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NOTE

Short-term studies of heart rate variability: comparison of two methods for recording

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Abstract

Heart rate variability (HRV) is often analysed using short-term studies. Our objective was to compare two of them in a group of diabetic patients (reduced HRV) and in a control group. From the same 10 min surface electrocardiogram (ECG) two recordings were obtained. In one of them the whole signal was acquired through an A/D converter (post-event method). In the other (real-time method), an interface between the electrocardiograph and a parallel port of a computer was used to perform real-time processing of the ECG signal. The *R–R* intervals were measured after a visual validation in the post-event method. In the real-time method, the stored *R–R* intervals were automatically filtered. For both methods HRV indexes were calculated using the same software. The values of mean *R–R* intervals for each subject were almost identical regardless of the method. Accordingly, we found a high correlation between HRV indexes obtained from both methods (all Spearman values $\geqslant 0.9441$ and $P < 0.0001$). In addition, we found similar P values in the comparisons between the diabetic and control groups. We conclude that both methods are suitable for HRV analysis. Therefore, the selection of method can be based on other considerations such as the capability to store the ECG of the post-event method or the speed of analysis and lower cost of the real-time one.

Keywords: heart rate variability (HRV), short term method, real time acquisition

1. Introduction

The intervals between heartbeats normally show subtle variations in duration that are mainly related to autonomic nervous system (ANS) activity. The analysis of these variations, known as heart rate variability (HRV), is widely used for research and diagnostic or prognostic purposes in many pathologies such as: diabetes, heart failure, coronary artery disease, and arrhythmias (Akselrod *et al* 1981, Task Force of the ESC and the NASPE 1996, Malik 1999, Malpas and Maling 1990, La Rovere *et al* 2003, Bigger *et al* 1992, Huikuri *et al* 2003).

HRV can be analysed using either 24 h monitoring (Holter) or short-term recordings. In a previous work we have shown that a surface electrocardiogram (ECG) recorded over 10 min is as useful as Holter for diagnosis of reduced HRV in diabetes (Migliaro *et al* 2003), and we can speculate that this comparison could be extended to other conditions related to reduced HRV as described in many papers (La Rovere *et al* 2003, Pontet *et al* 2003).

The goal of our present work is the comparison of two different short-term methods for HRV analysis, selected among the broad spectrum of techniques used for short-term studies (Fei *et al* 1996, Radespiel-Troger *et al* 2003, Risk *et al* 2001).

One method acquires the whole ECG signal through an A/D converter (post-event method). The other method only detects the *R* wave peak that is fed into the computer (real-time method). To compare both modalities, we chose a group of patients who have suffered from diabetes for a long time; these patients are known to have reduced HRV due to diabetic neuropathy (Malpas and Maling 1990). HRV was simultaneously measured in each individual using both methodologies. The same procedure was carried out on a control group (normal HRV).

2. Methods

After a detailed explanation of the aims and methods of our research, all volunteers expressed their conformity. The diabetic group was composed of 15 insulin-dependent diabetic patients (8 women and 7 men). They were allowed to receive their usual medication. The control group was composed of 15 healthy subjects (9 women and 6 men), they were non-smokers and had a body mass index <30. They were not receiving any medication. Both groups had similar age (see table 4).

Recordings were performed in a quiet room in supine position. Three silver electrodes were placed on the chest surface in order to obtain a bipolar lead (plus ground) which was connected to an ECG recorder (Fukuda FJC 7110). The lead used was the one known as 'V5 like' (Bayés de Luna 1993).

Seeking similar conditions in all volunteers, they were instructed to avoid caffeine, alcohol and heavy exercise the day before the study. All tests started between 4 and 6 PM. The subjects were allowed to relax for 20 min in order to stabilize their heart rate before a 10 min recording period.

The collection of data was performed in two different ways:

(a) *Post-event method*. Details of acquisition and processing have already been published (Migliaro *et al* 2003). Briefly, the ECG signal was fed into a computer (Compaq Armada) by means of an A/D converter (National Instruments DAQ Card-1200). The sampling rate was 500 Hz. After that, the *R* waves were detected as described in the appendix of Migliaro *et al* (2003). Later, they were visually inspected together with the ECG to correct either false positives or negatives. Then, intervals between successive *R* waves (*R–R* intervals) were measured and the HRV indexes were calculated. For this work we chose SDNN, rMSSD and the high- and low-frequency bands of the spectral analysis (see table 1).

Table 1. Definition of the heart rate variability indexes used in this study.

HRV index	Definition
SDNN (ms)	Standard deviation of all normal *R–R* intervals
rMSSD (ms)	Root-mean-square successive difference (the square root of the squared differences between two adjacent normal *R–R* intervals)
LF (ms^2)	Low frequency power. The energy in the heart period power spectrum between 0.04 and 0.15 Hz
HF (ms^2)	High frequency power. The energy in the heart period power spectrum between 0.15 and 0.4 Hz

(b) *Real-time method.* This method uses another type of interface between the ECG recorder and a parallel port of a PC type computer. This interface was designed to detect the *R* waves (see appendix). Each time an *R* wave is detected, the equipment triggers a square pulse of fixed voltage. The pulse reaches the PC through a parallel port. Specially developed software (see appendix), measures the time between pulses (i.e. the duration of the *R–R* interval) and stores these data in ASCII data files. The values of the *R–R* intervals were filtered using a previously described automatic filter (Machado *et al* 2000). Such a filter corrects or eliminates the spurious intervals that lie outside $\pm 20\%$ of the mode value or of the mean of the preceding accepted intervals. *R–R* intervals were finally processed with the same routine used for the post-event method to calculate the same HRV indexes.

The first approach to compare the methodologies was the evaluation of the mean *R–R* interval measured for each method in the same individual. As another strategy, correlations were done between the same HRV indexes obtained with both methods within each group. A non-parametric method (Spearman) was used to calculate the *r* values. We also evaluated the ability of the two methods to differentiate the group of healthy individuals (control group) from the diabetic group. For this purpose we also used a non-parametric test (Mann–Whitney). In all cases a two-tailed *P* value <0.05 was considered significant, in these conditions the exact *P* values are given.

3. Results

The post-event method was able to capture the ECG in all individuals. The real-time method failed in two subjects, one in each group (see discussion); then, both groups were reduced to fourteen individuals each ($n = 14$).

The comparison of the mean *R–R* interval duration, measured with both methodologies for each individual of the diabetic and control groups, showed that values are very close except for two subjects in the diabetic group. Table 2 shows the results for this group. The two cases with high differences are both due to very low *R–R* interval values erroneously measured with the real-time method (see discussion). These subjects were not considered for the subsequent comparisons; then the diabetic group was reduced to twelve subjects, whereas the control group remained composed of fourteen persons.

Spearman correlation coefficients (r) and *P* values calculated for HRV indexes measured with each method within the same group are shown in table 3. In the scatterplots (not shown) most points lie on the line of equality, indicating not only a high correlation ($r \geqslant 0.9441$) but also a good agreement between both methodologies.

HRV comparisons between the diabetic and control groups were made using HRV indexes obtained from both methods. Results are shown in table 4. As we expected, all HRV indexes were significantly lower in the diabetic group. Since both groups were similar in age and

Table 2. Mean *R–R* interval for each subject of the diabetic group calculated for both methods and the difference between them.

Mean *R–R* interval (ms)		
Real-time method	Post-event method	Difference (ms)
991.68	990.47	1.21
1009.50	1009.40	0.10
882.82	881.69	1.13
771.99	772.61	−0.62
866.01	866.36	−0.35
756.39	755.81	0.58
743.06	743.12	−0.06
719.12	718.68	0.44
691.28	691.25	0.03
757.81	757.70	0.11
983.81	984.83	−1.02
728.61	728.36	0.25
132.94	780.40	−647.46
69.00	961.71	−892.71

Table 3. Correlation of analogue HRV indexes obtained from both methods within each group.

	SDNN	rMSSD	LF	HF
	Diabetic group, $n = 12$			
r	0.9860	0.9441	1.0000	0.9860
P	<0.0001	<0.0001	<0.0001	<0.0001
	Control group, $n = 14$			
r	0.9956	0.9912	0.9912	0.9956
P	<0.0001	<0.0001	<0.0001	<0.0001

resting heart rate, as shown in the same table, the HRV difference can be ascribed to the diabetes effect (diabetic neuropathy).

4. Discussion

The mean value of the *R–R* interval for each subject was almost identical measured with both methods. Therefore, the high correlation and good agreement between analogue HRV indexes it is not surprising, since they were calculated from *R–R* intervals that were shown to be very close (Bland and Altman 1986). Consequently, both methods are able to distinguish diabetic from normal subjects, with a similar power of discrimination.

The two operator failures in the real-time method should not be ascribed to the method itself, since human failure could affect any method. The other two failures are related to *R* wave detection errors, and could have been avoided by changing the detection parameters. However, we decided to maintain the same protocol (see appendix) in order to test the ability of the interface to detect the *R* waves in all individuals compared with the post-event method. If we had changed the parameters of the interface, we would probably have obtained a normal *R* wave detection. However, in such a case we would have introduced a bias in the comparison of the two methods. We preferred to maintain a rather 'strict' protocol to increase the strength of the test. Once the above-mentioned records were discarded, the results obtained with both methods yielded very close results.

Table 4. Comparison of HRV indexes, age and heart rate between the control and diabetic groups for both methods (real-time method and post-event method).

	Real-time method			Post-event method		
	Median (range)			Median (range)		
	Diabetic group $n = 12$	Control group $n = 14$	P-value	Diabetic group $n = 12$	Control group $n = 14$	P-value
Age (years)	54 (44–63)	55 (42–70)	ns	54 (44–63)	55 (42–70)	ns
Heart rate (beats/min)	78.5 (59.0–87.0)	70.5 (63.0–81.0)	ns	78.4 (59.4–86.8)	70.4 (63.2–80.7)	ns
SDNN (ms)	21.2 (10.7–47.0)	41.3 (30.7–56.3)	0.0011	20.4 (9.0–50.0)	41.3 (30.8–56.0)	0.0003
rMSSD (ms)	8.4 (5.7–45.4)	21.2 (8.4–40.0)	0.0310	7.8 (3.8–46.3)	20.9 (8.3–40.6)	0.0148
LF (ms^2)	67.3 (2.6–540.7)	403.1 (89.0–893.4)	0.0005	65.8 (2.7–627.2)	430.0 (83.3–898.2)	0.0004
HF (ms^2)	19.0 (2.6–450.5)	153.7 (14.7–1219.2)	0.0270	18.6 (2.5–354.6)	152.5 (14.7–1218.6)	0.0091

Table 5. Features of the real-time method and the post-event method.

	Real-time method	Post-event method
Controlled conditions	Yes	Yes
Stores ECG	No	Yes
Visual control of *R–R*	No	Yes
Cost	Lower	Higher
Processing time	Lower	Higher
File size, approximate (Mb)	0.004	2

For clinical or population screening purposes, both methods can be used indistinctly. Then, the selection of a method can be based on other considerations. One of them is the time of analysis; the post-event method includes a visual inspection, which is time-consuming and requires the intervention of an expert. On the other hand, the real-time method is faster and does not require special knowledge of cardiology. Another consideration is the cost of the equipment. The A/D converter is fairly expensive compared with the device used to detect *R* waves in the real-time method. Table 5 summarizes the characteristics of each method.

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Appendix A.

A.1. Interface for the real-time method

We used a specially designed interface between the ECG recorder and a parallel port (usually LPT1) of the computer. This equipment detects the *R* waves from the ECG signals delivered

by the electrocardiograph. A Butterworth fourth order filter (pass band 0.3–25 Hz) eliminates low and high frequency components, and the first derivative of the filtered signal is obtained. Electronic circuits based on operational amplifiers perform both operations.

The signal and its first derivative are compared with thresholds previously selected by means of two potentiometers. If both signal and derivative exceed the selected thresholds a square wave pulse is delivered. The output pulse is adapted to be compatible with a TTL signal. A LED gives a visual feedback, flashing with every *R* wave detection.

In every case we used the same protocol to determine the thresholds for the signal and its derivative. Starting with both potentiometers at the minimum position (LED was on), the amplitude potentiometer was slowly moved towards the maximum until the amplitude of the *R* wave was surpassed (LED turned off). That value was noted down and the potentiometer was returned to the minimum position. The same procedure was done for the derivative potentiometer. The final position for each potentiometer (selected thresholds) was determined as 40% of the values noted down.

A.2. Measurement of R–R intervals (real-time method)

The real-time method includes specially designed software to measure *R–R* intervals. This software calculates the time between successive picks of the signals introduced to the computer as mentioned above. It was written in assembler language and can be used on the MS-DOS operating system (version 3.0 or higher).

The input signal is connected to the 13th pin of the parallel port. It must contain rectangular pulses of at least 0.2 ms of duration and 2–5 V of amplitude. Intervals between picks are calculated with a minimum temporal resolution of 1 ms.

The operation is based on the configuration of the system timer and the interrupt controller to produce interruptions of the timer with a fixed period equal to the selected temporary resolution. The algorithm scans the 13th pin of the parallel port and stores the quantity of interruptions that happened between each pulse of the signal. Starting from this, it calculates the intervals between picks. These data are stored in ASCII format files as a column of intervals. The first value represents the total number of intervals in the file.

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