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CONCEPTION OF A LOW-COST RECORDER FOR THE HEART RATE VARIABILITY STUDY IN THE ATHLETE

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Abstract: A simple, compact and low-cost device is presented. It is able to measure, store and transfer to a computer the beat-to-beat interval of the heart, using a POLAR chest belt and receiver. The conception of this device is based on a microcontroller 8051 associated with flash memory and a real time clock. The statistical error on this interval is below one millisecond. The device suits particularly well for studying the heart rate variability (HRV) at rest in athletes.

Keywords: heart rate variability, heart rate recorder, biomedical instrumentation, overtraining, staleness.

1. INTRODUCTION

In sportsmen, an imbalance between training stress and recovery can lead to a state of excessive fatigue called overtraining or staleness [1]**.** Although many psychological and hormonal indicators characterize this syndrome, presently no system is available to identify physiological features of overtraining by means of a non invasive and reliable tool. Some researchers hypothesize a possible relationship between overtraining and heart rate variability (HRV). However, the existing data are sometimes contradictory and clearly, more results are required to conclude. The aim of the present development is to contribute to the clarification of this issue.

To study HRV, the time interval between two consecutive heart beats (RR intervals of the ECG – see figure 1) must be measured over a certain period of time. Then a data processing programme must extract from the RR interval file pertinent parameters characterizing HRV.

Even if a variety of ambulatory heart rate recorders are available on the market, there is a lack of low-cost, user-friendly instruments, of satisfactory autonomy, able to insure the follow-up of athletes during a few months. We thus designed a new instrument prototype, called *R2I-recorder*, the particularity of which is to use as heart sensor the popular POLAR chest belt transmitter widely used by sport practitioners, coupled with a remote wireless receiver. The *R2I-recorder* is able to store the acquired data which can be transferred to a PC for further processing. Moreover, sportsmen can use it autonomously during one year.

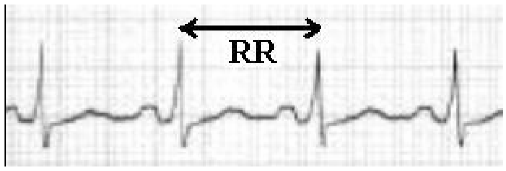

Fig.1. RR interval on the ECG

2. METHOD

2.1. The circuit

The circuit board of this battery-powered recorder is centred on a microcontroller (from 8051 family) connected to an external flash memory (to store the records), a calendar or real-time clock (RTC) (to measure RR intervals and keep track of date and time of the recording sequences), a serial port (for RS232 communication with a PC), a LCD screen (for giving some information to the user) and push-buttons (for the user interface).

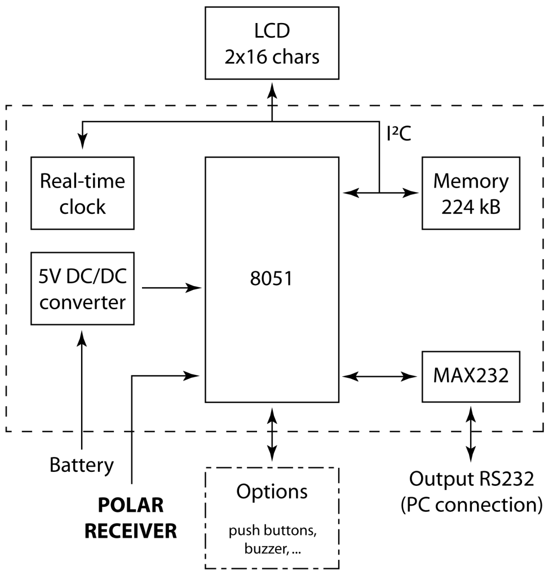

Fig. 2. General scheme of the *R2I recorder* circuit

We used the I2C communication protocol between the microcontroller and most of the other elements (RTC, memory and LCD). This protocol allows to use only two bus lines for all the communications with these elements. In that way, we limited the number of I/O pins necessary.

The signal input of the recorder board is coming from the POLAR receiver, an OEM item – the largest dimension of which is 37mm, plug non included - wirelessly receiving heart rate information from a POLAR chest-belt transmitter (figure 3). This receiver generates a pulse for each heart beat: the RR interval corresponds to the duration between two successive rising edges of this signall. This interval is calculated using the RTC: when a pulse is received, the time of occurrence (with 10ms accuracy, limited by the RTC resolution) is stored in a register (called R1). The following pulse is then detected and the time is stored in another register (R2). The difference R2-R1 giving the RR interval is stored in the flash memory and R1, R2 are updated. This succession of steps is repeated during the whole measurement time.

The *R2I−recorder* has a total memory of 224kB, which corresponds to about 12 months of recording on the basis of 10 minutes a day. This figure is achievable with the three AA-1.5V alkaline cells of our battery.

Our prototype box has a size of 170 x 85 x 25 mm^3.

Fig.3. The POLAR receiver

2.2. Daily use

The functioning of the *R2I-recorder* is simplified to be used by anyone. At power on, the LCD screen invites the user to confirm or to modify the configurable options of the recorder: the measurement duration can be adjusted, by one minute steps, from 1 minute to 59 minutes. The time (day, hour,…) is also adjustable. When this is completed, the instrument is ready to start a measurement run.

2.3. Data transfer

After the acquisition period, the full information memorised in the *R2I-recorder* memory has to be transferred through RS-232 protocol, to an external computer in order to finalize the data processing. Data are sent in the ASCII standard format ; in that way, the standard compatibility of our device is increased.

2.4. Computer processing

The study of the HRV consists of analysing various parameters extracted from a RR intervals sample. Each of these can have a physiological interpretation justifying the importance of knowing it [2]. These parameters are obtained by linear (in the time domain or in the frequency domain) or nonlinear methods:

- time domain parameters : mean RR interval (*RRmean*), standard deviation of the RR intervals (*SDNN*), rate of RR intervals for which the difference between two consecutive intervals is higher than 50ms (*pNN50*),...
- frequency domain parameters : power spectral density (*PSD*) of the tachogram , total power (*TP* : integral of PSD which is the variance), power in the VLF domain (*VLF* : <0.04 Hz), in the LF domain (*LF* : 0.04-0.15 Hz) and in the HF domain (*HF* : 0.15 – 0.4 Hz), *LF/HF*,…
- nonlinear methods. We can cite the *Poincaré plot* analysis in which each RR interval is plotted as a function of the previous one. This graph gives both a qualitative visual information but also quantitative at the beat-to-beat level [3], [4].

A computer program was developed which calculates all of these values. The start point of the frequency domain values is the PSD of the sample. In order to determine it, we use an autoregressive (AR) process ([5]). Equation (1) is the expression of the PSD obtained by AR process.

$$S_{AR}^{(p)}(\omega) = \frac{\sigma_u^2}{|1+\sum_{k=1}^{p} a_k e^{-j\omega k}|^2} \qquad (1)$$

σ_u^2 is the sample variance, the a_k are the coefficient found with the AR process and p is the order of the AR model. We choose p=20 which gave satisfactory results.
This expression justifies the use of an external computer. Finally, from this PSD and integrating between different limits, the program calculates most of the components we need.

A typical protocol is to measure every morning at the wake-up the RR intervals of the athlete during a few (3 to 10) minutes. For each sequence, the HRV parameters are calculated. It is the evolution of these parameters along the test period (e.g.. a training season of the athlete) which is the information of interest that we will try to correlate with the overtraining phases during the competitive periods.

2.5 Embedded data processing: feedback to the athlete

In order for the athlete to have a minimum of on line feedback after the measuring campaign, it was necessary to implement inside the *R2I-recorder* some information relevant to the results of the measurements he made.

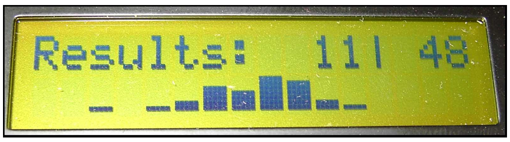

Fig.4. Screen display at the end of a measuring sequence

Two kinds of data are displayed on the LCD screen of the instrument at the end of each measurement sequence. The main one is the histogram i.e. the number of occurrences in function of each defined class of RR intervals. This is displayed on the lower line of the screen with a 7 pixels vertical ranged scaled to 14 occurrences: the one occurrence classes are thus not visible (figure 4). This histogram is completed by two parameters giving some information about its spreading. We choose the number of represented classes (thus with a minimum of one occurrence) and the total of occurrences which don't belong to the dominant class (figure 4: upper line).

2.6. Accuracy

The device measures RR intervals with a 10ms accuracy (limited by the RTC resolution). However the calendar clock is running continuously during the sampling period. So there is a mean effect which increases the accuracy. To test it, we applied to the recorder input a signal pulse with a known frequency. The results pointed a statistical error lower than 1 ms (for a sampling period of 3 minutes).

A statistical accuracy of about one millisecond is thus a typical value for our device: this figure is similar to the performance obtained with ECG recorders available on the market. The beat-to-beat resolution of 10 ms is sufficient for the HRV study with regard to the large heart rate variability in humans [6].

3. RESULTS

3.1. Preliminary measurement campaign

A first measurement campaign was performed with the aim to verify the correct functioning of our recorder in real condition and its acceptability by the sportsman. We followed a 23 years old male cyclist during a pre-competitive and a competitive period (3 months). Every morning at his wake-up and in a supine position, he measured his RR intervals during 10 minutes. He did it before any other movements, to minimize all other biological interferences (the chest belt was worn during the night).

There was no complaint from this sportsman about the instrument and the proposed protocol during this campaign. We nevertheless experienced that the correct positioning of the chest belt in order to obtain valid results is a critical point.

3.2.Examplative results

After the campaign, the measured RR values are transferred into the PC and stored in a specific file in order to compute all the needed values to study HRV. The program also delivers some important and interesting graphs for this study: Figure 5 to 7 represent these graphs for a typical 3 minutes recording period. The tachogram (the RR interval in function of each successive beat) is on figure 5. The PSD plot is on figure 6: the HF lobe reflects the parasympathetic activity while the two LF lobes reflect the interaction between parasympathetic and sympathetic activities. The Poincaré plot is on figure 7: the variability of this file appears rather low.

Even if this punctual campaign didn't reveal any significant heart rate variability in the athlete under test, our *R2I Recorder* has proven its ability to fulfil its mission: the prototype can now be replicated in a few copies in order to start the planned HRV study in the overtrained athlete.

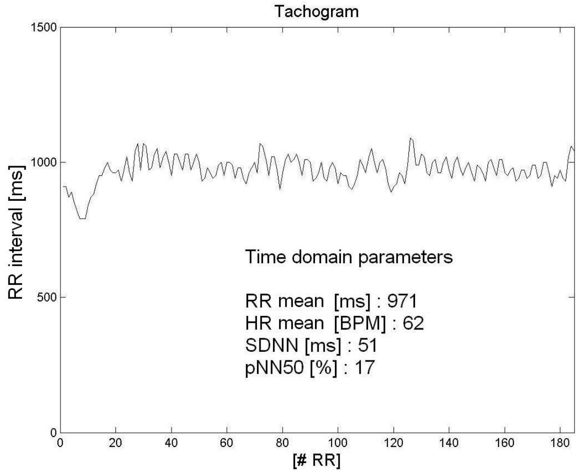

Fig 5. Tachogram

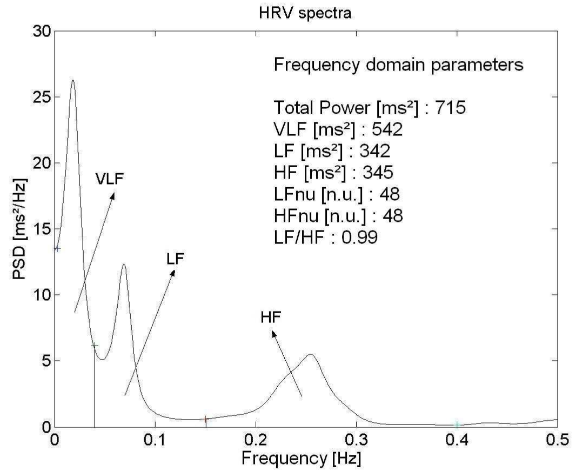

Fig. 6. PSD plot

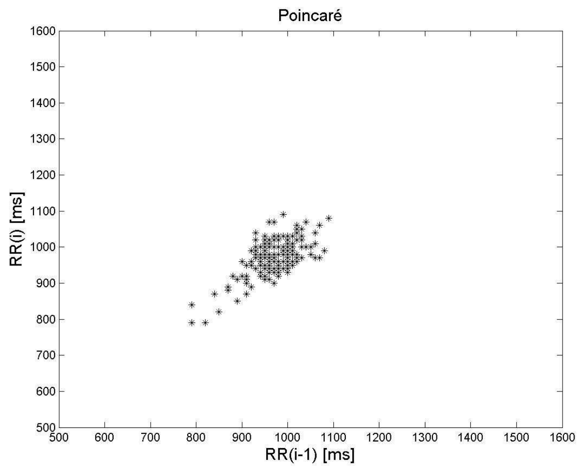

Fig 7. Poincaré Plot

4. CONCLUSION

We designed a very simple tool to measure, store, transfer and process samples of RR intervals, namely in order to evaluate, with an appropriate accuracy, the HRV in the overtrained athlete.

Ones of its main advantages are its price (in comparison with Holter type commercial devices), its user-friendliness for an athlete and its compatibility with the existing POLAR material.

The first results seem to confirm that the measurement method is appropriated for that kind of study. The correct positioning of the chest belt is a critical point which deserves attention.

Another general conclusion of our study is that we showed that the access to the signal at the receiver output of the very popular POLAR heart rate monitor opens the way of all kinds of studies implying long term RR intervals recording.

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