MCG 시계열 신호에서 RR간격 분석

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The Hurst Exponent of RR Intervals in MCG Heartbeat Time Series

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Abstract

We know that the Hurst Exponent (HE) is a real number in [0, 1] which denotes randomness of time series. In this research, we suggest non-linear analysis of human biological signals through HE. The feasibility of human biological signals using inductive incitement provides some diagnosis for active treatment. In our experiment, we measured the heartbeat through the MCG, 20 healthy and 34 abnormal subjects ostensibly.

The raw data of acupuncture incitement are supported by opinions of gross examination and pathological diagnosis. The mean values of HE are 0.848, 0.755 and 0.805 for the periods of before, during and after acupuncture treatment, respectively in case of abnormal subjects. On the other hand, the mean values, 0.808, 0.797 and 0.785 are for normal cases, correspondingly. From this data, we show that HE is very significant in abnormal controls according to an acupuncture incitement, and the incitement effect is evidently extracted in abnormal subjects. But, in normal subjects, the incitement effect is meaningless.

Keywords : Non-Linear Analysis, Hurst Exponent(HE), RR Intervals, MCG Heartbeat Time Series

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1. Introduction

The outputs of many physiological systems, such as the normal heartbeat time series, are extremely inhomogeneous and non-stationary. The presence of scaling properties suggest that the regulatory systems are operating far from equilibrium, and the application to fractal analysis may provide new approach to recognize disease states by studying changes in the scaling properties. It has been observed that fractal scaling is degraded in some disease states [C.K. Peng et. al., 1995], [P. Ch. Ivano et al., 1999], [C. L. Bolis et al., 1999; M. Martinis et al., 2002].

Different self-similar time series can be classified into random or non-random series by estimating their HE. In order to determine the long-time dependencies in time series of RR intervals during controlled physical activity, the Hurst exponent has been needed [Martinis et al., 2002].

The linguistic analysis, which is based on rank order statistics of symbolic sequences to discriminate patterns generated from healthy and pathology states as well as aging, could be applied to estimate heartbeat time series [A. C.-C Yang et al, 2003].

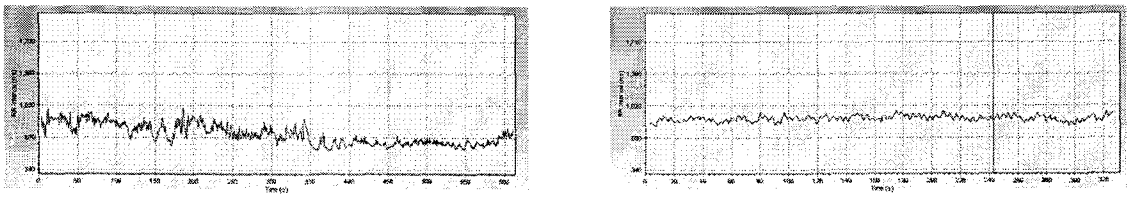
The analysis of randomness like time series is influenced on initial conditions. The Lyapunov exponent analysis, which has the sensitive dependence on initial conditions, is able to measure the brain consciousness. Especially, when the α wave appears, the brain states are more active and chaotic than trance or sleepy states. In our model, almost every data are stable, we do not need a lot of computational data to reconstruct attractors on phase space.

In this research, we reconstruct Hurst Exponent (HE) to time depended RR interval series, which is one of non-linear analysis of human biological signals, to find out heart defect. If HE is near 0.5, because randomness is near random walk, the acupuncture incitement effect largely appear in HRV, but when HE is near 07~0.9, the acupuncture incitement effect is not observed in HRV as in <Figure 1>.

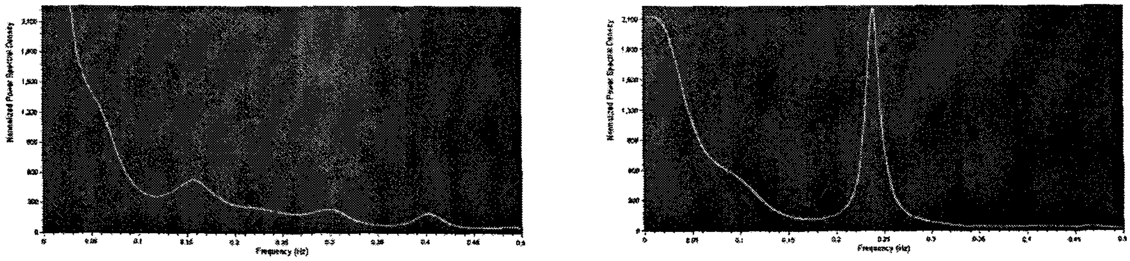
In our experiment, many data has a value ranging HE 0.7~0.8 except for few data, we cannot figure out the difference in HRV forced by acupuncture. Although it is difficult to observe HRV, the difference in HE is extracted from abnormal experimented group. We shall show the process of HE reconstruction with RR interval time series and experimental results. We measure the heartbeat through the MCG of 20 healthy and 34 abnormal subjects ostensibly. In this situation, healthy means the group in which any member has not taken medical treatment during recent two years, and abnormal means not healthy. The data of acupuncture incitement are convinced by gross examination, pathological diagnosis, and immunotherapy staining obtained from biological signals. These acupuncture incitements are more effective to abnormal patients but are not to healthy ones through the HE of heartbeat intervals.

2. Hurst Exponent of Heartbeat intervals

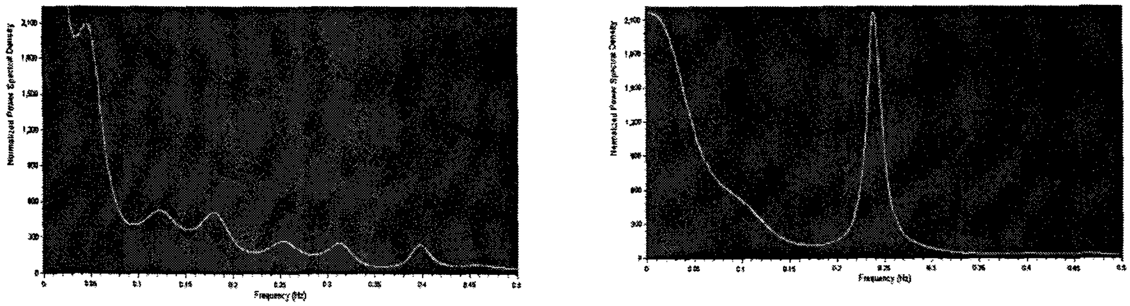
The fractal scaling properties of the heartbeat time series are studied in a controlled



a) HE is about 0.5 in left and HE is near 0.8 in right where horizontal axes denotes time(s) and vertical axes is RR interval(ms).



b) Normalized power spectral density through frequency where 512 data points, 24 orders in left HE 0.5 and right HE 0.8 before acupuncture.



c) Normalized power spectral density through frequency where 512 data points, 24 orders in left HE 0.5 and right HE 0.8 after acupuncture.

〈Figure 1〉 HE is 0.5 in left and 0.8 in right, normalized power spectral density changes by acupuncture and no other change detected

regometric regime in the Hurst rescaled range R/S analysis. The long-time "memory effect" quantified by the value of the Hurst exponent(HE), H>0.5, is found to increase during progressive physical activity in healthy subjects in contrast to those having stable angina pectoris(SAP), where it is decreasing [Martinis et al., 2002].

For a heartbeat time series data of length N $\{u(n), n = 1, \Lambda\ \Lambda\ , N\}$, where $u(n) \equiv R(n) = t(R_{n+1}) - t(R_n)$ is the nth RR intervals defined by difference in time position for R-wave peaks. Running mean $\overline{u}(n)$ for given n, and the accumulated deviations from the mean $X(l,n), l = 1, K, n$: are calculated as follows.

$$\overline{u}(n) = \frac{1}{n}\sum_{k=1}^{n} u(k),$$

$$X(l,n) = \sum_{k=1}^{l}[u(k) - \overline{u}(n)]$$

The range $R(n)$ is the distance between the minimum and the maximum value of X, and is rescaled by dividing it by the standard deviation $S(n)$.

$$R(n) = \max_l X(l,n) - \min_l X(l,n),$$

$$S(n) = \sqrt{\frac{1}{n}\sum_{k=1}^{n}(u(k) - \bar{u}(n))^2}$$

The rescaled range (R/S) is a dimensionless quantity and for large n it is expected to show power law dependence :

$$R(n)/S(n) \sim n^H,$$

where H is Hurst Exponent.

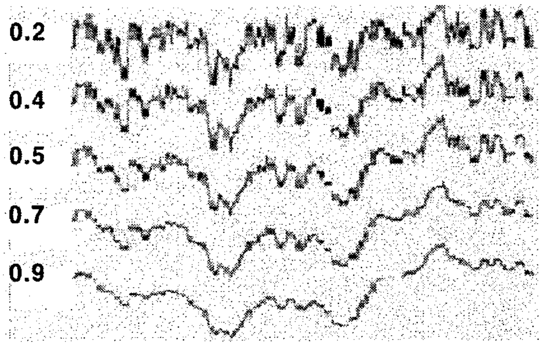
The non-linear analysis of randomness like HE is influenced by initial conditions. If n is large enough, when initial difference is m, $R(n)$ is influenced about m/n, because many data are stable time series. In this case, since the acupuncture time is near 3 minutes and initial difference is 3 seconds, m/n is 0.017. Since the $S(n)$ is not small, this value 0.017 does not change HE largely.

If the time series is long enough, the relationship between the fractal dimension D and the Hurst Exponent is :

$$D = 2 - H$$

The time series of RR intervals can be divided into 3 distinct categories :

$H<0.5$, $H=0.5$, and $H>0.5$. The case, $H=0.5$ corresponds to random or uncorrelated RR intervals. If $H>0.5$, the RR intervals are persistent and characterized by long time correlations or "memory" effects for all the time scales as shown in <Figure 2>.



<Figure 2> The time series as HE 0.2~0.9

3. Experiment and Analysis

The time series of heartbeat intervals (RR intervals) are commonly used in various analysis for Holter type data or data from steady state measurement [Martinis et al., 2002]. We are able to find the RR peaks by adjusting the threshold of MCG data. However, the MCG signals cannot provide RR peaks sometimes in real data because of distorted noise. If distorted signals appear continuously, they are discarded and the next peaks are adopted.

In order to find out the acupuncture incitement effect, we compare HRV before and after acupuncture, but if HE has some value as near as 07~0.9, HRV difference is not observed as shown in <Figure 1>, but acupuncture incitement effect is meaningful. Hence we consider HE difference only. For non-linear Hurst exponent analysis of human heartbeat, the experimental condition was kept at 20 ± 2℃ temperature and 45 ± 5% humidity, and all subjects have stable condition for 10 minutes before measurement.

We measured the heartbeats of 34 abnormal subjects whose average was 59 year-old for 3 minutes through channel 10 of MCG machine, EQ1061H (61-channel MCG System) made in Eagle Technology, Inc. (Japan) at Samsung Medical Center (SMC) in Seoul. Also heartbeats of 20 healthy subjects whose average was 22 year-old were measured at the same time using same machine EQ1061H.

Once we have collected all the RR intervals of the subjects, we applied them into HE algorithm. We calculate the paired sample statistics and correlations of abnormal subjects to compare the effect of acupuncture as shown in <Table 1>, where Pair 1, and Pair 2 show the data before-during acupuncture state, and during-after acupuncture, respectively.

In <Table 2>, H0 is rejected, p-value (2-tailed) < 0.025, especially for Pair 1, which means acupuncture is effective to abnormal as in <Figure 3>.

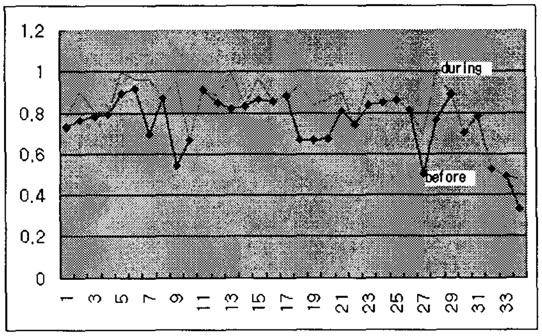
〈Table 1〉 Paired sample statistics of abnormal subjects where, Pair 1, Pair 2 show the data of before-during acupuncture state, and during-after acupuncture, respectively

	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	0.847982	34	0.1518138	0.0260358
	0.754906	34	0.1387766	0.0238000
Pair 2	0.754906	34	0.1387766	0.0238000
	0.804965	34	0.1757822	0.0301464

〈Table 2〉 Paired samples test in abnormal subjects

	Paired Differences			t	df	p-value(2-tailed)
	Mean	Std. Deviation	Std. Error Mean			
Pair 1	0.093076	0.1148689	0.0196999	4.725	33	0.000
Pair 2	-0.050059	0.1575915	0.0270267	-1.852	33	0.073

In a similar way, we have performed experiment for healthy subjects using the previous method as <Table 3> and <Table 4>. For all cases, H_0 is not rejected because of p-value (2 tailed)>0.025. This means acupuncture incitement effect is meaningless. In <Table 5>, we show the acupuncture effects accordingly 4 cases of abnormal (patient) and normal (healthy), before and during, during and after acupuncture.



〈Figure 3〉 Before-during acupuncture HE state of 34 abnormal subjects vertical axes denotes HE values

〈Table 3〉 Paired sample statistics of healthy subjects where, Pair 1, and Pair 2 show the data of before-during acupuncture state, during-after acupuncture, respectively

	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	0.808128	20	0.1023453	0.0241230
	0.797228	20	0.1110894	0.0261840
Pair 2	0.797228	20	0.1110894	0.0261840
	0.785200	20	0.1219364	0.0287407

〈Table 4〉 Paired-sample tests for healthy subjects

	Paired Differences			t	df	p-value(2-tailed)
	Mean	Std. Deviation	Std. Error Mean			
Pair 1	0.010900	0.1466683	0.0345700	0.315	19	0.756
Pair 2	0.022028	0.1647448	0.0388307	0.567	19	0.578

〈Table 5〉 the acupuncture effects accordingly 4 cases such as abnormal (patient) and normal (healthy), before and during, during and after acupuncture

	Abnormal	Normal
Before and during	Meaningful	Meaningless
During and after	Meaningless	Meaningless

4. Conclusions

In this research, we reconstruct HE model to make a diagnosis for active treatment of Chinese medicine from several types of heartbeats. We measure the heartbeats using the MCG, for 20 healthy and 34 abnormal subjects. In our experiment, the mean values of HE are different for before and during acupuncture treatment for the abnormal subjects. On the other hand, the mean values of HE have no meaning for every acupuncture treatment for the normal subjects.

Consequently, when the HE is near 0.5 then the effect acupuncture is detected by HRV only, but when HE is about 0.8 then it is difficult to find the change of the effect of acupuncture through HRV. Nevertheless, we show that the HE of before-during acupuncture is very different in abnormal controls. In the future, we want to suggest variability HE in experiments with sufficient samples, and to classify the heart disease patients individually using HE of the acupuncture.

References

[1] Yang, A.C.-C., Hseu, S.-S., Yien, H. - W., Goldberg, A.L., and Peng, C. - K., "Linguistic Analysis of Human Hearbeat using Frequency and Rank Order Statistics", *Physical Review Letters*, Vol. 90, No. 10, 2003.

[2] Peng, C.K., Havlin, S., Stanley, H.E., and Goldberger, A.L., Chaos 5, 1995, p. 82.

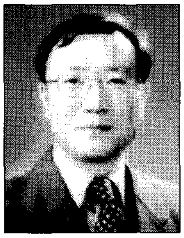
[3] Bolis, C.L., Licinino, J., eds., "The autonomic Nervous System", *World Health Organization, Geneva*, 1999.

[4] Jeong, H.-J., Hong, S.-H., Nam, Y.-C., Yang, H.-S., Lee, H.-J., and Kim, H.-M., "The Effect of Acupuncture on Proinflammatory Cytokine Production in Patients with Chronic Headache", *The American Journal of Chinese Medicine*, Vol. 31, No. 6, 2003, pp. 945-954.

[5] Martinis, M., Knezevic, A., Krastacic, G., and Vargovic, E., "Changes in the Hurst exponent of heatbeat intervals during physical activities", *arXiv : physics*, Vol. 1, 2002.
[6] Ivano, P.Ch., Amaral, L.A.N., Goldberger, L., Havlin, S., Rosenblum, M.G., Struzik, Z.R., and Stanley, H.E., Nature 399, 1999, p. 461.

저자소개

이 형
저자는 서울대학교 사범대학 수학과 졸업하고 성균관대학교 경영대학원 전자계산학과(석사)를 취득하였으며, 조선대학교 대학원 컴퓨터공학과 박사를 취득하였고, 현재는 대전대학교 정보통신공학부 교수로 재직 중이다. 1995~1997 대전대학교 전자계산소장, 1999~2001 대전대학교 공과대학 학장, 2000~2003 한국정보기술응용학회 회장, 2000~2004 대전대학교 산학협력연구원장을 역임했다. 현재 대전대학교 한의학응용공학연구 소장직을 맡고 있다.



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