Original Article

# Evaluating Cardiac Autonomic Nervous System Activity during a Tea Ceremony through Tone-Entropy Analysis

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**Abstract**：
**Purpose:** This study evaluated autonomic nervous system activity related to tea ceremony scenes that affect mental calm. We used a heart rate monitor to measure changes in the heart rate of guests at a tea ceremony and calculated the mean heart rate values for different scenes of a tea ceremony.
**Method:** The participants were healthy adult men and women ($N$ = 25). In this experiment, a tea ceremony expert hosted a simulated tea ceremony in a tearoom following the basic tea ceremony manners. The participants wore a heart rate monitor that measured the R-R interval before they entered the tearoom until after they left the room. We calculated the heart rate's tone and entropy values from three-minute data segments during six events: just after entering the tearoom, before eating Wagashi, after eating *Wagashi*, before drinking tea, after drinking tea, and before leaving the tearoom.
**Results:** A two-way ANOVA showed a significant main effect of the events on tone and entropy. Results of multiple comparisons indicated that the entropy value at the end of the event was significantly lower than that when sitting and before eating *Wagashi*. Moreover, the entropy value before drinking tea was significantly lower than before eating sweets.
**Conclusion:** These results indicated that entering a tearoom and participating in a tea ceremony did cause psychological relaxation, but rather it increased tension. These results suggest that the mental calm after attending tea ceremonies might be due to the release of tension.

**Keywords:** Tone-Entropy analysis, Autonomic nervous system activity, Sympathetic nerves, Parasympathetic nerves, Traditional culture

## Introduction

"*Sado*," or the "tea ceremony" developed by *Sen-no Rikyu* in the *Azuchi-Momoyama* period (1573-1603), is the art of making tea and serving guests according to prescribed etiquette (Chiba, 2022). The tea ceremony is representative of traditional Japanese culture. The philosophy of the tea ceremony is expressed in words such as "*Ichigo Ichie*" (once-in-a-lifetime encounter) and "*Wakei Seijaku*" (its essential elements of harmony, respect, purity, and tranquility). Moreover, the tea ceremony is full of the spirit of "hospitality." It is possible to develop a spirit of hospitality, calm the mind and cultivate the spirit through the etiquette of making tea (Kurokawa, 2009; Ota, 2022). Many Japanese learn the tea ceremony for this purpose. In recent years, "business *Sado*" has been proposed to calm the minds of businesspeople and enhance their productivity (Mizukami, 2022). In addition, the number of foreign tourists visiting *Sado* experience classes increased before the COVID-19 pandemic.

People generally believe that drinking tea at a tea ceremony calms the mind. However, there are only a few physiological studies on a tea ceremony's mental and emotional calming

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effects. Kurokawa (2009) focused on healing among tea ceremony effects and advocated tea therapy. The mental calm at tea ceremonies might be related to healing through relaxation. Mental stress and relaxation are often evaluated through autonomic nervous system activity (Zygmunt et al., 2010), which consists of sympathetic and parasympathetic systems. In recent years, autonomic nervous activity has been evaluated using waveforms, which are changes in the R-R interval of an electrocardiogram over time. However, the fluctuation of an electrocardiogram's R-R interval result from influences other than autonomic activity, which limits the findings of R-R research. This study used heart rate variability, which reflects a part of cardiac autonomic nervous system activity. Several electrocardiogram studies have analyzed R-R interval waveforms' high and low-frequency components (Camm et al, 1996; Hayano, 2001). However, the magnitude of the heart rate variability is affected by the respiratory rate independently of autonomic nervous activity (Hirsch & Bishop, 1981; Hayano et al., 1994). Therefore, it is necessary to constantly control the breathing rate when evaluating autonomic nervous activity using frequency components. Moreover, it has been indicated that the evaluation of everyday situations is complex. The tone-entropy analysis developed to solve these problems has attracted attention as a technique for evaluating cardiac autonomic nerve activity without respiratory control (Oida et al, 1999a; Amano et al, 2005).

The tone-entropy analysis evaluates autonomic nervous activity using the PI (Percentage Index) value calculated from the R-R interval of the heartbeat (Oida et al, 1997). Tension generally causes a fast heartbeat and a short R-R interval, whereas relaxation results in a slow heartbeat and a long R-R interval. Therefore, a small PI value indicates a relaxed state. The tone is the average PI value, an index of the balance between the sympathetic and parasympathetic nervous systems. The R-R interval is longer in the relaxed state. Therefore, a negative tone indicates a tendency to relax with parasympathetic nervous predominance. Entropy is defined as the probability distribution of PI, which expresses the magnitude of the heart rate variability. The entropy value increases when the heart rate fluctuation is large. As a result, it indicates the state of autonomic nervous system activity. Generally, the autonomic nervous system becomes active, and the heart rate variability increases in a relaxed state, whereas the heart rate variability decreases in a tense state. Entropy also decreases during strenuous exercise and in diabetes patients. Therefore, the higher the entropy, the more relaxed a person tends to be (Oida et al, 1999b).

This study assessed heart rate changes in tea ceremony guests using a heart rate monitor to clarify tea ceremony scenes that affect mental calm. We measured changes in the heart rate and assessed tea ceremony scenes, and calculated their mean values. We also evaluated autonomic nervous activity values for different tea ceremony scenes.

## Materials & Methods

### 1. Participants and ceremony

Healthy adult men and women ($N$ = 25); 15 Japanese men (mean age 35.6 ± 15.1 years) and ten international students (2 US citizens, 5 Chinese, 1 Vietnamese, and 1 Malaysian; 6 men and 4 women, mean age 26.9 ± 3.9 years) participated in this study. This experiment was the international student's first experience with a tea ceremony. Several Japanese participants had experienced tea ceremonies; however, none had learned to perform a tea ceremony. We explained the purpose and methods of the study to the participants, who gave their written consent to participate. This study was conducted with the approval of the Human Research Ethics Review Committee.

The experiment was conducted in a tearoom holding Japanese tea ceremonies. An expert tea ceremony performer with over 30 years of experience hosted five *Usucha* (thin-tea) tea ceremonies following basic tea ceremony etiquette. These ceremonies were conducted in a four-and-a-half tatami-mat-sized tearoom. Five guests participated in each ceremony. The host made tea on a *tatami-mat-sized* area with a brazier placed in the center of the mat. The five participants entered the tearoom and sat facing the host around the brazier in the *seiza* position on an approximately two-and-a-half *tatami-mat-sized* area. First, the host served *Wagash*i (Japanese sweets) to the participants, one by one, who ate the *Wagashi* using *Kaishi* paper and *Kuromoji* (Japanese confectionery picks). After that, the host served the participants *Usucha* green tea. The host made the tea for the first participant and served the tea, and then made the tea for the second participant, and so on. The five participants chatted for a few minutes and left after they finished the tea. We explained the flow of the tea ceremony to the participants and confirmed that they understood the procedure before conducting the experiment. However, we did not explicitly instruct the participants on how to behave at the ceremony, even though many of them had no previous experience with a tea ceremony. As far as possible, we held this tea ceremony in a traditional, solemn atmosphere.

## 2. Autonomic nervous system activity evaluation by measuring the heart rate

The participants wore a heart rate sensor (H7 heart rate sensor, POLAR) on their chest to measure their heart rate, and the data were recorded on a wristwatch-type heart rate monitor (V800, POLAR). The R-R interval was recorded in 1 ms units starting before the participants entered the tearoom until after they left the room. We also set up a video camera in the tearoom to video record the participants.

We evaluated the participants' autonomic nervous activity during the tea ceremony, which we divided into four scenes: "Entering the room," "Eating *Wagashi*," "Drinking tea," and "Leaving the room." "Entering the room" was when a participant entered the tea room and kneeled in the *seiza* position, "Starting to eat *Wagashi*" was when a participant picked up the sweets, "Finishing eating *Wagashi*" was when a participant finished eating the sweets and put the *Kaishi* on the floor, "Starting to drink tea" was when a participant picked up the tea bowl, "Finishing drinking tea" was when a participant finished drinking tea and put the tea bowl on the floor, and "Leaving the tea room" was when the tea ceremony was over, and participants bowed to the host. We also divided the scenes into six criteria to compare before and after consuming sweets and tea: "Entering the tea room," "Before eating *Wagashi*," "After eating *Wagashi*," "Before drinking tea," "After drinking tea," and "Leaving the tea room."

Since the tone entropy method requires an R-R value of about 200 beats, we thought that 3 minutes was appropriate from the number of measured data of the heart rate monitor. Therefore, in this study, starting from the reference time, the tone and entropy values were obtained based on the R-R value for 3 minutes from the reference time. Since the autonomic nervous activity is easily affected by eating and drinking, we measured intervals that did not involve eating or drinking by excluding 20 seconds before and after eating sweets and 20 seconds before and after drinking tea from the analysis. As a result, we used the following six reference times: (1) When the participants entered the room and sat down; (2) 3 minutes and 20 seconds before starting to eat *Wagashi* to evaluate the condition before eating; (3) 20 seconds after finishing *Wagashi*, to evaluate the state after eating; (4) three minutes and 20 seconds before starting to drink tea, to evaluate the condition before drinking; (5) 20 seconds after finishing the tea, to evaluate the condition after drinking, and (6) 3 minutes before the final bow, to evaluate the condition just before the end of the tea ceremony.

**3. Tone-Entropy analysis**

First, we obtained the *PI* (Percentage Index) using the R-R interval (*H*) measured by the heart rate monitor to find the tone and entropy values with the following formula.

$$PI(n) = \frac{H(n) - H(n+1)}{H(n)} \times 100$$

The tone is the mean *PI* value, considered an index of the balance between sympathetic and parasympathetic nervous systems calculated with the following formula.

$$Tone = \sum_{n} \frac{PI(n)}{N}$$

Entropy is defined as the probability distribution of *PI*, which was obtained by the following formula (Shannon, 1949). The probability of the *PI* value is denoted by *p*.

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

**4. Statistical analysis**

We used the statistical processing software (SPSS 26, IBM) to conduct a two-factor analysis of variance (ANOVA) for the six events (entering the tearoom, before eating *Wagashi*, after eating *Wagashi*, before drinking tea, after drinking tea, and leaving tea room) as within-subject factors and the student's nationality (Japanese, international) as between-subject factors. We conducted multiple comparisons using the Bonferroni method if we observed a significant main effect. We set the significance level at 5%.

## Results

The video recordings confirmed that this experiment proceeded in a solemn atmosphere. Figure 1 shows a typical example of a participant's heart rate variability. This figure shows the six target intervals from before entering the tearoom to before leaving the tearoom based on the time of entering and leaving the room, eating sweets, and drinking tea. Figure 2 is a probability distribution graph displaying participants' 1's PI and probability distribution of PI.

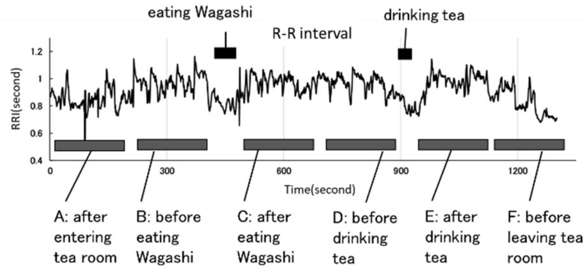


**Figure 1: Typical example of heart rate variability (Participant 1)**

The data of Participant 1 are shown as a typical example of the heart rate R-R interval. The vertical axis indicates the R-R interval, and the horizontal axis indicates the time from the start of data collection. The figure shows the six scenes that were analyzed: (A) after entering the tearoom, (B) before eating Wagashi, (C) after eating Wagashi, (D) before drinking tea, (E) after drinking tea, and (F) before leaving the tearoom. The recording time for each scene was three minutes.

We excluded the data of one participant due to heart rate measurement problems and analyzed

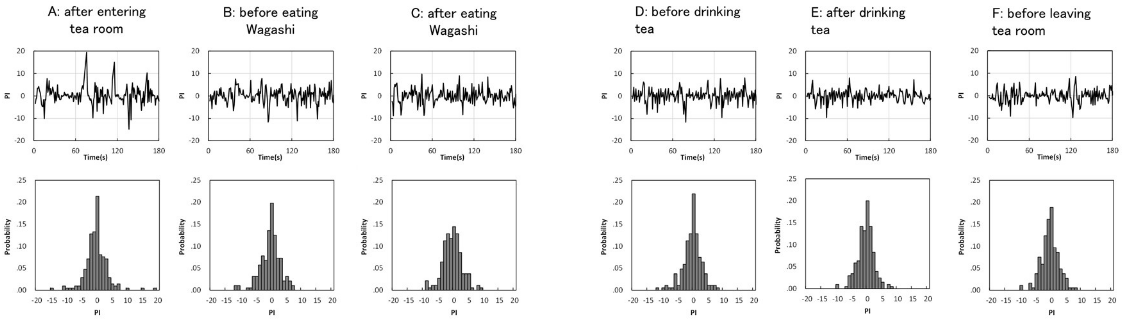


**Figure 2: PI and its probability distribution (Participant 1)**

A typical example of the PI calculated from the R-R interval for Participant 1 and its probability distribution.

the data of 24 participants. We obtained each participant's three minutes tone and entropy values for the six events. The results shown in Table 1 indicate a significant interaction for both tone and entropy. Moreover, there was a significant main effect of the event (tone, $F_{5,110} = 2.680$, $p = .025$, $\eta^2 = .109$; entropy, $F_{5,110} = 7.712$, $p < .001$, $\eta^2 = .260$). However, there was no significant main effect of the country of origin. Figure 3 shows the overall mean values because there was no significant interaction or main effect of the country of origin. The results of multiple comparisons using the Bonferroni method indicated no significant difference in tone. However, the entropy value was significantly lower at the end of the session than when sitting and before eating the sweets. Moreover, it was significantly lower before drinking tea than before eating sweets.

## Discussion

We used tone-entropy analysis to assess heart rate variability changes as a physiological response to stress and evaluated the physiological and psychological reactions of participants' responses to different scenes of a tea ceremony. Studies have indicated that tea ceremonies generally produce a calm mental state (Kurokawa, 2009; Ota, 2022). Therefore, we expected that drinking tea would have a relaxing effect. However, the results indicated that the tone increased after entering the tearoom until before drinking tea and that entropy was significantly low before drinking tea. Oida et al. (1997) suggested the entropy value was approximately 4.14 in the relaxed state before exercise, and the tone value was approximately

**Table 1: Tone and Entropy values of the scenes**

| | sccene | | | | | | main effect | | | | interaction | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | after entering tea room | before eating Wagashi | after eating Wagashi | before drinking tea | after drinking tea | before leaving tea room | country | | sccene | | country × sccene | |
| | *M*±*SD* | *M*±*SD* | *M*±*SD* | *M*±*SD* | *M*±*SD* | *M*±*SD* | *F* | *p* | *F* | *p* | *F* | p |
| Tone | | | | | | | | | | | | |
| Japanese | -0.063 ± 0.076 | -0.069 ± 0.088 | -0.054 ± 0.083 | 0.013 ± 0.079 | -0.028 ± 0.112 | -0.020 ± 0.102 | 3.661 | .062 | 2.680 | .025 | 0.667 | .650 |
| Foreigner | -0.147 ± 0.166 | -0.128 ± 0.168 | -0.105 ± 0.129 | -0.086 ± 0.126 | -0.038 ± 0.101 | -0.092 ± 0.059 | | | | | | |
| Entropy | | | | | | | | | | | | |
| Japanese | 3.736 ± 0.644 | 3.754 ± 0.653 | 3.653 ± 0.701 | 3.603 ± 0.636 | 3.685 ± 0.578 | 3.605 ± 0.568 | 0.240 | .629 | 7.712 | <.001 | 1.698 | .141 |
| Foreigner | 3.988 ± 0.752 | 3.974 ± 0.765 | 3.790 ± 0.869 | 3.743 ± 0.884 | 3.687 ± 0.854 | 3.707 ± 0.828 | | | | | | |

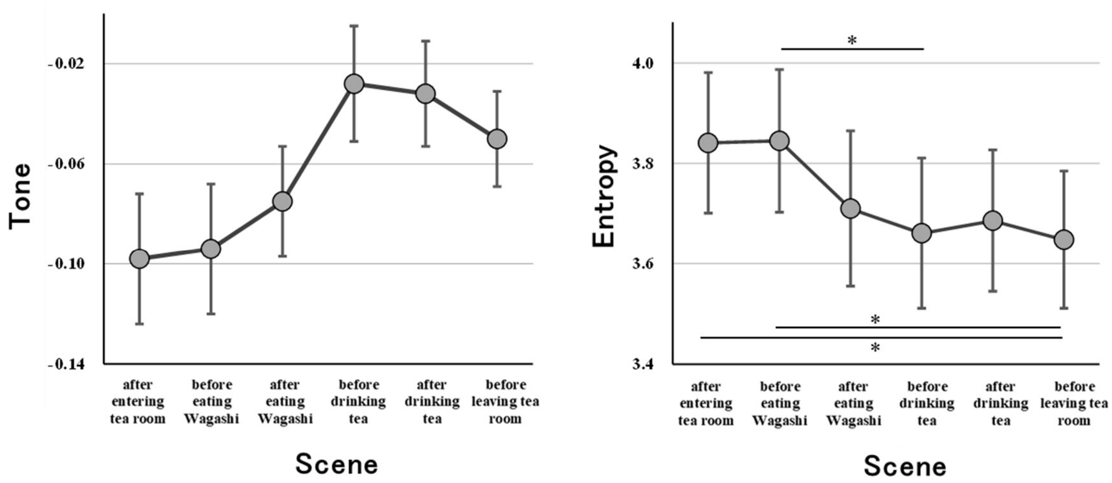


**Figure 3: Scene-by-scene tone and entropy**

No significant interaction between the country of origin and the scene, nor a significant main effect of the country of origin was detected. Therefore, we have shown displayed the means and standard deviations of all the participants for all the scenes.

0 and the entropy value is approximately 1.66 when the sympathetic nervous system becomes dominant after exercise. The tone returns to a value of -0.13 and entropy to an approximate value of 4.18 in the relaxed state after recovering from exercise. Although the conditions of the current experiment differed from Oida et al., we can compare the two situations. In the current experiment, the tone value increased to nearly 0 because there was no vigorous exercise in the experimental protocol. The increased tone suggested that the sympathetic nervous system was dominant, and the decreased entropy indicated that the autonomic nervous activity decreased (Oida et al., 1997). Therefore, the results of this study suggest that entering a tearoom and participating in the tea ceremony does not result in psychological relaxation but increases tension, which was contrary to our expectations. No research has evaluated autonomic nervous functioning in relation to the psychological effects of a tea ceremony, which includes "hospitality." This study's results indicate that hospitality does not make guests feel relaxed and calm while eating sweets and drinking tea at a tea ceremony, but rather, it increases the tension. Moreover, there was no significant interaction between the tea ceremony's events and the participant's country of origin on the participant's sympathetic nervous activity. These findings suggest that the tea ceremony's ritualistic nature and behaviors might increase psychological tension, regardless of cultural knowledge or understanding of the ceremony.

Furthermore, the tone was at the highest level before drinking tea and tended to decrease after drinking tea and until before leaving the tearoom, although a multiple comparison analysis indicated that this difference was not significant. Entropy also had the lowest value before drinking tea and a tendency to increase after drinking tea. These results suggest that the participants' tension was relieved and relaxed after drinking tea. We suggest that releasing tension leads to mental calm, and tension and relaxation are critical cultural elements of a tea ceremony.

Many physical activities occurred after leaving the tearoom, such as going to a different room, which might have significantly affected cardiac autonomic nervous activity. However, this study focused only on the heart rate variability in the tearoom and did not measure subsequent events. The psychological relaxation effect of the tea ceremony can be further clarified in the future by continuously measuring the heart rate variability after the tea ceremony and controlling the environment.

The tea ceremony had a calming effect, although there was no mental relaxation during the tea ceremony because, contrary to expectations, tension increased, and the sympathetic nervous system dominated. Sympathetic nervous activity peaked before drinking tea, whereas the tone decreased and entropy increased after drinking tea, suggesting that the subsequent recovery period might affect relaxation. However, this issue was not examined in this experiment.

Cardiac autonomic nerve activity is strongly affected by exercise and diet. However, the effect of autonomic nerve activity was minimal in this experiment because we did not analyze the 20-second period before and after eating sweets and drinking tea. Nevertheless, we could not eliminate the possibility that eating sweets or drinking tea might cause changes in autonomic nervous activity, which is an issue that should be investigated in future studies.

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