A Textile-Based Wearable System for the Prolonged Assessment of Cardiac Mechanics in Daily Life

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Abstract— **Seismocardiogram, SCG, can be detected over the 24 hours in ambulant subjects by a textile-based wearable system together with the electrocardiogram, ECG and respiration. In this pilot study we explored the possibility to derive 24h profiles of cardiac time intervals, i.e. indexes of heart mechanical function, from the SCG recordings performed in daily life conditions by the above wearable system. Two healthy subjects were recruited for the study. They worn the system for 24 hours during a working day. From each recording, every 30 minutes the following parameters were derived from the ECG and SCG signals: RR interval, RRI, Pre-Ejection Period, PEP, Isovolumic Contraction Time, ICT, Left Ventricular Ejection Time, LVET, Isovolumic Relaxation Time, IRT. From the analysis it appears that 1) all parameters are characterized by a coefficient of variation in the same order of magnitude, and 2) 24h LVET time profiles mirrors the long term RRI behavior. Common trends in PEP and ICT profiles were observed in one subject.**

This study indicates that indexes of cardiac mechanics can be derived from SCG recordings performed over the 24 hours. The obtained positive results encourage further studies to refine this methodology and confirm the present findings.

I. Introduction

In 2012 we proposed the use of a smart garment, the MagIC-SCG system, for the assessment of Electrocardiogram (ECG), respiration and Seismocardiogram (SCG) in ambulant subjects [1]. SCG is the measure of the precordial vibrations produced by the heart contraction and blood ejection. From the SCG analysis we may obtain information on cardiac mechanical events, including the opening and closure of mitral and aortic valves, filling and contraction of left atrium and ventricle, blood flow from ventricle to aorta. These events corresponds to specific peaks and valleys in the SCG waveform as shown in fig. 1. SCG vibrations can be detected by an accelerometer positioned on the thorax. Their magnitude is in the order of few milli-gs, thus, in daily life SCG can be measured whenever the subjects stay spontaneously still for few seconds. This is because major movements, including walking or physical activity, may mask the minute precordial vibrations. From the analyses of 24h recordings obtained by the smart garment in 5 healthy subjects, we previously observed that during the day a subject remains spontaneously still several times per hours thus making possible an intermittent but frequent estimation of SCG throughout the whole day [1]. At night, SCG could be estimated almost continuously. These observations make it conceivable the exploitation of the frequent SCG measures for deriving 24h profiles of indexes of cardiac mechanics.

In this paper we addressed the above issue. In particular, from data collected in two healthy subjects, we explored the possibility to derive, for the first time, 24h profiles of cardiac time intervals, i.e. indexes known to reflect the cardiac mechanical function, in ambulant subjects.

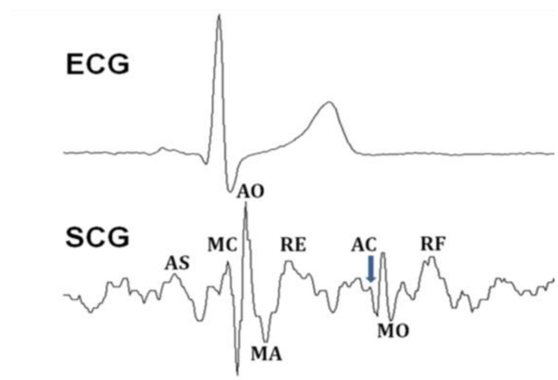

Fig. 1. *Upper panel:* ECG complex. *Lower panel:* SCG waveform and fiducial points associated with cardiac mechanical events. AS= Atrial Systole, MC= Mitral valve Closure, AO= Aortic valve Opening, MA= Maximal blood Acceleration, RE= Rapid Ejection, AC= Aortic valve Closure, MO= Mitral valve Opening, RF= Rapid ventricular Filling (according to nomenclature proposed by Crow et al. [2]).

II. Methods

A. The smart garment

Data were collected by using the MagIC-SCG smart garment. Briefly, this device is composed of a sensorized vest and an electronic unit (see fig.2). The vest is mainly made of cotton and incorporates textile sensors for the ECG and respiratory detection. The electronic unit includes a tri-axial accelerometer (ST LIS3LV02DL, ±2g, 12 beat) and is positioned on the vest so to be in mechanical contact with the sternum and detect the SCG vibrations. Data are locally stored on a memory card and can be transmitted in real time to an external device through a Bluetooth connection. Further details on the system may be found in [3].

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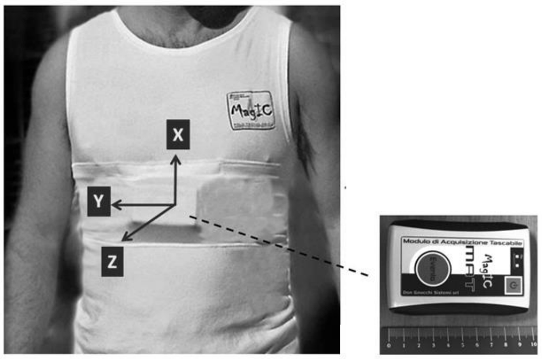

Fig.2 - *Left panel:* the MagIC-SCG garment with orientation of the accelerometric axes: x (longitudinal: foot-head), y (lateral: left-right), z (sagittal, back-front). *Right panel:* the electronic board, to be located into the vest pocket at the sternum level. Redrawn from [1] by permission.

B. Subjects and data analysis

Two healthy male subjects (age: 26 yrs and 38 yrs) were recruited for the study. Each subject worn the MagIC-SCG garment for 24 hours, starting from 8:00 a.m., in a working day. During the recording, they performed their usual daily tasks. Both subjects were researchers and their work activity included a mix of work at the computer and experimental activity in the research laboratory.

Although the accelerometer of the system provides data over the three orthogonal axes, in accordance with the prevalent literature we estimated SCG from the sagittal (dorso-ventral) acceleration component. The 24h ECG and sagittal acceleration profiles obtained from the recording of the subject #1 and the corresponding schedule of his daily activities are reported in fig. 3.

From each recording, a possible slow oscillation of the acceleration signal induced by respiration was removed by a wavelet-based filtering procedure previously proposed [1]. In short, the sagittal acceleration series was decomposed by using the db4 mother wavelet, then the level 6 approximation component was subtracted from the original signal. The whole detrended acceleration series was then automatically scanned in the search of 5-second motionless segments. This was done by verifying that the standard deviation of the magnitude of the acceleration vector were < 4 milli-g [1].

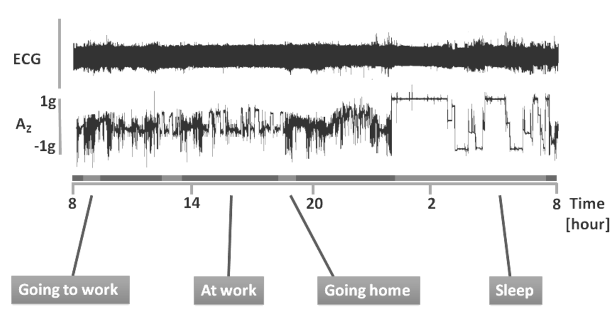

Fig. 3 - 24h profiles of ECG and sagittal acceleration component (A_z) measured in subject 1 and corresponding activity schedule.

Subsequently, one motionless data segment was randomly selected every half hour of recording, after having visually confirmed the presence of the SCG waveforms in the accelation signal. To reduce the level of possible noise, a single average SCG waveform was obtained from the 5-sec motionless data segment by an ensemble averaging synchronized with the R peak of the ECG.

With reference to the fiducial points illustrated in figure 1, from each of the 48 SCG average waveforms we estimated the following cardiac time intervals: 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).

For each of the above indexes we plotted the 24h profile and estimated mean, standard deviation and coefficient of variation over the 24 hours and separately over the awake hours (Day) and sleep time (Night).

III. Results

The figures 4 and 5 display the 24h profiles of RRI, PEP, ICT, LVET and IRT estimated from the SCG vibrations in the two subjects.

Mean, standard deviation and coefficient of variation for each index estimated over the whole 24 hours, Day, and Night are reported in Table I and II.

As a first observation, all cardiac time intervals are characterized by comparable coefficients of variation. This means that all of them display a long term variability that remain in the same order of magnitude after normalization by their respective mean value.

Second, in both subjects a marked similarity was observed in the RRI and LVET profiles over the 24 hours with a significant upward shift at night.

TABLE I - **Subject 1**. Parameters of Variability for RRI, PEP, ICT, LVET and IRT estimated from SCG over the 24 hours.

		RRI	PEP	ICT	LVET	IRT
Mean	**24h**	978	111	60	282	69
	D	933	112	61	272	71
	N	1061	108	58	301	67
SD	**24h**	84.5	5.9	4.6	19.2	8.4
	D	64.5	6.4	3.7	12.2	7.6
	N	45.8	3.7	5.2	15.3	9.1
CV	**24h**	8	5	7	7	12
	D	7	6	6	4	11
	N	4	3	9	5	14

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

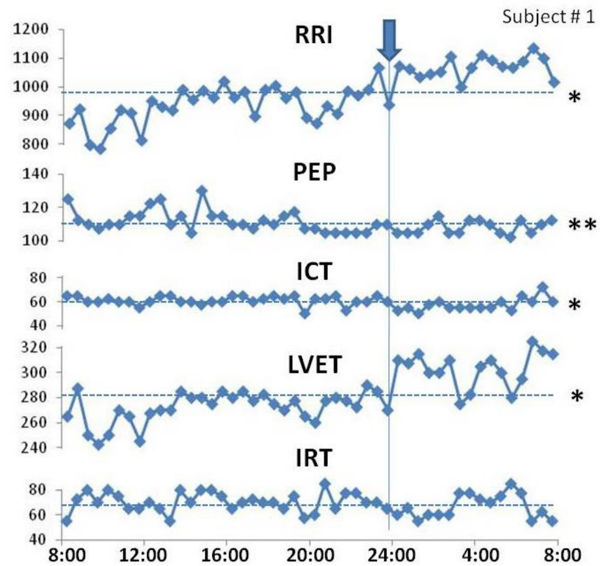

Figure 4 - 24h profile of RRI, PEP, ICT, LVET and IRT for the subject 1 and respective means, standard deviation and coefficient of variation. The arrow indicates the start of the sleep period. Vertical axes represent time periods in ms. Significance level of day vs. night difference: *=p<1%, **=p<5%

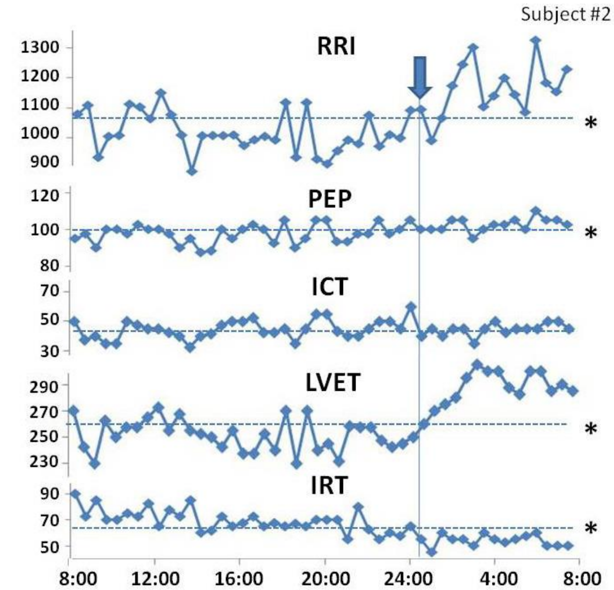

Figure 5 - 24h profile of RRI, PEP, ICT, LVET and IRT for the subject 2. Details in the caption of figure 4.

Third, in subject 2, but not in subject 1, also PEP and ICT displayed similar time profiles.

Profiles of the other indexes seem to be less or at all correlated each other.

IV. CONCLUSION

SCG can be detected over the 24 hours in ambulant subjects by a textile-based wearable system. In this study we explored the possibility to derive 24h profiles of cardiac time intervals, from SCG recordings performed in daily life conditions.

The obtained results represents the first description of the 24h variability of indexes of cardiac mechanics in ambulant subjects. We observed that the circadian variability, as quantified by the coefficient of variation, is in the same order of magnitude for all indexes. Moreover, from this pilot study, it appears that LVET time profile mirrors the long term RRI behavior. Links between LVET and RRI have been previously observed in spot assessments obtained in laboratory conditions, but never described over prolonged time periods.

TABLE II - **SUBJECT 2**. PARAMETERS OF VARIABILITY FOR RRI, PEP, ICT, LVET AND IRT ESTIMATED FROM SCG OVER THE 24 HOURS.

		RRI	PEP	ICT	LVET	IRT
Mean	**24h**	1063	99	45	263	65
	D	1019	98	45	251	69
	N	1162	102	44	287	54
SD	**24h**	98.6	5.1	5.7	20.6	10.2
	D	65.6	5.0	6.3	11.8	8.4
	N	86.8	3.4	3.9	12.4	4.3
CV	**24h**	9	5	12	8	16
	D	6	5	14	5	12
	N	7	3	8	4	8

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

From the methodological perspective, the proposed approach, once refined and validated over a larger population, could be used to evaluate the dynamics of cardiac mechanical features over time and explore in healthy subjects and patients how these cardiac features change in response to the challenges of real life, out of the laboratory setting.

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