www.s2is.org
International Journal on Smart Sensing and Intelligent Systems
ISSN 1178-5608

EFFECTS OF LOW FREQUENCY WEAK MAGNETIC FIELD ON THE CARDIOVASCULAR SYSTEM THROUGH THE BRAIN CORTEX

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Submitted: Sep. 30, 2015   Accepted: Jan. 5, 2016   Published: Mar. 1, 2016

Abstract-In order to study the effect of low frequency weak magnetic field on the cardiovascular system through the central nervous system, this paper design the experiment that is using a rotating magnetic field acts on the cerebral cortex, the different frequency when different parts of the brain, collecting and analysis ECG and blood pressure signal, and discussing the effect of low frequency rotating magnetic field on cardiovascular system through the brain cortex. It proved that a rotating magnetic field can affect blood pressure through cerebral cortex, has different effects on blood pressure by using different frequencies, the effects on blood pressure is not the same because a different position focused on by magnetic field. The results show the frequency and location stimulated with rotating magnetic field may have certain therapeutic effect for controlling hypertension.

Index terms: low frequency magnetic field; cardiovascular system; blood pressure; biological effect of magnetic field.

I. INTRODUCTION

Cardiovascular disease has become a danger to human life "first killer". For the treatment of cardiovascular disease has a lot of, the most basic diet, drug therapy, surgical treatment and the rise of new intervention treatment. These treatment methods play a role for the treatment of cardiovascular disease (CVD).And the use of the biological effects of the magnetic field as a kind of non traumatic to regulate cardiac function, concerned with by the broad masses of medical workers and researchers, is also a hotspot in the research of the biomedical engineering at present[1,2].

The biological effect of magnetic field is nearly thirty years to gradually get the attention of the people, more than 30 years of research and through this paper to analyze the content, which focused on the diminish inflammation, analgesic action; on the role of the central nervous system; the effects on the circulation of the blood system (mainly for the heart, blood pressure, the influence of the microcirculation and hemorheology)[3-5]; the effects on the digestive system (mainly influence on the movement of the gastrointestinal tract and absorption function); the effect on tumors of paper, etc. Previous role in magnetic therapy in our country community recognized magnetic field treatment of six main functions, namely the diminish inflammation, detumescence, analgesia, sedation, step-down, anti-diarrhea effect completely consistent [6,7]. These magnetic biological effects of study for magnetic field therapy provide a reliable experimental and theoretical basis. Some research has shown that low magnetic field tends to increase the activity of animals, increased excitability; strong magnetic field can reduce the activity of the organism, excitability, render response inhibition. In addition, the magnetic field also has some effect on plant nerve, the heart, blood pressure, and breathing [8,9].

At home and abroad a large number of researches from different angles discussed the influence of magnetic field on the nervous system and cardiovascular system. It shows that the magnetic field can stimulate the cerebral cortex, adjust plant nerve system, thus improving the potential of the cardiovascular system [10-12]. For specific parameters used and mechanism of the magnetic field is opinions vary, some studies have also just made some general description and speculate that there is no exact explanation [13, 14].So the effect of magnetic field on cardiac function and cardiovascular system remains to be further discussed. In this paper, using a rotating magnetic field acts on the cerebral cortex, the different frequency when different parts of the brain, through collecting electro cardio(ECG) and blood pressure signal of the body, to find the low frequency rotating magnetic field effects on the cardiovascular system through the brain cortex.

II. MATERIALS AND METHODS

A. Equipments of the Experiment

Use the rotating magnetic field instrument made by the paper to produce a rotating magnetic field, magnetic field intensity measured by gauss meter, surface magnetic field strength of permanent magnet is 0.3 T (tesla),and at the position of 3 cm from the center of magnetic field, the intensity is about 2 mt, adjustable frequency in the range 0 to 15 Hz. Using the continuous noninvasive blood pressure measurement instrument(FMS, produced by Dutch Finapres medical system)and the multi-channel electrophysiology recorder (MP150,produced by Biopac companies in the United States) record the continuous blood pressure of human body.

B. Subjects

The subjects are 21 boys in school at Xi 'an Technological University, age from 20 to 24 years old, healthy body. Before the trial, requires all participants fill out questionnaires experiment.

C. Methods

The surface central node of rotating magnetic field respectively focused on the forehead (Fp), above the central point (Cz), Fp and Cz intermediate point, center distance of magnetic field on the surface of the scalp is 1 cm. Stimulate on each point with two diffrient magnetic, 15 Hz and 2 Hz frequency spin magnetic stimulation, and measure 6 minutes every time, among the time of magnetic stimulation is 2 minutes. Record the continuous blood pressures in the process of experiment. Analysis the changes of blood pressure before the magnetic field, among magnetic field, and after the magnetic field, to explore the magnetic field through the brain cortex effects on blood pressure.

D. Statistical Analysis Method of Data

Experimental data is analyzed by SPSS statistical analysis software, with a mean plus or minus standard deviation for the systolic pressure (SP), diastolic pressure (DP) and mean pressure (BP) according to measurement data, recorded before magnetic field, magnetic field, and after the magnetic field. Compare the difference between the data using paired t test.

III. PHYSIOLOGICAL SIGNAL PROCESSING METHOD AND PRINCIPLE

After collecting experimental data it needs to process the data further and extract the feature parameters. By analysis the characteristic parameters, study effects on the cardiovascular system of low frequency rotating magnetic field. Include ECG data filtering processing, R wave extraction and analysis of heart rate variability, the blood pressure signal preprocessing and feature point extraction.

A. R wave of ECG signal extraction Methods and principles

R wave of ECG signal is that at the same time ventricular cells in a short period of time depolarize to produce, when ventricular cells excited. In the ECG signal it has a frequency of concentration and peak, large amplitude characteristics obviously. And in the heart rhythm activity often used to calculate the heart rate by the location of the R wave and the period of two adjacent R wave (RR interval).The methods of localization R wave have many, including simple finite difference method, threshold method, a complex wavelet decomposition, pattern recognition, etc. In this paper, R wave of ECG extracted using wavelet singularity detection.

a. Wavelet Transform principles

Wavelet transform is the basic idea of scaling and translation, through this kind of transform to get time-scale information of a signal.

$$0 < \int_0^{+\infty} \frac{|\Psi(\omega)|^2}{\omega} d\omega < +\infty \qquad (1)$$

In formula (1), $\Psi(\omega)$ and $\psi(\omega)$ is the Fourier transform. If $\psi(\omega)$ is a square integrable function, and satisfy formula (1), a small wave generating function is called. Scaling is done in the peaceful move into wavelet basis function, as follows:

$$\psi_{a,\tau}(t) = a^{-\frac{1}{2}} \psi\left(\frac{t-\tau}{a}\right) \ (a > 0, \tau \in R) \qquad （2）$$

In formula (2), a is the scale factor; τ is the translation factor.

Wavelet basis function make inner product with an arbitrary function, expressed as $f(t)$, then get the continuous wavelet transform(CWT) function.

$$WT_f(a,\tau) = \langle f(t), \psi_{a,t}(t) \rangle = \frac{1}{\sqrt{a}} \int_R f(t) \overline{\psi}\left(\frac{t-\tau}{a}\right) dt \qquad （3）$$

In formula (3), $WT_f(a,\tau)$ is referred to as the wavelet transform coefficients.

By wavelet transform can only achieve for the information of the frequency on a certain moment observed, if you need to do the operation of the filter or other also need to get signal by inverse transformation the wavelet coefficient obtained. According to the inverse transformation of wavelet coefficients to get signal is as follows:

$$f(t)=\frac{1}{C_{\psi}}\int_{0}^{+\infty}\int_{-\infty}^{+\infty}\frac{1}{a^{2}}WT_{f}(a,\tau)\bullet\psi_{a,\tau}(t)d\tau da \tag{4}$$

The scale of the wavelet function and translation is a continuous value, clearly as you can see this kind of transformation is a transformation of redundancy, and especially in the field of signal processing the signal in the digital signal processing are discrete values, therefore, discrete wavelet transform(DWT) is more important[15]. Discrete wavelet transform the most commonly used is binary wavelet transform, the scale factor scale in the form of 2 times, seamless translation. Wavelet generating function shift and change in the following dimensions to get binary wavelet:

$$\psi_{2^{k},t}(t)=2^{-\frac{k}{2}}\psi(\frac{t-\tau}{2^{k}}) \tag{5}$$

To do the binary wavelet and signal inner product obtains the binary wavelet transform coefficient.

$$WT_{f}(2^{j},\tau)=\langle f(t),\psi_{2^{j},\tau}(t)\rangle=\frac{1}{2^{j}}\int_{R}f(t)\psi(\frac{\tau-t}{2^{j}})dt \tag{6}$$

When select wavelet generating function as tight framework model, binary wavelet inverse transformation for:

$$f(t)=\sum_{k\in Z}\int WT_{f}(2^{j},\tau)\bullet\psi_{2^{k},\tau}(t)d\tau \tag{7}$$

b. Wavelet singularity detection principles and Methods [16]

Signal singularity is often more important points, such as a machine in the operation of the running state of the data collected, the singular point Might indicate that the failure of the machine. So usually in the signal processing need fix the specific point. The singularity of the point is quantitative description with Lipschitz index. It is defined as: to 0 or less alpha 1 or less, such as there is constant C makes any real t satisfy the formula(8).

$$|f(t)-f(t_{0})|\leq C|t-t_{0}|^{\alpha} \tag{8}$$

In the local singularity in the wavelet transform is defined as:

$$\forall t \in \partial t_0 ,\quad | WT_f (s,t) | \leq K s^{\alpha} \qquad (9)$$

In formula(9), K is a constant. If $f(t)$ satisfy with the express in the formula (9), α is called as a singularity index.

If $f(t)$ satisfy with the express in the formula (10), t_0 is the local extremum of wavelet transform scales.

$$\forall t \in \partial t_0 ,\quad | WT_f (s,t) | \leq | WT_f (s,t_0) | \qquad (10)$$

Mallat pointed out that in the scale of the wavelet decomposition is enough big, when signal wavelet decomposition in point have local modulus maxima, the point is the singularity of signals. So it can be resolved by detecting specific scale of local modulus maxima of wavelet coefficient to detect signal singularity.

The wavelet analysis method is excellent in detecting the R wave of ECG signal, because the R wave of ECG is a singular point of large amplitude. R wave frequency are mainly concentrated in 17 Hz or so, so at 500 Hz sampling rate for the original ECG signals do 5 layers wavelet decomposition, R wave energy is mainly concentrated in the fourth layer (15.6~31.3 Hz frequency range), and R wave appears in your location will be in the fourth layer decomposition modulus maxima. But R wave frequency fluctuate under some special cases, in order to guarantee to detect R wave, need to detect the fifth layer and layer 3 on the decomposition of modulus maxima. So the detection of R wave should be considered in the process of actual 3-5 layer on each local modulus maxima position. Figure 1 shows the ECG signals to db3 wavelet as the mother wavelet, do 5 decomposed 3-5 layers on each component and the original ECG signal. Figure 2 shows a certain subject R wave detection, in figure (b)，″。″is the location of detected R wave.

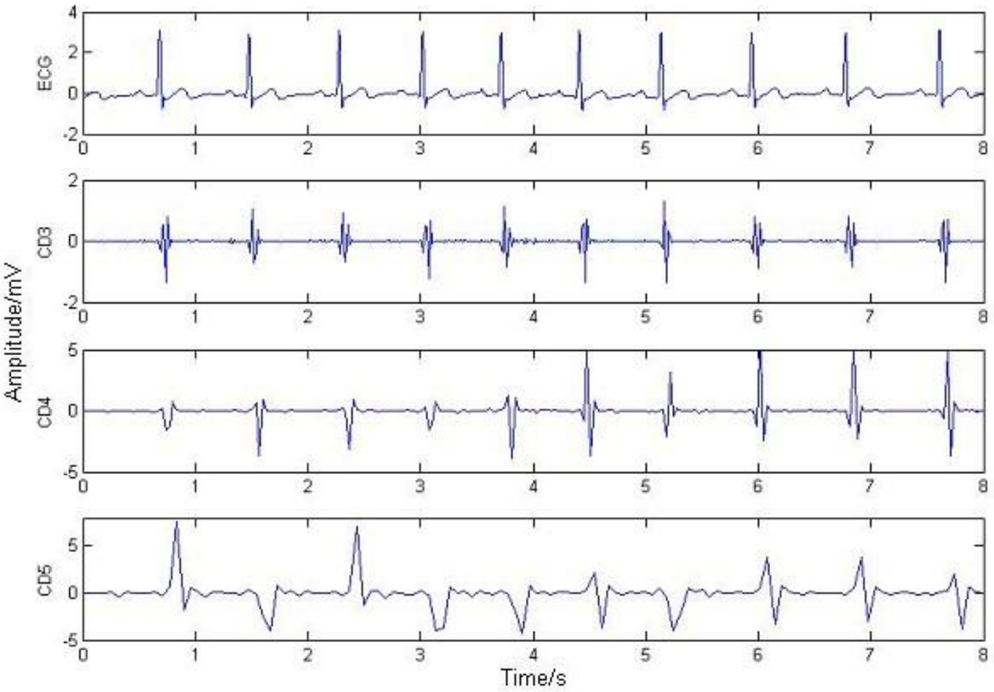

Figure 1Eachlayer and the original ECG signal

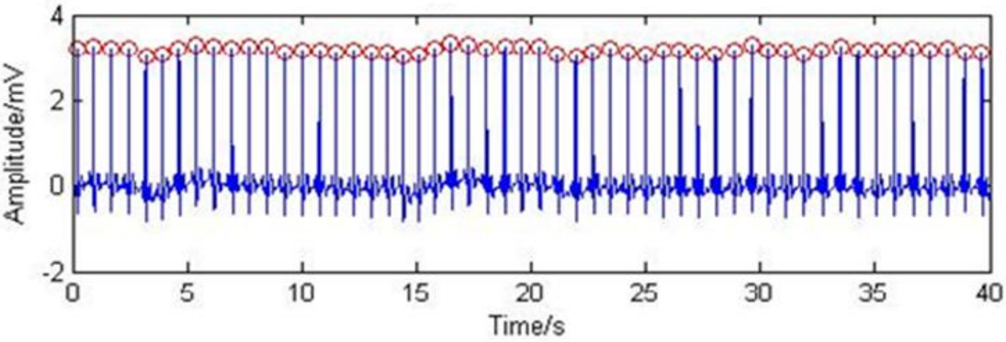

Figure 2. R wave detection

B. Spectral analysis of heart rate variability

a. RR interval resampling

Through the signal processing, has been gotten the R wave of ECG sequence. After get sinus heart rate RR interval, it needs to be resampled. Based on the analysis of heart rate variability, we will abstract a cardiac cycle into a single point (R). But the cardiac cycle is not completely equal, therefore creates the RR interval data has not asamestandard. And in the frequency spectrum analysis, demand signal must be first class interval sampling data, So we need resampling the RR interval data in the case of without introducing extra spectrum peak. In this paper,the method is used that the cubic spline resampling, and the sampling at a rate of 1 Hz. Figure 3 shows the original RR intervals sequence and resampling to 1 Hz sequence.

The cubic spline interpolation usually used to solve the curve function group is a smooth curve through a series of points. In mathematics, generally get its function by solving the three moment equations [17].

Let $a \leqslant x_0, x_1, \ldots, x_n \leqslant b$ is a part of the interval [a, b], if the function S(x) in the interval [a, b] satisfies the condition on:

(1) S(x), S'(x), S"(x) in the interval [a, b] continuous, then $S(x) \in C2$ [a, b];

(2) If function S(x) is satisfied in each cell $[x_k, x_{k+1}]$ is the three polynomial, then call S(x)is the cubic spline function for the interval [a, b];

(3) If the function f(x) at the nodes x0, x1, …, xn , the values were $f(x_j)=y_j$, j=0, 1, …, n, and cubic spline function S(x) also meets $S(x_j)=y_j$, j=0, 1, ⋯, n, then called S(x) is the cubic spline interpolation function of f(x) in [a, b].

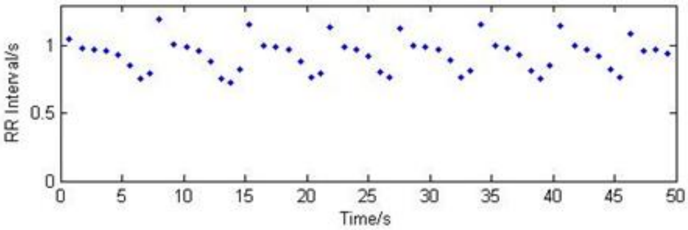

Figure 3(a).The original RR intervals

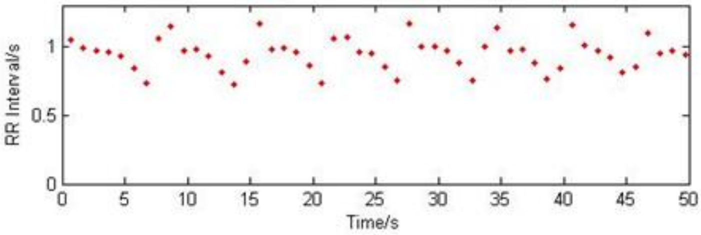

Figure 3(b).The resampling RR intervals

b. AR model power spectrum analysis for heart rate variability

Heart rate variability (HRV) in the frequency domain analysis method has parameter estimation method and non-parametric estimation method. Nonparametric estimation methods using fast Fourier transform, general data is long enough, and the spectrum has such problems as saw tooth shoulder peak [18-21]. In this paper, effective length of the data is only 2 minutes, so we used the parameter spectrum estimation method of autoregressive (AR) model. AR model (auto-regressive model) power spectrum estimation, also known as self-regression model [22]. Any of a random signal having a power spectral density, can be seen by the white noise generated by a particular physical network [22, 23], it can be used as a differential equation to represent:

$$x(n) = -\sum_{k=1}^{p} a_k x(n-k) + \omega(n) \tag{11}$$

Z transform of the formula, you can get AR model of the system transfer function is:

$$H(z) = \frac{1}{1+\sum_{k=1}^{p} a_k z^{-k}} \tag{12}$$

The transfer function H(z) only has pole, and there is no other zero except the origin. So it is known as the full pole model, and the power spectral density obtained by this method can be written as:

$$P(\omega) = \frac{\sigma_\omega^2}{\left|1+\sum_{k=1}^{p} a_k e^{-j\omega n}\right|^2} \tag{13}$$

Firstly solve the AR parameters, generally through the Levinson-Dubin recursive algorithm based on linear prediction or theory of Burg algorithm or Marple AR parameters determined by the Yule-Walker equations, in addition to the modified covariance method and the like can be used the AR model parameter estimation [24].

Because in this article analysis 2 minutes RR intervals, extremely low frequency power sequence does not need. So before this paper estimate the power spectrum using coif1 wavelet decomposition, remove the weight of the RR interval frequency is lower than 0.03 Hz. After by AR model can estimate the RR intervals power spectrum, the order of AR model to choose 16 orders, the result is shown in figure 4.

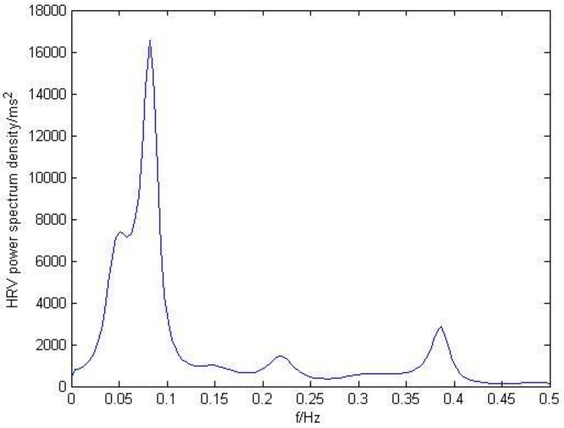

Figure 4 RR intervals power spectrum density

C. Blood pressure signal feature point extraction method

Blood pressure waveform feature points contain systolic pressure (SP), diastolic pressure (DP) and mean blood pressure (MP) parameters. Systolic blood pressure, that is cardiac contraction producing the maximum pressure, pushed forward the blood into the aorta, and maintains the systemic circulation. Period between ventricular contraction, cardiac aortic valve open, at this time of arterial pressure usually reflect the ventricular mechanical movement; Achieved the lowest pressure when the heart to expand as the diastolic blood pressure, it can make the blood back into the atrium. During the ventricular diastolic heart aortic valve closed, at this time the arterial pressure reflect the changes from the aorta to the peripheral vascular system flow ability. Average pressure throughout the cardiac cycle is the average of the arterial pressure, MP = DP + (SP - DP) / 3.

In this paper, extraction of systolic pressure (SP) corresponding to the peak value of blood pressure waveform, diastolic pressure (DP) corresponding to the valley value of blood pressure waveform average pressure can be made of SP and DP calculated by formula. As the blood pressure waveform peak valley value extraction using wavelet singularity detection method, the principle is the same as the ECG R wave extraction. Peak and trough blood pressure values of detecting waveform are shown in figure 5.

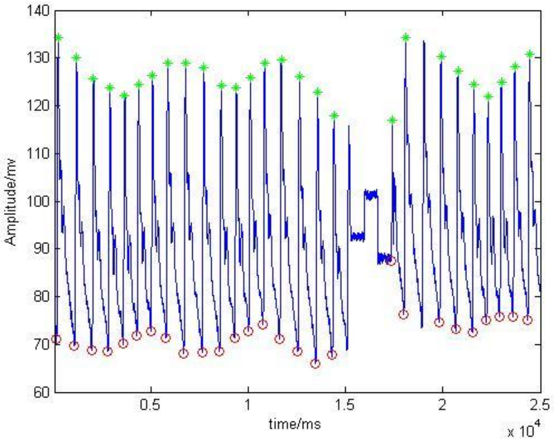

Figure 5 Blood pressure waveform feature points detection

IV. RESULTS

A. Influence of Different Magnetic Field on Systolic Blood Pressure

See table 1 and 2. Under the stimulation of gyro magnetic with 2 Hz frequency, when the center of the magnetic field is focused on the frontal area (FP), the average systolic blood pressures (SBP) is 123.56±10.68 mmHg, before adding magnetic SBP was 126.86±11.72 mmHg, and after magnetic systolic SBP was 121.14 ±10.48 mmHg. There are differences between the three systolic blood pressures by pair-wise comparison ($P < 0.05$). When the magnetic field were focused on the two positions, one is the central head points (Cz), another one is intermediate point of Fp and Cz (Cz - Fp), there are no differences between the three systolic blood pressures by pair-wise comparison ($P > 0.05$). Under the stimulation of gyro magnetic with 15 Hz frequency, when the magnetic field were focused on Cz and Fp, there is a difference between before and among the magnetic field (P <0.05), no difference between after and among (P >0.05), and a difference between before and after the magnetic field (P <0.05). When the magnetic field was focused on Cz-Fp, there is a difference between before and among the magnetic field (P <0.05), all of the two station with after the magnetic field have no differences (P >0.05).

Table 1. SBP changes in 2Hz frequency magnetic field irradiate head position

SBP($\bar{x}\pm s$, mmHg)

Station of being stimulated on head	2Hz		
	before	among	after
FP	126.86±11.72	123.56±10.68①②	121.14±10.48③
Cz-FP	124.81±16.10	124.77±14.68	124.15±13.85
Cz	132.25±14.35	134.29±14.98	133.65±15.66

Notes in table 1. ①Compared with before adding magnetic and magnetic, P<0.05; ② Compared with adding magnetic and after magnetic, P<0.05; ③Compared with before adding magnetic and after magnetic, P<0.05;

Table 2. SBP changes in 15Hz frequency magnetic field irradiate head position

SBP($\bar{x}\pm s$, mmHg)

Station of being stimulated on head	15Hz		
	before	among	after
FP	122.39±16.34	125.16±14.70①	125.70±15.23③
Cz-FP	128.91±14.70	131.35±14.24①	131.49±15.27
Cz	135.04±12.79	137.55±12.04①	139.05±13.25③

Notes in table 2. ①Compared with before adding magnetic and magnetic, P<0.05; ② Compared with adding magnetic and after magnetic, P<0.05; ③Compared with before adding magnetic and after magnetic, P<0.05;

B. Influence of Different Magnetic Field on Diastolic Blood Pressure

See table 3 and 4. Under the stimulation of gyro magnetic with 2 Hz frequency, when the center of the magnetic field is focused on the frontal area (FP), the average diastolic blood pressures (DBP) adding magnetic DBP is different with before magnetic. There is a difference between among and after magnetic stimulation, no difference between before and after. When the magnetic field were focused on the two positions, one is the central head points (Cz), another one is intermediate point of Fp and Cz (Cz - Fp), there are no differences between the three systolic blood pressures by pair-wise comparison ($P > 0.05$). Under the stimulation of gyromagnetic with 15 Hz frequency, when the magnetic field was focused on Fp, there is a difference between before and among the magnetic field ($P < 0.05$), no difference between after and among ($P > 0.05$), and a difference between before and after the magnetic field ($P < 0.05$). When the magnetic field were focused on Cz-Fp and Cz, there are no differences between the three systolic blood pressures by pair-wise comparison ($P > 0.05$).

Table 3. DBP changes in 2Hz frequency magnetic field irradiate head position

DBP($\bar{x} \pm s$, mmHg)

Station of being stimulated on head	2Hz		
	before	among	after
FP	69.77±9.96	68.49±10.10①	67.81±9.91③
Cz-FP	67.75±10.48	67.97±11.00	68.10±10.40
Cz	74.15±8.62	74.86±9.32	74.78±9.94

Notes in table 3. ①Compared with before adding magnetic and magnetic, P<0.05; ② Compared with adding magnetic and after magnetic, P<0.05; ③Compared with before adding magnetic and after magnetic, P<0.05;

Table 4. DBP changes in 15Hz frequency magnetic field irradiate head position

DBP($\bar{x} \pm s$, mmHg)

Station of being stimulated on head	15Hz		
	before	among	after
FP	64.73±11.31	66.10±10.91①	66.77±10.55③
Cz-FP	68.78±9.93	70.09±9.77①②	71.34±9.82③
Cz	74.69±7.64	76.20±7.83①②	77.52±8.98③

Notes in table 4. ①Compared with before adding magnetic and magnetic, $P<0.05$; ② Compared with adding magnetic and after magnetic, $P<0.05$; ③Compared with before adding magnetic and after magnetic, $P<0.05$;

C. Influence of Different Magnetic Field on Mean Blood Pressure

See table 5 and 6. Under the stimulation of gyromagnetic with 2 Hz frequency, when the center of the magnetic field is focused on the frontal area (FP), the average mean blood pressures (MBP) adding magnetic MBP is different with before magnetic. There is a difference between among and after magnetic stimulation, no difference between before and after. When the magnetic field were focused on the two positions, one is the central head points (Cz), another one is intermediate point of Fp and Cz (Cz - Fp), there are no differences between the three systolic blood pressures by pair-wise comparison ($P > 0.05$). Under the stimulation of gyro magnetic with 15 Hz frequency, when the magnetic field were focused on Fp and Cz-Fp, there is a difference between before and among the magnetic field ($P < 0.05$), no difference between after and among ($P > 0.05$), and a difference between before and after the magnetic field ($P < 0.05$). When the magnetic field was focused on Cz, there are all differences between the three systolic blood pressures by pair-wise comparison ($P < 0.05$).

Table 5. MBP changes in 2Hz frequency magnetic field irradiate head position

MBP($\bar{x}\pm s$, mmHg)

Station of being stimulated on head	2Hz		
	before	among	after
FP	86.36±9.85	84.85±10.09①	83.84±9.84③
Cz-FP	84.49±10.93	84.76±11.18	84.74±10.59
Cz	91.23±9.51	92.19±9.93	92.09±10.49

Notes in table 5. ①Compared with before adding magnetic and magnetic, $P<0.05$; ② Compared with adding magnetic and after magnetic, $P<0.05$; ③Compared with before adding magnetic and after magnetic, $P<0.05$;

Table 6. MBP changes in 15Hz frequency magnetic field irradiate head position

MBP($\bar{x}\pm s$, mmHg)

Station of being stimulated on head	15Hz		
	before	among	after
FP	81.59 ±11.77	82.91 ±10.93①	83.70 ±10.84③
Cz-FP	86.03 ±10.49	87.68 ±9.99①	88.86 ±10.40③
Cz	91.22 ±9.71	93.98 ±8.40①②	95.36 ±9.67③

Notes in table 6. ①Compared with before adding magnetic and magnetic, P<0.05; ② Compared with adding magnetic and after magnetic, P<0.05; ③Compared with before adding magnetic and after magnetic, P<0.05;

V. CONCLUSIONS

Based on the effect of low frequency weak magnetic field, this paper, using a rotating magnetic field acts on the cerebral cortex, the different frequency when different parts of the brain, through analysis ECG and blood pressure signal, discussed the effect of low frequency rotating magnetic field on cardiovascular system through the brain cortex. According to digital signal processing, used wavelet singularity method to detect R wave of ECG and blood pressure characteristic value (SP, DP and MP), and heart rate variability spectrum analysis method is studied.

After a gyro magnetic preliminary inspection of the experiment, it is shown that under the stimulation of gyro magnetic with 2 Hz frequency, when the magnetic field were focused on Fp, the blood pressure including SP, DP and MP reduced. And found that under the stimulation of gyro magnetic with 15 Hz frequency, when the magnetic field was focused on Fp, Cz-Fp, and Cz, the blood pressure all raised. It is proved that a rotating magnetic field can affect blood pressure through cerebral cortex, has different effects on blood pressure by using different frequencies, the effects on blood pressure is not the same because a different position focused by magnetic field. By selecting the frequency and location stimulated with rotating magnetic field may have certain therapeutic effect for controlling hypertension, but it needs to take a more scientific and fine experimental verification.

ACKNOWLEDGEMENTS

This work were supported by National natural science fund projects (11372244), Scientific research plan projects of Shaanxi Education Department (15JK1355) and President fund research projects of Xi'an Technological University(XAGDXJJ1313).

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