Vectorcardiographic Changes During Exercise Test - Correlates to Lactate and Anaerobic Threshold?

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Abstract

The aim of the study was to investigate the correlations between blood lactate concentration, different vector ECG (VECG) parameters, ventilatory parameters and heart rate during exercise and recovery periods. Six (25-37 years old) non athlete, healthy, male subjects participated in the study. All subjects performed two different bicycle ergospirometric protocols (P1 and P2). The aim in using two different protocols was to attain different lactate levels with different heart rate profiles. VECG parameters were observed to be very sensitive to measurement artifacts, and thus, they were not as informative during exercise as heart rate and spirometer parameters. However, during recovery period changes in T-wave angle (θ_T) were similar to those in lactate concentration. Correlations between lactate and RR interval were r = -0.72 (P1, p<0.001) and r = -0.53 (P2, p<0.001), whereas between lactate and θ_T they were r = -0.54 (P1, p<0.001) and r = -0.71 (P2, p<0.001). The correlation between θ_T and RR interval was very low. The results suggest that VECG parameters is a potential non-invasive tool for recovery monitoring.

1. Introduction

It is known that low blood glucose concentration (i.e. hypoglycemia) affects repolarization characteristics of the heart. In hypoglycemic clamp studies where electrocardiogram (ECG) or vector ECG (VECG) recordings have been analysed, it has been observed that the repolarization time (i.e. the interval from Q-wave onset to T-wave end) lengthens, T-wave amplitude decreases and the angle between the QRS and T-wave vector loops is reduced in hypoglycemia [1, 8]. Motivated by these findings, we decided to study if any other analytes have observable effects on cardiac electrophysiology.

Measuring of lactate is an important tool for defining anaerobic threshold (AT), i.e. it corresponds the onset of the blood lactate accumulation (OBLA), where lactate concentration threshold is normally about 2 mmol/l [2]. Another commonly used method for defining AT is the ventilatory threshold measured by on-line gas analysis [6], which is associated with the maximal steady state of lactate concentration (MLSS), normally 4 mmol/l. AT and lactate measurements can be used to prescribe the training intensity and therefore, are important tools for athletes. Lactate concentrations could also be used for recovery monitoring. Ventilatory threshold measurements require expensive equipments and can be performed only in laboratory conditions. Furthermore the lactate measurements, on the other hand, are invasive and are not easy to take during dynamic exercise.

Two previous studies have tried to define AT by using

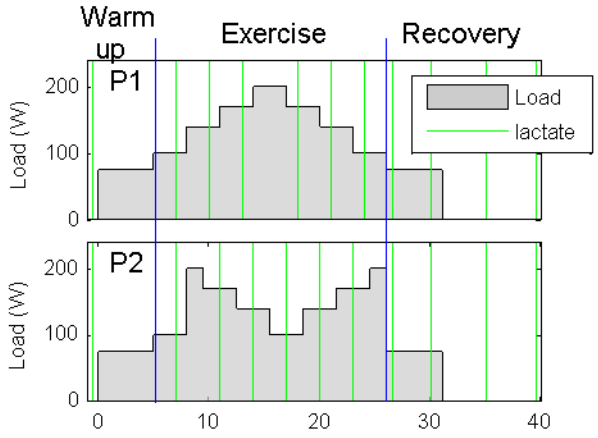

Figure 1. The two measurement protocols. Protocols consist of three periods: warm up, exercise and recovery periods. Bicycle load is marked as gray fill and lactate measurement times are marked as green lines.

heart rate variability (HRV) [3],[4]. Although some evidence that these methods fail to define AT passably have been presented [5], the idea of measuring the exercise intensity or even estimating lactate concentrations based on HRV or other biomedical signals is very interesting.

The aim of the study was to determine whether VECG was related to different exercise intensity markers in particular lactate levels. The correlations between different VECG parameters, blood lactate concentrations, ventilatory parameters as well as heart rate (HR?) was explored during exercise and recovery periods. For this purpose, two different bicycle ergometer protocols were performed (see figure 1). The two protocols were designed to produce changes into lactate levels with different heart rate levels in order to be able to identify the parameters actually correlating with lactate irrespective of the heart rate.

2. Materials

Six (25-37 years old) nonathlete, healthy male subjects participated in the study. All subjects performed two different bicycle ergospirometric tests. The test were separated by minimum of 7 days. Measurement protocols are presented in figure 1. Both protocols consisted of five minutes warm up period, 21 minutes exercise period and 20 minutes recovery period. The work required by the two protocols were equal (bicycle loads are shown with the gray areas in figure 1).

VECG was measured using Frank's vectorcardiographic lead system [7] using Schiller CS-200 ECG unit (Schiller, Switzerland) with sample rate of 1000Hz. Ventilatory variables were measured continuously using the power cube gas analysis device (Ganshorn Medizin Electronic, Germany) which was integrated to Schiller CS-200 ergospirometry system. Blood pressure was measured continuously (sample rate 500Hz) from the fingertips (right hand index and middle fingers) using a Portapres device (Finapres Medical Systems, Amsterdam, The Netherlands). 25 μl of blood were collected from left hand index finger and lactate concentrations were measured using enzymatic electro-chemical lactate analyzer (Ebioplus, Eppendorf).

3. Methods

When measuring ECG during exercise, movement artifacts resulting from chest's respiratory movements and from other body movements cannot be avoided and therefore ECG must be heavily pre-processed. First baseline drifts caused by chest movements were removed by applying median filter in a 1.5 second long window into the ECG. Secondly EMG and power line noise were reduced using sixth order low pass filter with cutoff frequency at 48Hz. After these preprocessing steps QRS complexes were detected.

Next, an advanced principal component regression (PCR) approach was used to model QRS-complexes and T-wave epochs from x, y and z components of the VECG simultaneously. The aim of using the PCR approach is to further improve the signal to noise ratio of the ECG. The PCR method was originally proposed in [8] for one channel ECG, but here it was applied to all three channels simultaneously. In the PCR approach, signal to noise ratio of T-wave and QRS-complexes is improved by modeling them using three optimal basis vectors. These basis vectors are obtained as eigenvectors of data correlation matrix computed from an ensemble of the modeled waveforms. 25 previous and 25 following T-wave and QRS-complex segments were extracted from all three channels for modeling these waves at a given time instant. After basis vectors were computed, few most significant of them were fitted to individual QRS-complex and T-wave segments beat by beat and modeled QRS and T-wave segments were attained. Because ECG wave forms are similar for each beat, first basis vectors contains information of wave forms and its normal variation. On the other hand noise is random and thus it is shown with less significant basis vectors. By using only few most significant basis vectors in wave model, most of the noise can be removed.

After x,y and z components of QRS-complexes and T-waves were modeled, QRS-complex loop and T-wave loop were constructed and angles to x axis (θ_R and θ_T) and angles to xy-plane (ϕ_R and ϕ_T) were estimated beat by beat. Beat by beat variation was large and for better comparability low frequency trend components for these parameters were estimated using smoothness priors method with cutoff frequency 0.01Hz.

In addition to these VECG parameters, we also computed the mean RR interval (for heart rate information) and the standard deviation of beat to beat RR intervals (SDNN, for the overall heart rate variability). We also computed the pulse transit time (PTT) from the ECG and blood pressure measurements and the minute ventilation (VE) from the spirometric measurements.

4. Results

In figure 2 trends of each time series are presented for protocols P1 and P2. Baseline value of individuals is variable and therefore PTT, θ_T and ϕ_T are presented as a changes from normal value. It is observed that SDNN, PTT and VE changes track the used bicycle load and heart rate. VECG parameters do not so clearly follow the used load or the heart rate, but in recovery period θ_T changes are similar to measured lactate values.

In figure 3, the correlations between lactate and the parameters shown in figure 2 are presented. Individual baseline value is removed from all parameters before correla-

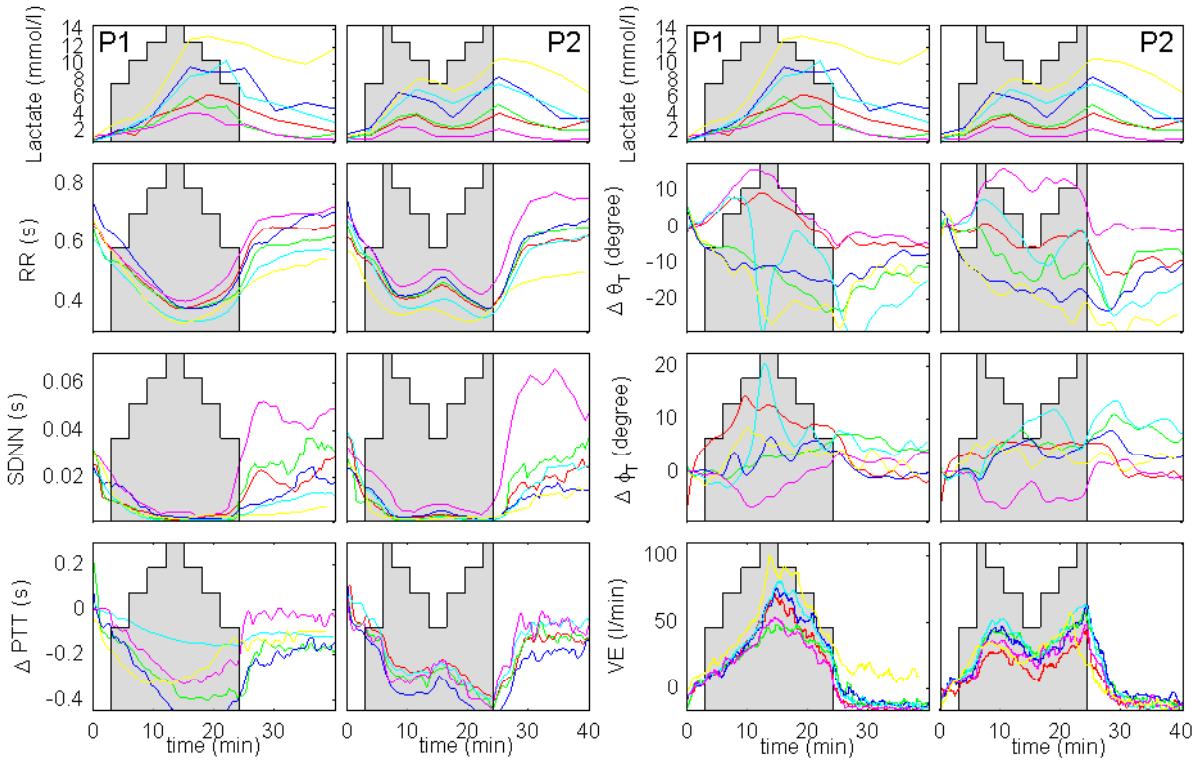

Figure 2. Lactate values and trends of estimated parameters for both protocols. Values for the six subjects are presented as unique line colors. Lactate concentrations are presented in first row and parameters estimated from measured signals are presented in lower rows.

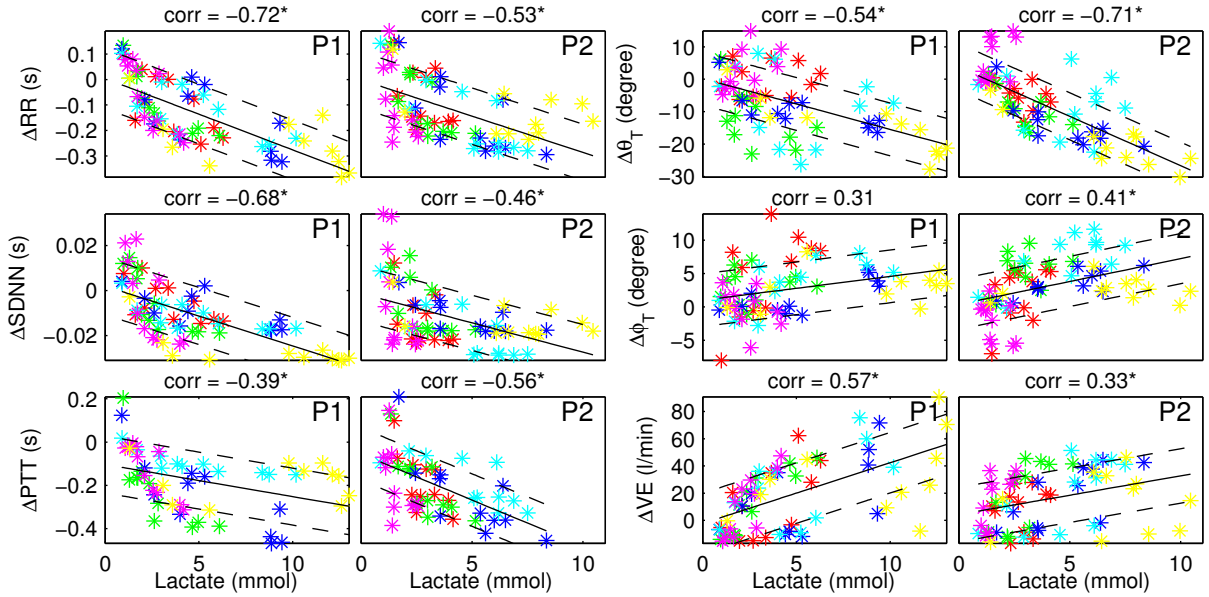

Figure 3. Correlations of estimated parameters presented separately for both protocols. Correlation coefficient r and statistical significance of the correlation (* $p<0.01$) is presented ontop of each axis. Different subjects are presented as unique colors in all axes. Correlation lines $\pm$ standard deviation limits are presented as black lines.

tion estimation. Correlations are calculated using a mean value of each parameter calculated using ± 2.5 minutes window corresponding to each lactate measurement time.

Table 1. Parameter correlations to Lactate and RR-time for both protocols P1 and P2. Statistical significance ($p<0.01$) of correlation is marked by star (*).

parameter	P1 lactate	P2 lactate	P1 RR	P2 RR
RR	-0.72*	-0.53*	1*	1*
SDNN	-0.68*	-0.45*	0.88*	0.84*
PTT	-0.39*	-0.56*	0.73*	0.90*
θ_T	-0.54*	-0.71*	0.24	0.15
ϕ_T	0.31	0.41*	-0.34*	-0.29
VE	0.57*	0.33*	-0.88*	-0.88*

The parameter correlations to lactate and to RR interval are summarised in table 1. In table 1, it can be seen that SDNN, PTT and VE depend strongly on the RR interval time. The best correlations to lactate are with RR interval and $\Delta\theta_T$. In addition, it is noted that the correlation between $\Delta\theta_T$ and RR interval time is very small. Correlations calculated only for recovery period values were: between lactate and RR r = -0.81 (P1 $p<0.001$), r = 0.72 (P2 $p<0.001$) and between lactate and $\Delta\theta_T$ r = 0.45 (P1 $p<0.01$), r = 0.89 (P2 $p<0.001$).

5. Discussion

Analysis of vectorcardiographic changes in two different protocols during exercise and recovery period have been presented. During exercise period RR-interval, SDNN and minute ventilation change simultaneously with bicycle load and with lactate concentration. However during recovery period these parameters approach normal values much faster than lactate concentration. This can be seen especially in protocol P2 where lactate concentrations are at higher beginning of the recovery period.

VECG parameter estimation is challenging especially during exercise periods. VECG parameters are based on the waveform estimations of the QRS complex and low amplitude T-wave. HRV parameters, on the other hand require only detection of the strong R-waves. Thus, it is obvious that the VECG parameters are more sensitive to noise than HRV parameters. In this paper, VECG parameters were estimated using PCR-modeling, but nevertheless noise and other movement artefacts caused bias to the angle estimates during exercise periods. This is the probable cause of the large oscillations of θ_T and ϕ_T (figure 2).

During the recovery period, however, T-wave angle θ_T seems to correlate well with lactate concentration, i.e. it returns slowly towards to normal values simultaneously with the lactate concentration. Therefore θ_T could be informative tool for monitoring recovery process and evaluation of physical performance after intensive physical training.

As mentioned in introduction estimating training intensity from ECG measurements is very interesting idea. ECG is much easier and cheaper to measure than lactate concentrations or spirometric variables, and thus, it achievable even for normal exercisers. Measuring AT from ECG parameters could be processed towards to performance estimation during and after exercise. The VECG parameter findings of this study can have a significant contribution on this approach, especially during recovery period.

In conclusion, presented vectorcardiographic changes during recovery period are promising and raise some ideas for recovery monitoring and predicting physical performance from ECG parameters during and after exercise.

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