ISBN: 83-916590-1-1

Edited by

POLISH ACOUSTICAL SOCIETY,
DIVISION KRAKOW

with cooperation of

STRUCTURAL and BIOMEDICAL ENGINEERING LABORATORY,
STASZIC UNIVERSITY of KRAKOW, AGH

STRUCTURES - WAVES - HUMAN HEALTH

BIOMEDICAL ENGINEERING

Editor
Ryszard Panuszka

KRAKOW 2003
VOLUME XII, No.2

Vol. XII, No 2

I. Relationship between Heart Beats and External Magnetic Field

Stanisław Micek[1], Zenon Nieckarz[1], Dawid Owsiak[1], Andrzej Kułak[2], Adam Michalec[2], Andrzej Surdacki[3], Joanna Pociask-Karteczka[4],

I. Zależność pomiędzy rytmem serca a zewnętrznym polem magnetycznym

SUMMARY

Results of simultaneous measurements of ECG and very low frequency magnetic field for 39 subjects in urban conditions are presented. It is observed that the amplitude of average magnetic disturbance in urban conditions was higher prior to the cardiac cycle than in other time periods. It is also presented how observed effect depends on the place of measurement. This effect could be repeated in laboratory conditions with the use of artificial magnetic field mimicking the natural ones.

STRESZCZENIE

Przedstawiono wyniki równoczesnych pomiarów EKG i pola magnetycznego bardzo niskiej częstotliwości dla 39 osób w warunkach miejskich. Zaobserwowano, że amplituda średnich zaburzeń magnetycznych poprzedzających cykl pracy serca jest większa niż w innych odcinkach czasowych. Przedstawiono też jak obserwowane zjawisko zależy od miejsca pomiaru. Zjawisko to mogło być powtórzone w warunkach laboratoryjnych z zastosowaniem sztucznego pola o charakterystyce pól naturalnie występujących.

[1] Instytut Fizyki, Uniwersytet Jagielloński, ul. Reymonta 4, 30-059 Kraków, e-mail:ufmicek@cyf-kr.edu.pl,
[2] Obserwatorium Astronomiczne UJ, ul.Orla 171, 30-244 Kraków
[3] II Klinika Kardiologii Collegium Medicum UJ, ul. Kopernika 17, 31-501 Kraków
[4] Instytut Geografii i Gospodarki Przestrzennej UJ, ul. Grodzka 64, 31-044 Kraków

INTRODUCTION

It has been well established that heart rate variability (HRV), as measured by the beat-to-beat variation in R-R intervals recorded by means of electrocardiogram (ECG), is an important physiological parameter [1-4]. Sinus node generates regular heartbeats seen in the electrocardiogram. The sinus node is located at the posterior wall of the right atrium of the heart. Autodepolarization of the cells of the sinus node initiates a wave of cellular depolarisation that moves across both atria, which results in the contraction of the atria and filling of the ventricles with blood. The arrival of the impulse into the ventricles via artioventricular node initiates a wave of cellular depolarisation, which results in the contraction of the ventricles and the ejection of blood into the pulmonary and systematic circulation. Then repolarization of the ventricles starts, which results in their relaxation and subsequent ventricular filling with blood that flows through atrioventricular valves. At this point, cardiac cycle has been completed and a new cycle can be initiated by a new impulse.

The analysis of a R-R time series exhibits different sources oscillations in the variability of heartbeat generation. The different regions in the power spectrum are related to special physiological phenomena. The high frequency band (HF) (0,15-0,45 Hz) represents the modulation of the vagal activity especially influenced by respiration and the low frequency band (LF) (0,03-0,15 Hz) reflects the modulation of both sympathetic and parasympathetic tone by baroflex activity (blood pressure regulation). Recent work has suggested that HRV analysis can be used to characterise illnesses such as major depression [6], panic disorder [7] and anxiety and worry [8].

Our group has showed that exposition to some frequencies of the external magnetic field might produce changes in the length of R-R interval [9]. We have also observed excessive magnetic disturbances prior to the onset of next cardiac cycle, which could suggest that in a specific time window relatively small magnetic disturbances could change the starting point of the subsequent cardiac cycle [5]. As a mechanism of the influence of external conditions on cardiac electrical activity a previously proposed model can be used [11], where the membrane potential and conductance of ion channels may be modulated by external signals (e.g. electrical and magnetic fields) [10].

This paper shows that not only the frequency of external magnetic field is important. The most crucial momentum is the timing of magnetic disturbances in relation to the cardiac cycle. From the previously proposed model [11], it could be expected that the highest potential to modulate the length of the cardiac cycle might have magnetic disturbances occurring just before the onset of atria depolarisation.

MEASUREMENT AND ANALYSIS

Standard ECG (Eindhoven I) for few subjects in addition to the magnetic field B_x, B_y, B_z in three perpendicular directions where measured. Three X, Y, Z coils (20 000 turns on ferromagnetic core) were used as magnetic field detectors. Silver electrodes were used for all bipolar ECG measurements. Subjects were sitting in a straight, high-backed chair to minimise postural changes, back to the North Pole, fitted with ECG electrodes.

The 12 bit ADC converter of the frequency 200 Hz was used. A standard amplifier was applied with the wide pass band filter from 0.5 to 20 Hz (to remove 50 Hz frequency). The data were stored as 5-min time series. These data contain synchronous ECG time series of few subjects and magnetic field information. Measurements were made in easy accessible places in the Wawel Castle Court, the Wawel Cathedral and the Niepołomice Castle and also in the laboratory. In the laboratory there were 25 subjects studied – all in the naturally existing magnetic field and in the external artificial magnetic field of an amplitude and shape observed in Wawel Hill generated by Helmholtz coils of 1 x 1-meter size. Over 39 subjects were involved in measurements and 72797 heart cycles was taken into account.

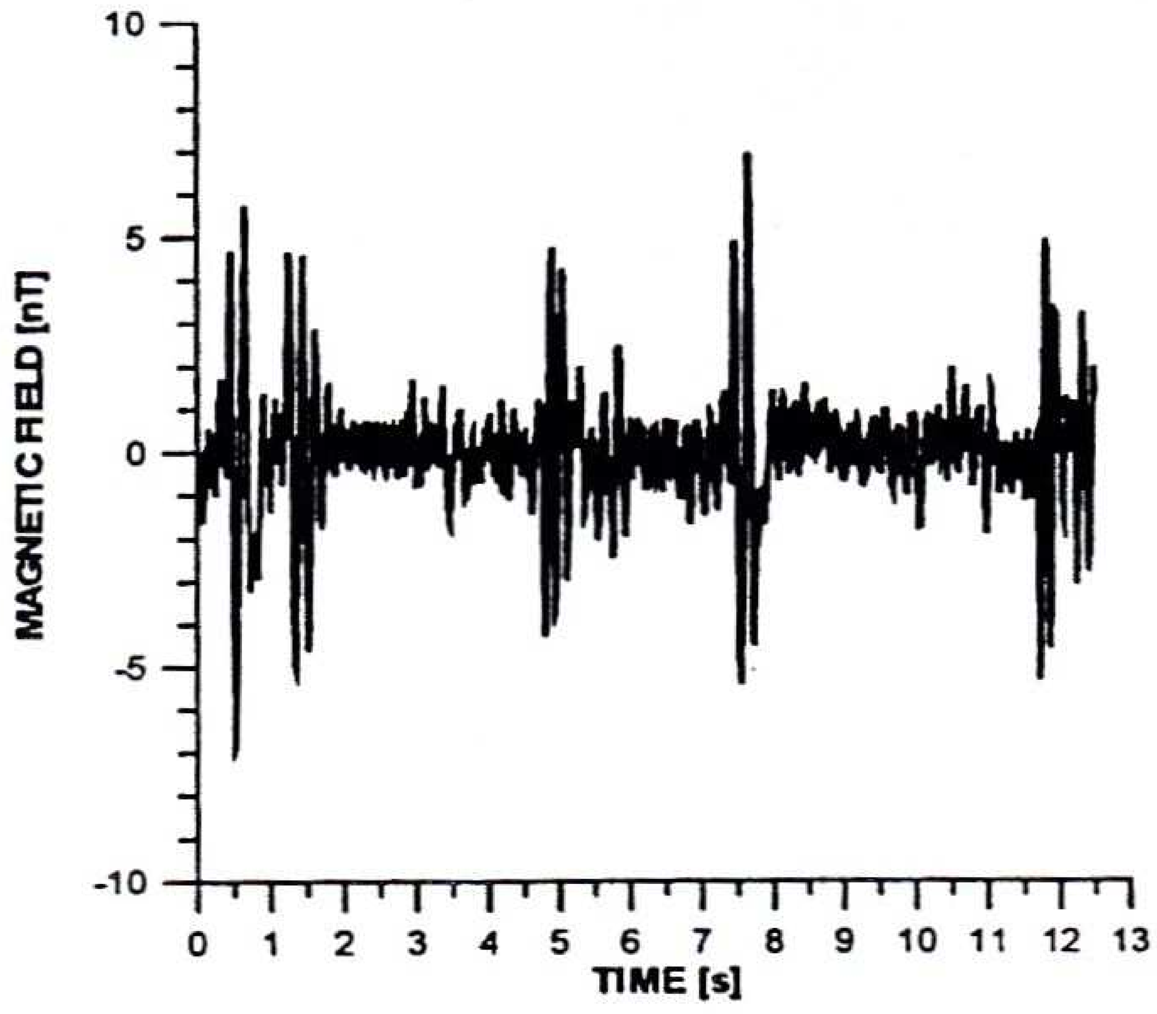


Fig.1. Shape of magnetic field disturbances measured in the Wawel Hill. From time to time we see pronounced oscillations of magnetic field with 5 nT amplitude. In some places of Wawel Hill they were up to 100 nT high.

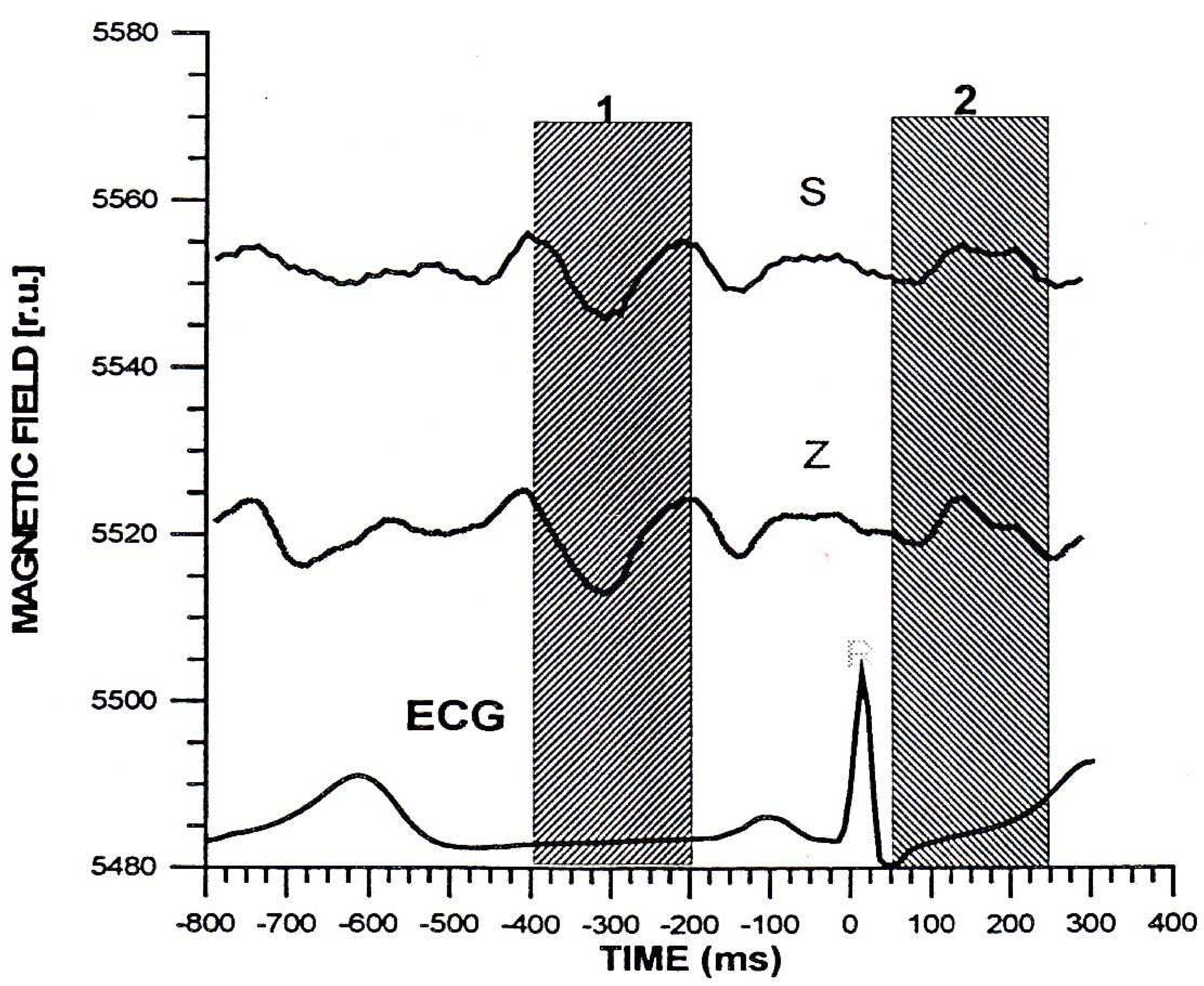
The magnetic field observed in Wawel Hill shows characteristic apparently accidental disturbances presented in Fig.1. They are seen as few oscillations randomly repeated in time.

For a given ECG time series the R point (the peak of the R wave) was estimated by looking on the first derivative in ECG time series in comparison to the given pre-set level determined in preliminary chosen data. Then a magnetic field signal in the surrounding time period was summed up for all R points. In this way the average magnetic signal in relation to the R wave in ECG was calculated.

In the averaged signal every disturbances are constructively summed only when they are in a similar phase relative to the R point. Opposite phase signals give in average almost zero after summation also in the case when they have high amplitude. This method is not taking into account single disturbances of magnetic field signal, because after averaging they are negligibly small. Accordingly, the method is magnifying signals of magnetic field only under the condition that magnetic field signals exhibit some non-random coherence with ECG.

RESULTS AND ANALYSIS

The average external magnetic field signal exhibited some coherence with ECG as shown



in Fig.2. Measurements were performed in the Wawel Castle Court.

Fig.2. The average magnetic field triggered by a cardiac cycle. Measurements were done for two subjects S and Z in the Wawel Castle Court. Lower line presents ECG. Two periods are marked as: period 1 (from 400 to 200 ms prior to the peak of the R wave) with pronounced disturbances of the magnetic field and period 2 lasting from 50 to 250 ms after the peak of the R wave (reference period).

In the period preceding the normal cardiac cycle (400-200 ms prior to the R wave) we observed magnetic field excesses of higher amplitude than in a reference period. A similar phenomenon (shown in Fig.3) was observed during measurements in the Niepołomice Castle.

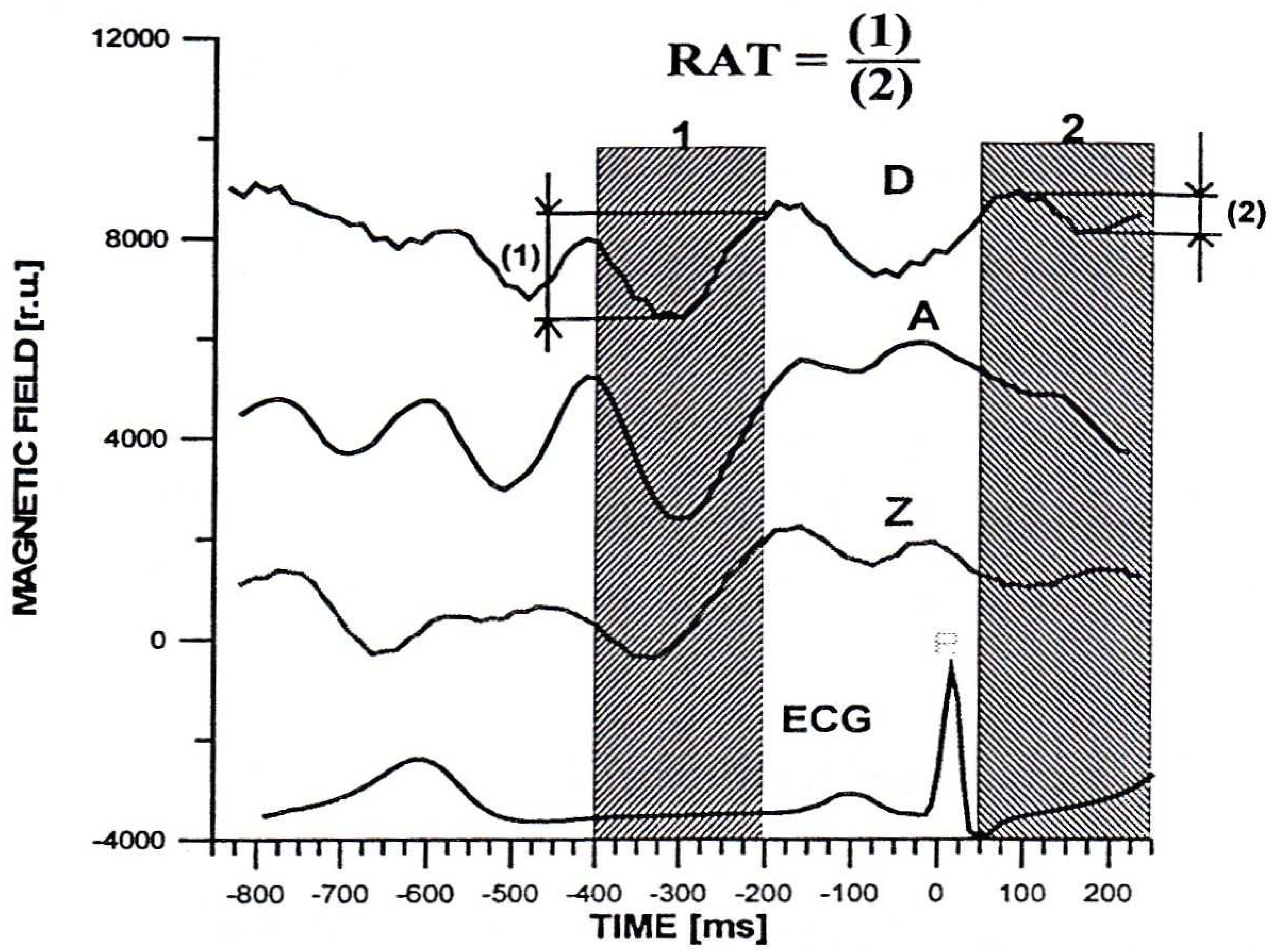


Fig.3. The average magnetic field with the reference to the cardiac cycle measured in the northern part of the Niepołomice Castle. Measurements were made for subjects D, A, Z. Lower line represents ECG time series with QRS points. Two periods are marked: region 1 preceding the cardiac cycle and region 2 during the cardiac cycle. The factor RAT is also defined.

Magnetic field excesses were randomly distributed in time. Excesses with many oscillations could be observed throughout the heart cycle. Taking it into consideration we calculated the amplitude of excesses in magnetic field in a 200 ms period 1 (Fig.3) and divided it by amplitude in a reference period (period 2). This ratio (RAT) bears an information when excessive magnetic field disturbances happened in relation to the QRS complex in ECG. When RAT is equal 1, it means that random signal was observed. The RAT value exceeding 1,0 means that some coherence between ECG and magnetic field was present so that excessive magnetic signal occurred prior to the QRS complex.

Calculations of RAT value in different places are shown in Table I. The average value of RAT in all studied places was 1,25, which indicates that average value of disturbances preceding the cardiac cycle was higher then during the cycle. However the RAT value differed among various places of measurements, which indicates different magnitude of coherence between ECG and magnetic field disturbances. One of potential reasons of this phenomenon can be the fact that the natural magnetic field disturbances are likely to have different characteristics in various places. In addition, individual differences in the sensitivity to external magnetic fields might have been operating in different sets of subjects studied.

In order to get insight into the above-proposed mechanisms of the variability, two sets of measurements (of both ECG and magnetic field with the subsequent calculation of RAT value) were done in laboratory conditions. At the beginning, measurements were carried out in a normally existing magnetic field (3 nT) (first set) and later every 5 s a magnetic impulse was generated (second set). The shape and amplitude of the external impulse was similar to that which was detected at the Wawel Hill (Fig.4A). Then two sets were repeated with each set lasting 5-min.

In the Table I measurements in the naturally existing magnetic field are referred to as LAB0, measurements with external artificial magnetic impulses - LAB1. Ratio RAT after application of magnetic pulses amounted from 1.14 to 1.4.

Abbr. of places	*NB of subjects*	*NB of heart cycles*	*RAT*	*SD*
KWAW1	3	891	**1,26**	±0,194
KWAW2	3	881	**1,02**	±0,158
KWAW3	3	845	**1,06**	±0,168
KWAW4	3	840	**0,84**	±0,133
KWAW5	3	844	**1,05**	±0,166
KWAW6	3	832	**1,1**	±0,175
KWAW11	3	592	**1,25**	±0,236
DWAW1	2	540	**1,51**	±0,299
DWAW2	2	532	**1,23**	±0,245
NIEP11	3	3000	**1,08**	±0,091
NIEP21	3	3000	**2,25**	±0,189
NIEP12	3	3000	**0,91**	±0,076
NIEP22	3	3000	**1,75**	±0,144
LAB0	25	24000	**1,14**	±0,034
LAB1	25	24000	**1,4**	±0,042
NIEP3	6	6000	**1,19**	±0,071

Table I. Coefficient RAT defined as magnetic field disturbance averaged amplitude in period 1 divided by respective amplitude in period 2. WAW indicates Wawel Hill, NIEP Niepołomice Castle and LAB laboratory measurement. Number of participants and number of averaged heart cycles are also shown.

Highest RAT values (2,25 and 1,75) were observed in the same place of the northern part of the Niepołomice Castle (NIEP21 and NIEP22). Measurements NIEP11 and NIEP12 took place in the southern part of the Niepołomice Castle and had lower RAT values 1,08 and 0,91. One year later in this place RAT equalled to 1,19 (NIEP3). Relatively high RAT values (1,23 and 1,51) were observed in northern part of the Wawel Castle Court (DWAW1, DWAW2). Measurements described as KWAW were done in different places of the Wawel Cathedral. Measurements KWAW1 and KWAW11 were made in the same place at the beginning (1,26) and at the end (1,25) of the experiments.

CONCLUSIONS

The value of RAT (averaged amplitude of magnetic field disturbances 200-400 ms before the peak of the R wave/amplitude 50-250 ms after this time point) was in most cases higher than 1,0 (Table I). It is noteworthy that disturbances of type „A" (Fig.4) produced a repeatable and statistically significant effect when applied to a group of 25 subjects in laboratory conditions (LAB0 vs LAB1, $p<0.01$).

In the Table I two places of measurements (KWAW4 and NIEP12) exhibited RAT below 1.0. In these cases we observed not only magnetic filed disturbances of type "A" (Fig.4), but also disturbances "B" and "C".

The obtained results are statistically significant and indicate some coherence between external very low frequency magnetic field and heartbeats. Average amplitude of magnetic disturbances before the heart cycle was higher than during the cycle. Our finding can be explained by some sensitivity of the heart electrical activity to external magnetic field disturbances. These disturbances should occur at a specific time window before the cardiac cycle. Future studies are required to clarify the nature and details of the phenomena.

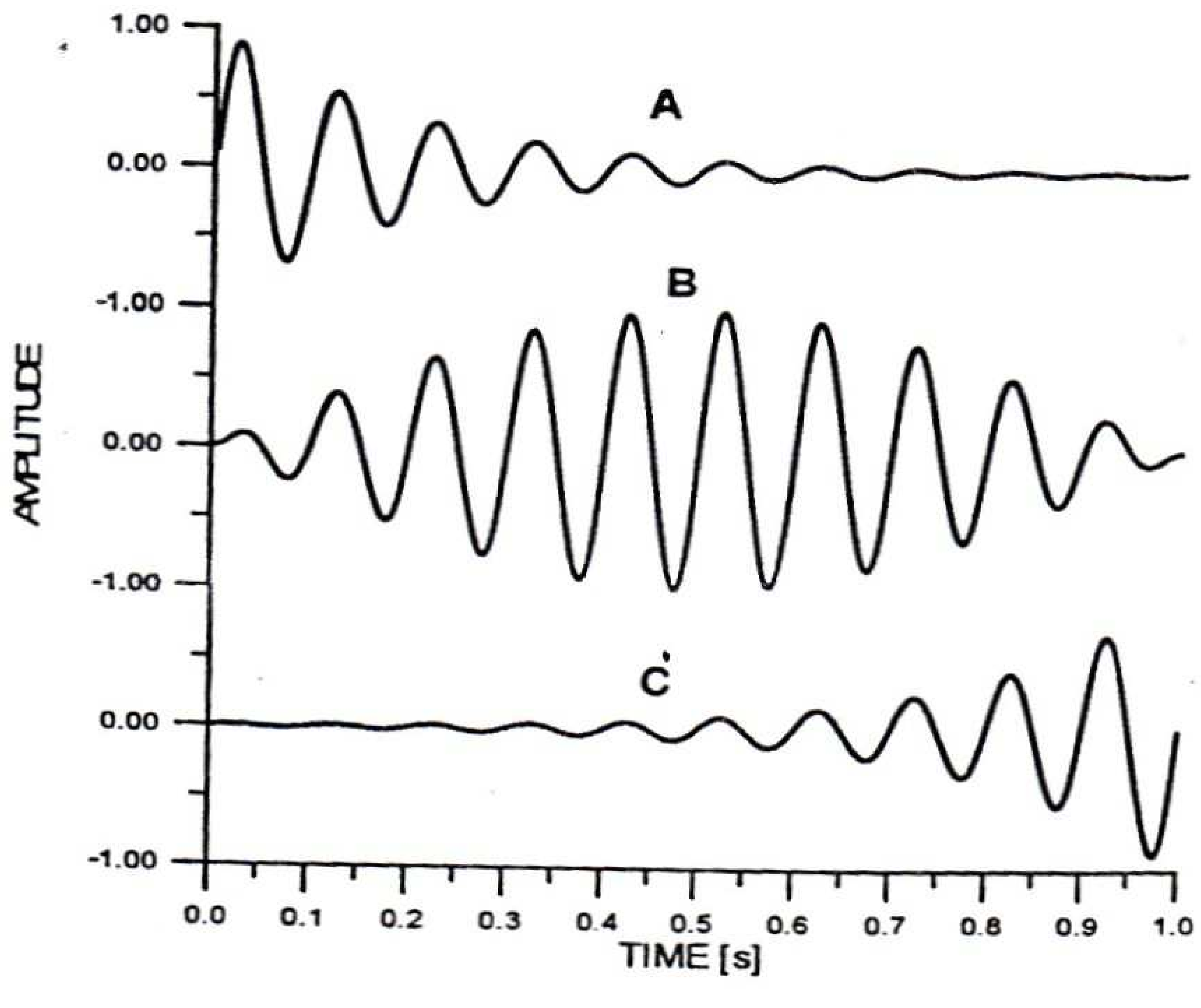


Fig.4. Three shapes of disturbances (A, B, C) of the natural magnetic field observed in urban conditions.

REFERENCES

[1] R.E. Kleiger P.K. Stein M.S. Bosner, J.N. Rottman: Time domain measurements of heart rate variability, Amb. Electrocardiol., 10, 487-498, 1992.

[2] Z. Ori, G. Monir, J. Weiss, X. Sayhouni, D.H. Singer: Heart rate variability frequency domain analysis, Amb. Electrocardiol., 10, 499-537, 1992.

[3] S. Akselrod, D. Gordon, F.A. Ubel, D.C. Shannon, A.C. Barger, R.J. Conen: Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control, Science, 213, 220-222,1989

[4] B. Pomerantz, J.B. Macaulay, M.A.. Caudill: Assessment of autonomic function in humans by heart rate spectral analysis, Am. J. Physiol., 248, H151-158, 1985.

[5] L.S. Micek, A.Surdacki, J.S. Dubiel: Heart Rate Variability in Ultra Low Frequency Magnetic Field, VIIIth National Symposium of Radio Science, Wroclaw, 80 and 241, 1996.

[6] V.K. Yerag, R. Pohl, R. Berger, R. Balon, C. Ramesh, D. Glitz: Decreased HRV in panic disorder patients: a study of power-spectral analysis of heart rate, Psychiat. Res., 13, 46-89, 1993.

[7] V.K. Yerag, R. Pohl, R. Balon, C. Ramesh, D. Glitz, I. Jung: Heart rate variability in patients with major depression, Psychiat. Res., 37, 35-46, 1995.

[8] J.F. Theyer, B.H. Friedman, T.D. Borovec: Autonomic characteristic of generalised anxiety disorder and worry, Soc. Biol. Psychol., 37, 1-11, 1995.

[9] S. Micek, A. Surdacki, J.S. Dubiel: Efekt Halla w oddziaływaniu pola magnetycznego na organizm, Waves Methods and Mechanics in Biomedical Engineering, Vol. IV, 173, 1999,

[10] S. Micek, A. Ilnicka-Micek: The Cyclotron Resonance for Action of Extremely Low Frequency Magnetic Field on Heart Rate Variability, Structures – Waves - Biomedical Engineering, Vol. X, 88-96, 2001.

[11] D. Owsiak, P. Burzynski, S. Micek: Modelling of Linked Sinoatrial Node Cells System, Biosignals and Biomechanics, vol.XI, 197-204, 2002.