ALTERATION OF AUTONOMIC NERVOUS SYSTEM ACTIVITY IN THE DAYTIME THROUGH TONE-ENTROPY ANALYSIS

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Abstract: The purpose of this study is to examine alteration of autonomic nervous system (ANS) activity in the daytime through Tone-Entropy (T-E) analysis which is the novel analysis based on acceleration of heart rate. Young 7 male and 3 female subjects (24.7+/-4.8yrs; mean+/-SD) were participated in this experiment. ECG signals of the subjects for 5min were recorded at 9, 12, 15 and 18 o'clock severally. To examine the reproducibility of this experiment, the same subjects' ECG signals were recorded in different two days. From the recorded ECG signals, heart rate, tone and entropy were calculated. No significant difference was observed on the relationship between the hours by means of two-way ANOVA (p>.05) and the relationship between the days by means of Student's t-test (p>.05). In both the two days, individual paths of T-E plots on each subject form the similar curvilinear path. In conclusion, our results support that alteration of individual ANS activity in the daytime on each subject can be evaluated through the curvilinear path on T-E space though any tendency on alteration of ANS activity in the daytime as a group cannot be observed.

Introduction

Physical conditions of whole lives always vary periodically; day, month or year. In other words, any lives do not keep just the same condition. Moreover, they are flowing eternally. Therefore, it is difficult to find standards absolutely to evaluate biological activity.

A variety of biological signals were measured to capture the variation of physical condition. Particularly, it was reported that body temperature and blood pressure alter in a day, called Circadian Rhythm. Autonomic nervous system (ANS) activity has familiar connection with human physical condition and ANS activity also synchronize time stream in a day.

The purpose of this study is to investigate whether or not ANS activity can be measured through tone-Entropy (T-E) analysis[1-3], which is a novel method to quantify ANS activity by acceleration of heart rate and to examine whether or not T-E analysis has the possibility as a standard of ANS activity. Oida et al.[1] firstly assessed that the relationship between tone and entropy is meaningful for measurement of ANS activity. On T-E space, T-E plots forms the curvilinear path as far as subjects settle down. Moreover, alteration of the displacement of T-E plots on the curvilinear path has significant physiological meanings to evaluate ANS activity. For example, in younger groups, the means of tone becomes lower and the means of entropy becomes higher as compared with elder groups [2]. Also, the worse diabetic impairments' conditions become, the lower ANS activity become [3]. Through T-E analysis, as the conditions of diabetic patients becomes advanced, tone is increased and entropy is decreased. Therefore, it can be recognized that ANS activity is reduced through T-E analysis.

Materials and Methods

The ECG recordings

The electrocardiographic (ECG) signals were recorded for 5 min with CM5 position. For measurement of heart rate and its variability, we developed the software which can detect R waves as soon as a background collection of 10 sec section of ECG signal has ended. The software was coded with Microsoft Visual C++. The software can also display heart rate and other parameters every 10 sec section with recording ECG signals. Therefore, as soon as an ECG recording is finished, we can immediately recognize heart rate and its variability and can judge whether or not the detection is proper because of doze or physical and mental stress, i.e. sound noise, uneasiness on different environment. We can figure out the condition of subjects immediately during and after recordings because our developed software can recognize irregularity and abnormality as soon as an ECG recording is finished. If we judge that a recorded detection is a failure, another detection of R waves would be performed again after the subject takes a rest for about several minutes. However, in this study, no misdetection of R waves was occurred. Moreover, the sub-standard data was omitted then and there because of poor health like lack of sleep and a cold. We need decide immediately whether or not we retry another recording in another day through questions about conditions to subjects themselves during the recording.

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The Protocol

Young 7 male and 3 female volunteers (24.7+/-4.8yrs; mean+/-SD) were participated after instructed to the informed consent on this experiment. In 9, 12, 15 and 18 o'clock, their ECG signals were recorded. The volunteers were asked to kept sitting on the comfortable chair and calming themselves as possible as they can during ECG recordings. They also avoided sports and intensive exercises like swimming and running from the previous day before this experiment. The same procedures were performed in two different days. At least the intervals between the days have more than 13 days (13-70days).

Tone-Entropy Analysis

T-E analysis is used to evaluate ANS activity. T-E analysis is a method based on statistical properties of variation of inter-duration between consecutive R-R intervals which is defined as Percentage Index (PI). PI presents the following equation:

$$PI_n = 100 \cdot \left(I(n) - I(n+1)\right) / I(n) \quad [\%]$$

where *I(n)* indicates the *n*-th duration of R-R interval. Therefore, PI increases when *(n+1)*-th duration *I(n+1)* is decreased as compared with *n*-th duration. Therefore, if heart rate is accelerated, PI is increased. Reversely, if heart rate is inhibited, PI is decreased. In short, acceleration of heart rate is defined as PI. From a PI sequence, a PI distribution is formed. From a PI distribution, tone and entropy as statistical indices are calculated.

Tone indicates expectation of PI distribution. Therefore, tone presents the balance of acceleration and inhibition of heart rate. The fact indicates that the balance of sympathetic and parasympathetic nervous activity may be reflected because sympathetic nervous activity accelerates heart rate and parasympathetic nervous activities inhibits heart rate. Tone is shown in the following equation:

$$Tone = \sum_{n=1}^{N} PI_n / N$$

Entropy is a uniform index of PI distribution. In short, entropy may be regarded as power of heart rate variability like total power in power spectral analysis. As heart rate variability is increased, entropy is increased because the PI distribution becomes flatter. Reversely, entropy is decreased if the PI distribution becomes sharper by reduction of heart rate variability. Therefore, entropy may reflect totally ANS activity. Entropy is shown in the following equation.

$$Entropy = -\sum_{i=-M}^{M} p(i) \log_2 p(i)$$

where *p(i)* indicates the probability density of PI distribution. *M* is the absolute number of a range from zero to each end of PI for calculation of entropy. From the above mentioned, entropy has the meaning like strength of heart rate variability though entropy is naturally a uniform quantity on a distribution.

As entropy is increased, heart rate variability is strengthen. Therefore, higher entropy may indicate higher ANS activity. Reversely, if heart rate variability is reduced, PI distribution becomes sharper. Consequently, entropy becomes lower.

Statistical Analysis

We examined statistical relationships of heart rate, tone and entropy between subjects and hours through repetitive two-way ANOVA to examine the statistical relationship between the ANS activity and hours. The critical rate was fixed as $\alpha = 0.05$.

To examine the statistical relationship between the first day and the second day, Student's t-test was applied to heart rate, tone and entropy on each hour. The critical rate was also fixed as $\alpha = 0.05$. By means of the statistical examination, reproducibility of this experiment will be evaluated.

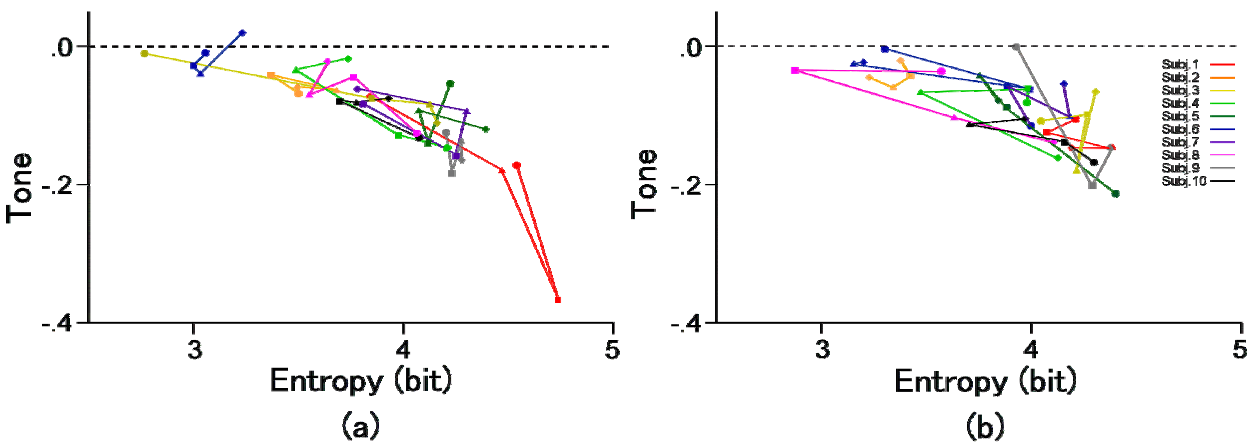

Figure1: Alterations of T-E plots in individuals and their distributions at 9, 12, 15 and 18 o'clock: (a) the first day (b) the second day. Each shape of the plots presents each hour when we recorded: ● 9, ■ 12, ▲ 15, ◆ 18.

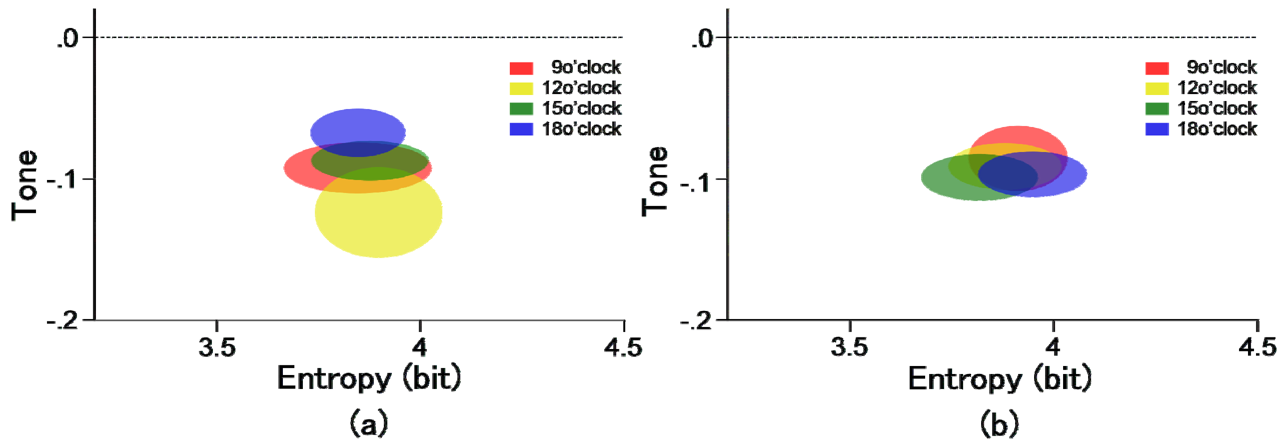

Figure 2: Alterations of T-E plots in individuals and their distributions at 9, 12, 15 and 18 o'clock: (a) the first day (b) the second day. The centres of every ellipse indicate the mean of tone and entropy of each distribution. The diameters of every ellipse also present standard error of tone and entropy.

Results

Figure1 shows the paths of T-E plots between individuals at 9, 12, 15 and 18 o'clock in different two days. From Figure1, the displacements of T-E plots in every subject vary between the hours. However, no trend can be observed from the plots between the subjects: some paths stay on around the same displacement and other paths decrease tone and increase entropy in earlier time. The remainders increase tone and decrease entropy in earlier time. However, the curvilinear paths in both Figure1(a) and (b) formed by the plots become similar. Moreover, the individual paths alter along the curvilinear path. The curvilinear paths also fit the previous reports' ones [1-3].

Figure2 shows the ellipses which present the mean and standard error (SE) in every hour. The centres of the ellipses of Figure1 shown as the distributions presents the means of tone and entropy and their diameters also indicate their SE.

From Figure2, every distribution of 9, 12, 15 and 18 o'clock positions almost the same area on the T-E space. In actual state, on heart rate, tone and entropy, it was not observed that the statistical relationship between the hours has no significant differences with repetitive two-way ANOVA (p>.05). To the contrary, the repetitive two-way ANOVA shows the significant differences on the relationship between the individuals to heart rate, tone and entropy.

We have also examined the statistical relationship of heart rate, tone and entropy between the two different days by means of Student's t-test. The examination showed that heart rate, tone and entropy do not have the significant differences (p>.05). Therefore, the examination indicates reproducibility of this experiment on every parameter. The displacements of the distributions between the hours and between the two days are also alike around tone is -.1 and entropy is 4 bits.

Discussion

T-E analysis enables us to measure the alteration of ANS activity in the daytime between the individuals because the T-E plots form on the curvilinear path reported previously. Therefore, we can absolutely evaluate ANS activity based on not age, gender, race and other ordinary discrimination but based on T-E space. Also, no significant difference of the distributions between hours (two-way ANOVA, p>.05) was observed though the statistical relationship between the individuals has significant difference (p<.05). Thus the fact indicates that there may be no difference of ANS activity in the daytime as human being. However, from alteration pattern of ANS activity in a day, it has already been suggested that types of subjects can be classified whether "morning" or "night". Only the results in these experiments cannot indicate the classification because there are only a small number of subjects. Further study should be required to investigate the possibility of distinction between the types.

From Figure1, no significant difference between the individuals could not been seen. In short, on these subjects, no tendency like Circadian Rhythm could be seen through T-E analysis. However, the individual paths of each subject alter along the curvilinear path. Therefore, we can evaluate alteration of ANS activity on the individuals through T-E analysis.

In this experiment, the most important fact is that distributions between the two days place at similar displacement on the T-E space. In actual state, it can be observed that the paths of every subject alter along the curvilinear path from Figure1. In actual state, no significant difference between the two days could be observed on every parameters (p>.05). Therefore, the fact presents that T-E analysis has high reproducibility. Therefore, the results support that the curvilinear path may be used as a standard of ANS activity.

Conclusions

In conclusion, T-E analysis may enable us to measure the alteration of ANS activity in the daytime between individuals because the T-E plots placed on the curvilinear path reported previously. Therefore, we can absolutely evaluate autonomic nervous system activity based on not ordinary parameters, age, various body indices but based on T-E space.

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