted 8 hours. In the present analysis we focussed on two paradigmatic data segments each lasting 30 min. The first segment (segment A, from 0:07 to 0:37 hours) includes data observed during a sleep phase characterized by a certain stability of the RR Interval

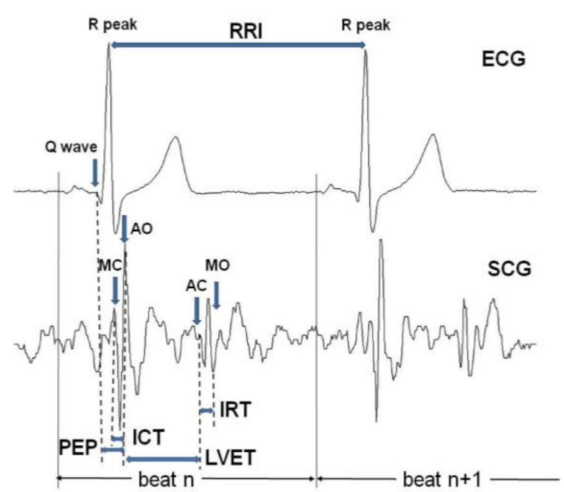

Fig. 1. *Upper panel:* ECG complex. *Lower panel:* SCG waveform and fiducial points considered for the parameter extraction (see methods). MC= Mitral valve Closure, AO= Aortic valve Opening, AC= Aortic valve Closure, MO= Mitral valve Opening (according to Crow et al. [1]). RRI= RR Interval, PEP= Pre Ejection Period, LVET= Left Ventricular Ejection Time, ICT= Isovolumic Contraction Time, IRT= Isovolumic Relaxation Time

(RRI) baseline, while the second segment (segment B, from 2:20 to 2:50 hours) contains an abrupt increase in the RRI mean value caused by a position change.

In each data segment a wavelet-based filtering procedure was applied to the SCG signal to remove a possible slow wandering of the baseline caused by breathing [3]. In short, the original SCG series was decomposed by using the db4 mother wavelet, then the level 6 approximation component (a6) was subtracted from the original signal. The detrended data were segmented into individual heart beats, each starting 200 ms before the ECG R peak. For each beat, RRI was estimated as the interval between consecutive R peaks. From SCG, with reference to the fiducial points illustrated in figure 1, we estimated the following cardiac time intervals, clinically considered as indices of cardiac contractility: the Pre Ejection Period (PEP, as the time interval between the ECG-Q wave and SCG-AO), the Left Ventricular Ejection Time (LVET, as the time interval between SCG-AO and SCG-AC), the Isovolumic Contraction Time (ICT, as the time interval between SCG-MC and SCG-AO) and the Isovolumic Relaxation time (IRT, as the time interval between SCG-AC and SCG-MO).

The detection of the SCG fiducial points, from which the above indexes are derived, has been obtained by an interactive procedure based on 1) a preliminary software scanning of the data with a tentative automatic point location, and 2) a subsequent supervision and editing by an operator. The software was able to correctly detect SCG fiducial points in 97% of the beats in segment A and 87% of the beats in segment B. The development of a fully automatic process is made difficult by the changing amplitude of specific SCG waveform displacements according to the respiratory phase and sleep position (supine, prone, on left or right side). This amplitude variability is mainly observed in the AC and MO peaks, at the end of the systolic phase of the heart cycle. We are still working on the refinement of the detection algorithm in order to improve the efficiency of the automatic procedure.

For each derived index, the average value, standard deviation, coefficient of variation and FFT-derived spectral characteristics were estimated over each data segment.

III. Results

This analysis considered 1615 heart beats for the data segment A, and 1363 beats for the data segment B.

The beat-to-beat profiles of RRI, PEP, ICT, LVET and IRC estimated from the ECG and SCG sleep data segments are shown in fig. 2 and 3. The respective mean, standard deviation and coefficient of variation are reported in table 1.

From the spectra and the detailed profiles in the mid and right panels of fig2 and 3, it is apparent a major influence of respiration on all the time intervals but the IRT. The magnitude of changes ongoing from inspiration to expiration is in the order of 80ms for RRI, 25ms for PEP, 20ms for ICT and 35 ms for LVET.

Concerning the spectral analysis, it is observed that only RRI spectra are characterized by a noticeable amount of power at the lower frequencies (≤ 0.1Hz). This makes it clear that the RRI variability is only in part synchronized with the

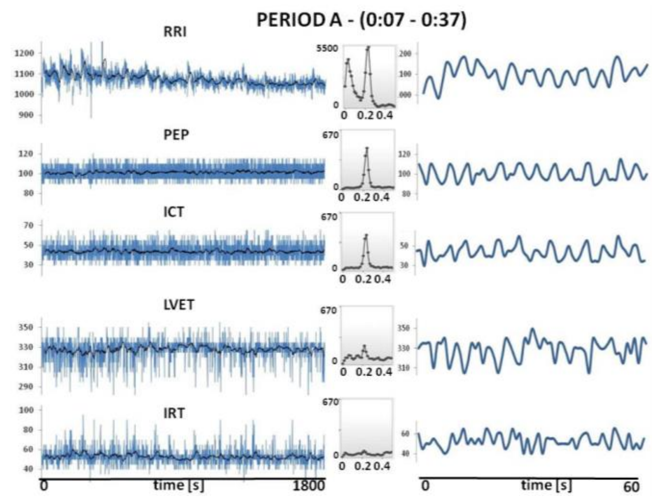

Fig. 2 - First segment of 30-min data.
Left panel: Profile of RRI, PEP, ICT, LVET and IRT over the whole data segment. *Mid panel:* Respective spectra. *Right panel:* Detail of profiles over the first 60s.
Vertical axes represent time periods in ms. Spectral density is shown in ms^2/Hz.

variability of the other parameters. This is even clearer in fig. 3, where an abrupt increase in the RRI mean value occurred. A synchronous upward shift in the mean value was only observed in the ICT, while the mean value of the other parameters remained virtually unchanged. Interestingly, PEP variability, but not its mean value, was reduced of about 50% after the RRI upward shift.

Concerning the IRT, its variability appears to be spread over a large frequency band being little or at all influenced by respiration.

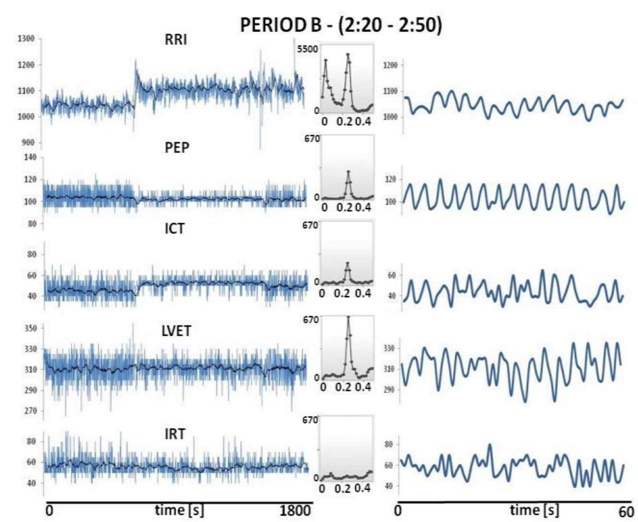

Fig. 3 - Second segment of 30-min data. For details see caption of figure 2.

TABLE I - PARAMETERS OF VARIABILITY FOR RRI, PEP, ICT, LVET AND IRT ESTIMATED FROM SCG OVER THE DATA SEGMENTS A AND B.

		RRI	PEP	ICT	LVET	IRT
Mean	**A**	1075	101	44	328	53
	B	1084	103	49	311	56
SD	**A**	43.8	7.9	8.6	10.9	8.2
	B	47.5	6.3	8.1	11.2	7.7
CV	**A**	4	8	20	3	16
	B	4	6	16	4	14

SD = standard deviation ; CV= coefficient of variation. Mean and SD are expressed in ms, CV in %.

IV. NEXT APPLICATION IN SPACE

During space missions on board the International Space Station (ISS) the quality of sleep is poor, with a consequent frequent use of hypnotics. This phenomenon may have adverse effects on attention and vigilance of astronauts during the awake activities. The causes of the limited sleep quality are still unclear, and previous EEG recordings did not reveal any significant change in the sleep structure in space with respect to the assessment on ground. On this basis we proposed to the Agenzia Spaziale Italiana (ASI) an experiment aimed at further evaluating the sleep physiology by a multiparametric data recording based on the methodology above described. Through this approach we will be able to investigate not only the respiration and the heart rate variability but also the effects of microgravity on cardiac mechanics during sleep. From December 2014 five sleep recordings will be performed onboard the ISS in a time span of three months by using a space qualified version of the MagIC-SCG device.

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V. DISCUSSION

SCG can be measured almost continuously during sleep by a textile-based wearable system. In this pilot study we investigated in a subject the feasibility of estimating indexes of cardiac mechanics on a beat-to-beat basis from ECG and SCG sleep recordings.

Our results are encouraging and indicate that the beat-to-beat estimation can be obtained. A number of additional findings stemmed from this analysis. First, a large influence of respiration is observed on the dynamics of most of the parameters we considered. Second, variability of cardiac intervals is only marginally influenced by the RRI dynamics and sudden transients in RRI are not invariably reflected by changes in the baseline of other parameters. Third, spectral power at frequencies ≤0.1 is only observed in the RRI spectrum and not in other spectra. Fourth, IRT has a broadband variability, that is clearly different from the dynamics of the other indexes. This may be due to the influence of biological mechanism that play a role during the diastolic phase of the cardiac cycle (all the other time intervals occurred during the systolic phase). In this respect at this moment we cannot exclude the possibility that a contribution to the IRT broadband variability might also derive from measurement noise possibly added to the original SCG signal.

VI. CONCLUSION

Although the observations from this study remain to be confirmed on a larger population, to the best of our knowledge the present fndings represent the first description of the beat-to-beat variability of cardiac mechanical indexes during sleep.

Besides the recruitment of additional subjects, next steps of the project will include an increase in the time resolution of the acquired data (now @5 msec) so to obtain a more precise estimation of ICT and IRT parameters.

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