

3-D Magnetic Measurement of Exercise-Induced MCG

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ABSTRACT

We carried out a three-dimensional (3-D) vector measurement of exercise-induced magnetocardiograms (MCGs) for normal subjects with a wooden and brass-based bicycle ergometer. MCGs were measured by a 3-D second-order gradiometer connected to 39-channel SQUIDs, which can detect magnetic field components perpendicular to the chest wall (B_z) and tangential to the chest wall (B_x , B_y) simultaneously. Time-frequency analysis was applied to rest times and exercise-induced MCG data. It was shown that the power spectrum of the ST segment was different between the rest times and exercise-induced MCG. Principal component analysis (PCA) was also applied to the result of time-frequency analysis and the time course of frequency for the ST segment was evaluated quantitatively. It found that dominant frequency of the ST segment in the rest time was ranged 5.5 to 6.5 Hz in all components. And it was clearly shown that the peak frequency of the exercise-induced MCG was shifted to 10.5 Hz compared to that of rest MCG.

KEY WORDS

Three-dimensional (3-D) exercise-induced magnetocardiogram (MCG), Time-frequency (t-f) analysis, Principal component analysis (PCA), QRS complex, ST-T segment, Target heart rate (THR).

INTRODUCTION

Biomagnetic field measurement is widely used for the magnetic field perpendicular to the body surface. There are a few reports concerning a 3-D vector measurement [Kobayashi, 1998] [Burghoff, 1999]. We have developed a 39-channel SQUID system consisting of 3-D second-order gradiometers (12 measurement position (4×3) and a noise measurement) for vector measurement of MCG and magnetoencephalogram (MEG) [Kobayashi, 1999]. This SQUID magnetometer can detect magnetic field components perpendicular to the chest wall (B_z) and tangential to the chest (B_x , B_y) simultaneously. The MCG data of normal subjects or cardiac patients have been investigated both at rest and under conditions of dynamic stress [Hanninen, 2000]. Most reports were about spatial distributions of the MCG data. Only a few [Kobayashi, 1999] were about a frequency change of the QT segment. We developed a wooden and brass-based bicycle ergometer for exercise-induced MCG measurement in magnetically shield room (MSR). The aim of this study is to investigate frequency change of the ST segment in exercise-induced MCG of normal subjects using a 3-D vector MCG measurement system.

METHODS

A 3-D vector measurement of exercise-induced MCGs for eleven male normal subjects was performed using a bicycle ergometer made of wood and brass. The MCG and the ECG (lead II) was measured simultaneously; all subjects had no history of cardiovascular disease, or signs of abnormalities in their ECG. The exercise-induced 3-D MCG measurement was done inside a MSR in all measurement. Fig. 1 shows the coordinate system and the forty-eight measurement positions indicated by fixed circles. The

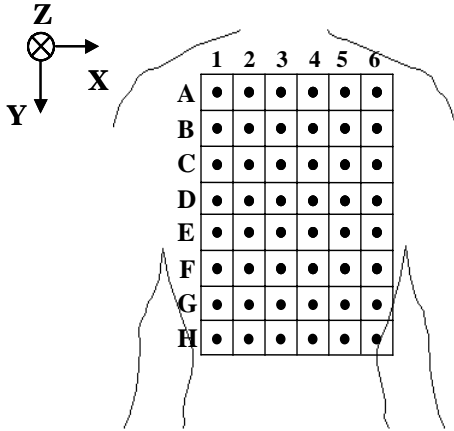


Figure 1. Coordinate system and locations of measurement positions on a subject's chest.

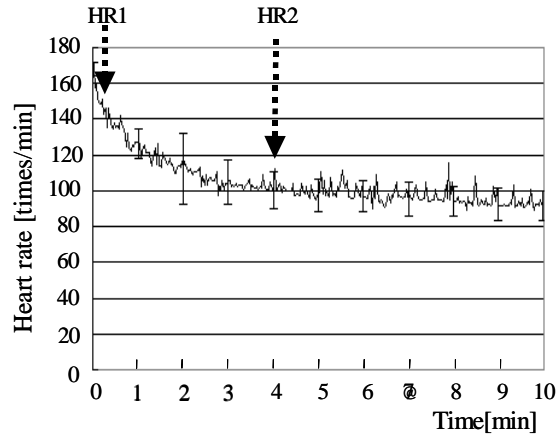


Figure 2. Example of time course of heart rate during exercise-induced MCG measurement.

MCG measurement of resting times was done in the first 4 minutes. Target heart rate (THR) for each subject (which is caused by exercise stress) was calculated using an equation represented by $THR = (220 - \text{age}) \times 0.85$. After reaching the THR, exercise-induced MCG measurement for ten minutes was carried out as shown in the example of Fig. 2. The exercise-induced MCGs from 0.5 to 300 Hz were sampled with 1000Hz. All magnetic data were averaged for 10 MCGs at the same heart rate. The reference signal for averaging was the R-wave of ECG and a digital filter was used in the range of 1 to 40 Hz.

RESULTS AND DISCUSSION

The example in Fig. 2 shows of the time course of heart rate during a measurement of exercise-induced MCGs. Target heart rates of all subjects were set by 166.6 to 168.3 [times/min]. This data was an averaged heart rate for the eleven subjects. Heart rate of HR1 (after 5 [sec] from starting exercise-induced MCG measurement) was 160 ± 5.1 [times/min] and heart rate of HR2 (after 240 [sec]) was 100 ± 10.1 [times/min]. It was found that heart rate of HR1 to HR2 was sharply decreased, but it was steady after

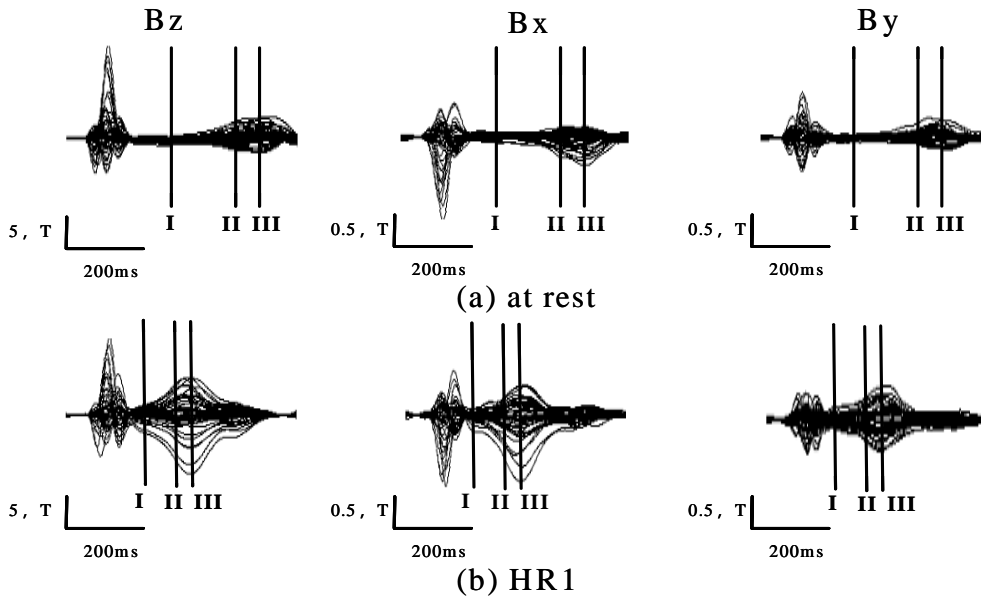


Figure 3. Examples of superimposed waveforms at rest and exercise-induced MCG measurements.

Phase	Component	Bz	Bx	By
I	Frequency [Hz]	6.0	6.0	6.5
	Score proportion [%]	21.2	7.9	6.4
II	Frequency [Hz]	6.5	5.5	6.0
	Score proportion [%]	21.3	11.9	13.5
III	Frequency [Hz]	5.5	6.0	6.0
	Score proportion [%]	29.1	18.6	13.8

(a) At rest

Phase	Component	Bz	Bx	By
I	Frequency [Hz]	6.0	6.0	6.5
	Score proportion [%]	13.8	9.1	7.6
II	Frequency [Hz]	10.5	10.5	10.5
	Score proportion [%]	22.1	19.1	16.7
III	Frequency [Hz]	5.5	5.5	6.0
	Score proportion [%]	38.8	15.4	7.6

(b) HR1

Table 1. Frequency and score proportion of maximum value of the first principal component at rest (upper panel) and HR1 (lower panel).

HR2. Fig. 3 shows a typical MCG superimposed with all measurement points (48 channels). It clearly showed that the ST segment of HR1 was short in all magnetic components.

The AR model [Vila, 1997] was applied to the time-frequency (t-f) analysis of the MCG waveforms, with a time window (100 ms) and was shifted every 5 ms in analysis. The order of AR model was decided by final prediction error criterion (FPE) between 15 and 20. The short-time spectrum is calculated by Eq. (1):

$$B(f) = \frac{\sigma_e^2 \Delta t}{\left| 1 + \sum_{k=1}^p a_k^p \exp(-j2\pi f k \Delta t) \right|^2} \quad (1)$$

where $B(f)$ is power spectrum of MCG, σ_e^2 is variance of white noise, a_k^p is coefficient of AR model, p is order of AR model, and Δt is sampling time interval. The PCA was applied to the result of t-f analysis. Three different phases of the ST segment were analyzed in the analysis (I to III in Fig. 3). Table 1 shows frequencies and score proportions of first principal component at rest and HR1 of three different phases from I to III. In HR1 just after reaching THR the dominant frequency of phase II was shifted 10.5 Hz from 6.5 Hz of Bz, 5.5 Hz of Bx, and 6.0 Hz of By in each component. And each score proportion of Bx and By was inverted compared to that of rest MCG. Dominant frequencies of phase I and III in both of at rest and HR1 ranged from 5.5 to 6.5 Hz in all components.

The dominant frequencies were found to change from 5.5-6.5Hz to 10.5Hz in all magnetic components. Furthermore, the By component showed higher score proportion (13.5%, Table 1a) than Bx in the first

principle component of phase II at rest. However, for the phase II in HR1 the score proportion of Bx component was higher (19.1%, Table 1b). This suggests that the main direction of the tangential component of the current changed from X to Y (Fig.1). These results show that 3-D vector MCG measurement is useful for detecting frequency change of the ST segment in exercise-induced MCGs.

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