Visual aided pacing in respiratory maneuvers

L R Rambaudi¹, E Rossi², M C Mántaras², M S Perrone¹ and L Nicola Siri²,³,⁴

Laboratorio de Biofísica y Fisiología “Antonio Sadi Frumento”¹ y Cátedra de Bioingeniería II², Facultad de Ingeniería, Universidad Nacional de Entre Ríos (FI-UNER); Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)³

Ruta 11, Km 10, Oro Verde, (3100) Paraná, Pcia. de Entre Ríos, ARGENTINA
Avda. Rivadavia 1917, (C1033AAJ) Ciudad Autónoma de Buenos Aires, Argentina
E-mail: nicolasirileo@yahoo.com

Abstract. A visual aid to pace self-controlled respiratory cycles in humans is presented. Respiratory manoeuvres need to be accomplished in several clinic and research procedures, among others, the studies on Heart Rate Variability. Free running respiration turns to be difficult to correlate with other physiologic variables. Because of this fact, voluntary self-control is asked from the individuals under study. Currently, an acoustic metronome is used to pace respiratory frequency, its main limitation being the impossibility to induce predetermined timing in the stages within the respiratory cycle. In the present work, visual driven self-control was provided, with separate timing for the four stages of a normal respiratory cycle. This visual metronome (ViMet) was based on a microcontroller which power-ON and -OFF an eight-LED bar, in a four-stage respiratory cycle time series handset by the operator. The precise timing is also exhibited on an alphanumerical display.

1. Introduction
Cardiovascular-related observables, such as heart-rate and blood pressure, present beat-to-beat changes on time-course, amplitude and phase. This variation is a consequence of cardiovascular control mechanisms, mainly the action of autonomic nervous system (ANS) that keep cardiovascular parameters within physiological values. Cardiovascular variability, especially heart-rate variability (HRV), is nowadays a reliable non-invasive tool to evaluate sympathetic and parasympathetic divisions of ANS as part of the cardiovascular control system. [1],[2]

Respiratory sinus arrhythmia (RSA) can be defined as the beat-to-beat changes in the heart period which happen in synchrony with respiration. RSA depends on tidal volume (TV) and respiratory frequency (RF) [3], [4], and is an indicator of a healthy heart.[5]. The underlaying mechanism of RSA

¹,²,³,⁴ To whom any correspondence should be addressed.
has not been established in a conclusive way, but in spite of controversy, RSA is believed to reflect the complex effects of the respiratory brain center on the baroreflex cardiovascular control center and of the respiratory mechanics on the heart and blood vessels within the thorax [5]. RSA is mediated mainly by influence of parasymptathetic division of ANS on sinus node (SN), and is considered the main marker of the vagal activity on the heart, in addition to the vagal central modulatory flux, the vagal cardiac tone and the parasympathetic baroreflex response. [2] Because of this, RSA interpretation will depend on which specific aspect of vagal control is under study.

The main indexes for HRV analysis come both from time domain and from frequency domain methods [1]. Time analysis of HRV includes descriptive statistics on global time series of consecutive RR intervals, and also on differences between adjacent RR intervals. Mathematical tools for frequency analysis of HRV include Discrete Fourier Transform and autoregressive models. [2]

Spectrum analysis of HRV indicates that the so-called high frequency band (HF) ranges between 0.15 and 0.4 Hz in normal resting adults (the upper limit can be extended up to 1 Hz in children and adults under physical exertion [2]). The HF band represents the SRA; it is correlated to respiration and is associated mainly with parasympathetic activity [6], [7] and [8]. On the other hand, the low frequency band (LF) between 0.04 and 0.15 Hz is determined by sympathetic and parasympathetic controls working together.

Works in the literature suggest that voluntary control on respiration permits a better interpretation of human autonomic cardiovascular rhythms [9]. As a result, numerous works have been carried out under different protocols which include respiration self control in the subject. A traditional way to perform this self control is by using an audible signal produced by an ordinary metronome, which in turn feeds the respiratory rhythm to the individual under study; this maneuver requires some previous training of the subject. Recently, visual metronomes have been introduced by researchers because they are easy to operate and more comfortable for the individual under study. Moreover, in our institution (FI-UNER), there are several research teams which carry out HRV studies. We were asked for devising a dedicated respiratory pacer, capable of being operated independently from the rest of the physiological recording instruments, to induce respiratory self control.

In the present work, we have developed a visual metronome (ViMet) which is based on a microcontroller, uses an optical signal as a trigger source for the respiratory self control and can be tuned manually for different respiratory patterns.

2. Design

Figure 1 shows the blocks diagram of a typical physiology recording system with a ViMet added. It can be seen that the ViMet is directly contacting the subject. For this reason, no special requirements for electrical patient security were considered in the design.

Fig. 1: Operative concept of a physiology recording system with self control of respiratory cycle: The individual is visually coupled to the ViMET, but wired to the physiology
In order to prompt the individual in a comfortable way, an eight LEDs bar was used, arranged vertically. Alternate sequences of ascending LEDs-ON (inspiration) and descending LEDs-OFF (expiration) were used to synchronize the self control of the respiratory cycles. Timing (see below) was set manually in analog form by the operator, by actuating on several rheostats of the front panel of the ViMet. The time values were displayed on a LCD, altogether with the microcontroller-calculated respiratory frequency. Then, any desired respiratory pattern could be induced.

The set times were read by a microcontroller which in turn calculated the respiratory parameters, displayed them on an LCD, and sequentially powered-ON and -OFF each LED in the LEDs bar. The LEDs bar was connected to the ViMet case with a cable of length enough to permit adjustment of the different parts of the entire system comfortably, for both the operator and the subject.

Figure 2 shows a typical graph of tidal volume against time for a normal respiratory cycle. The respiratory cycle is divided into four stages: inspiratory (It), inspiration retaining time (IRt), expiratory (EXt) and expiration retaining time (EXRt).

In the present work, a simplified respiratory cycle (a piecewise linear pattern) was generated, as shown in figure 3. Within the cycle, along the It stage, the LEDs in the bar were turned-ON one by one; all of them remained -ON during IRt; during the EXRt stage, a one-by-one turning-OFF of the LEDs followed, which remained –OFF until the end of ERt. The entire cycle was repeated, until actuating a manually-operated stop.

![Scheme of Tidal volume against t. Note the beginning and the end of each stage within the respiratory cycle (see text).](image)

**Fig. 2:** Scheme of Tidal volume against t. Note the beginning and the end of each stage within the respiratory cycle (see text).

![Piecewise linear respiratory cycle used with ViMet. (see text)](image)

**Fig. 3:** Piecewise linear respiratory cycle used with ViMet. (see text)
3. Development
For this ViMet, a microcontroller (PIC16F877-20P from Microchip, U.S.A.) and a 8-LED bar arranged vertically were used. The LEDs–ON sequence was upward, whereas, the LEDs–OFF sequences were downward.

The four parameters of the respiratory cycle (see above) were set by means of four linear potentiometers on the front panel of the ViMet. Each time value could be adjusted between 00.0 and 10,00 sec. From the analog signals, the PIC calculated the respiratory parameters and displayed them on a 20 x 4 characters LCD (from WinStar, U.S.A.), also located on the front panel of the ViMet.

Figure 4 shows the block diagram of the ViMet.

![Fig. 4: Blocks diagram of the ViMet. (see text)](image)

![Fig. 5: Flux diagram of the program executed by the microcontroller.](image)

The program that controlled the PIC performed the following tasks: ports assignment, ADC and DAC initialization, respiratory variables initialization, computation of slopes and durations, display of parametric values in alpha-numeric form, power-driving each LED. A scheme is shown in figure 5.

4. Proof of the ViMet
In order to evaluate ViMet performance, a bench proof was carried out. Four respiratory patterns were set on the ViMet, and the durations of each respiratory stage were directly measured by an observer using a hand chronometer, exactness within ± 0.1 sec, and visual synchronization through the –ON and –OFF conditions of the LEDs. A frequency of 12 respiration * min⁻¹ was chosen for the tests. Linearity was not tested. Table 1 shows the results of the tests performed. Within experimental errors, visual timing of LEDs produced similar values to those we preset through potentiometers in ViMet.
Table 1: ViMet bench proof

| Essay | It [sec] Set value (± 1 lsd) | Measured value | IRt [sec] Set value (± 1 lsd) | Measured value | EXt [sec] Set value (± 1 lsd) | Measured value | EXRt [sec] Set value (± 1 lsd) | Measured value | Respir. cycle (sec) Measured value |
|-------|---------------------------|----------------|-----------------------------|----------------|-----------------------------|----------------|-------------------------------|----------------|-------------------------------|
| 1     | 3.0                       | 3.0±0.2        | 0.0                         | 0.2±0.2        | 2.0                         | 2.1±0.2        | 0.0                           | 0.2±0.2        | 5.5±0.8                       |
| 2     | 3.0                       | 2.9±0.2        | 1.0                         | 1.0±0.2        | 1.0                         | 0.9±0.2        | 0.0                           | 0.2±0.2        | 5.0±0.8                       |
| 3     | 2.5                       | 2.5±0.2        | 0.0                         | 0.2±0.2        | 2.5                         | 2.5±0.2        | 0.0                           | 0.2±0.2        | 5.4±0.8                       |
| 4     | 2.5                       | 2.5±0.2        | 0.0                         | 0.2±0.2        | 2.0                         | 2.0±0.2        | 0.5                           | 0.5±0.2        | 5.2±0.8                       |

Respiratory cycle duration: 5 sec (12 resp * min⁻¹)
Measured uncertainty: ±0.1 sec at the start of chronometering, plus ±0.1 sec at the stop (manually operated)

On the other hand, a live essay of the ViMet was performed. To do this, five healthy volunteers were exposed to the respiratory pattern shown in table 2, in order to verify the difficulties of subjects in following the respiratory cycle induced by ViMet. An expert observer, blind to the set values, timed each of the four respiratory stages for the volunteers. Within experimental errors (± 0.2 sec), live respiratory stages were in accord with set times. Also, volunteers stated their feeling comfortable during manoeuvres, even though no previous training was made.

Table 2: ViMet live essay parameters

| Set value (± 1 lsd) | It[sec] | IRt[sec] | Ext[sec] | EXRt[sec] |
|---------------------|---------|----------|----------|-----------|
| 2.5                 | 0.5     | 1.5      | 0.5      |

Respiratory cycle duration: 5 sec (12 resp * min⁻¹)

5. Discussion

The tests on ViMet performance showed that the device satisfactorily reproduced the timing for the respiratory pattern preset by the operator. They also demonstrated that the study subjects were able to follow the light sequences while keeping their respiration in synchrony with the imposed pattern. Besides, the device resulted of easy operation by experimenter, when setting time sequences via the linear rheostats, and also when controlling the ViMet by means of the LCD.

We conclude that this ViMet complies with design specifications and is capable to drive respiratory patterns in respiratory manoeuvres needed in physiological studies such as HRV, among others. In addition, ViMet can be used for the learning of respiratory physiology as part of students’ experimental activities as another application field.

Nevertheless, the present ViMet has a couple of limitations. One is the single pattern provided (a piecewise linear-like), which reduces versatility in HRV studies. In a further development, the possibility to generate different waveforms for respiratory patterns will be considered. Another limitation is that ViMet induces self control on respiratory timing to the subject, excepting on tidal volume.

In the next stage of the design, the measurement of tidal volume and visual feedback for the subject will be incorporated in ViMet to better induce respiration self-control. To meet this purpose, we
indicate that ports D and E in the microcontroller, and the remaining bits in port A remain unused, which will permit an expansion of ViMet functions.

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