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Investigation of Effective Heart Rate Variability Indices for Emotion Estimation During Long-term Images Gazing

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Abstract

In recent years, demand for emotion estimation using heart rate has increased in fields such as life-log and healthcare. HRV indices can estimate the activity level of the autonomic nervous system, but their sensitivity varies depending on the task and stimuli, sometimes leading to inconsistent results. Therefore, selecting the optimal HRV indices for each task and stimuli is important, and this study focused on emotional induction during long-term visual stimuli. We constructed the experiment in which subjects gazed at images of consistent emotional evaluation values, and identified the effective HRV indices for emotion estimation. The results showed that SDRR and L were effective for estimating excitement, Mean and rMSSD for estimating disgust, and LF/HF for classifying boredom and relaxation. These results are expected to serve as a basis for emotion estimation in situations where people are exposed to visual stimuli for long periods, such as when viewing videos or scenery.

Keywords: emotion estimation, heart rate, long-term images gazing, visual stimuli

1 Introduction

In recent years, advances have been made in the acquisition of biometric data using wear- able devices [1]. In particular, demand for automatic emotion estimation using heart rate has been increasing in fields such as life-log [2] and healthcare [3].

The main reason for using heart rate is that the activity of the autonomic nervous system, which is related to emotions, affects the RR interval obtained from the ECG. The activity of the autonomic nervous system can be inferred by analyzing the RR interval. Several analytical methods exist for this, broadly classified into time-domain, frequency-domain, and nonlinear analysis methods [4]. Time-domain indices include rMSSD, an index of the parasympathetic nervous system, and SDRR, an index of the autonomic nervous system, are used [5]. Frequency-analysis indices include LF (low-frequency component of HRV), an index of the sympathetic nervous system, and HF (high-frequency component of HRV), an index of the parasympathetic nervous system, are used [6]. As an example of nonlinear indices, indices utilizing Lorenz plots are representative, of which CSI is used as an index of the sympathetic nervous system and CVI as an index of the parasympathetic nervous system [7].

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Such analysis methods and indices have been proposed, and ideally, the same system of indices should produce similar results regardless of which HRV analysis is performed. However, studies have shown that the sensitivity of the indices vary depending on the target task or stimuli, and leading to occasional inconsistencies in results [8][9].

Therefore, there is a need for a HRV index that is sensitive to each task and stimuli. For instance, Suzuki et al. [10] investigated HRV and other biological indices to effectively estimate emotions when subjects listened to music, and developed an emotion estimation model based on these findings.

In this study, we focused on when emotions are evoked by visual stimuli. We constructed an experiment in which four emotions (excitement, disgust, boredom and relaxation) were induced for 5 minutes each by continuously displaying a certain emotion-evoking image. We then investigated 11 HRV indices that were effective for emotion estimation. The main contributions are as follows.

- Construction of an experimental system for continuous induction of the same emotion using emotion-evoked images
  Video is sometimes used to induce emotions through visual stimuli. However, video has the problem of not being able to maintain the same emotion due to frequent scene transitions. Therefore, in this study, we constructed an experimental system that can continuously induce the same emotion by presenting a series of images with consistent emotional evaluation values.
- Verification of the optimal duration of the experiment, where boredom or fatigue due to long experiment is not reflected in the heart rate
  A common issue is that the heart rate reflects boredom or fatigue caused by a long experiment, resulting in results that are contaminated with noise. In this study, we focused on LF, an index of the sympathetic nervous system that reflects boredom and fatigue, and SDRR, an index of the autonomic nervous system activity level, and tested and verified the optimal experiment time without noise contamination.
- Investigation of HRV indices effective in detecting emotions
  In this study, we investigated HRV indices that are effective in detecting emotions evoked by image stimuli. The results provide a basis for the emotion estimation related to visual stimuli and may contribute to the emotion estimation during viewing of videos and scenery.

In this paper, we first introduce related studies in Section 2. Next, the image data set is introduced in Section 3. Section 4 outlines the exploratory experiments and presents the results. Furthermore, Section 5 outlines the main experiment and presents the results. Finally, conclusions are presented in Section 6.

2 References

Bradley et al. [11] investigated the heart rate features in the seconds following emotion-evoked image gazing. 72 images were selected from the IAPS [12], 8 genre pleasant images, 2 genre

neutral images, and 8 genre unpleasant images, 4 images per genre, and presented to the subjects. The flow of one task of the experiment is shown below: one set consisted of 36 tasks, and two sets were performed.

1. Rest for 3 s
2. Emotion-induced image gazing for 6 s
3. Rest for 2 s
4. 10 s image evaluation (20-point scale for valence, arousal, and dominance)

The heart rate acceleration during image presentation was calculated using the 1 second period before image presentation as the baseline. The following results were obtained.

· During the unpleasant images gazing, there was a rapid initial deceleration of the heart rate and a continuous deceleration of the heart rate for a few seconds.

· During pleasant images gazing, changes were observed that showed a triphasic pattern of deceleration, acceleration, and deceleration of the heart rate. The degree of this triphasic change varied by genre, with images of genres with high arousal showing rapid initial deceleration, while images of genres with low arousal showed gradual initial deceleration.

The results of their experiment revealed a temporary change in heart rate immediately after image gazing. However, they did not focus primarily on the case of continuous emotional induction by visual stimuli, such as during scenery or video viewing. In this study, we construct an experiment in which the same emotion can be continuously induced by visual stimuli by continuously gazing at images with close emotional valence. We will then investigate HRV indices that are useful for emotion estimation.

3 Image Dataset

In this study, we used IAPS [12], an image data set similar to related studies, in which valence and arousal are rated on a scale of 1-9 for images. In addition, according to Russell [13], emotions can be classified by a combination of valence and arousal. Based on IAPS ratings, the images were categorized into four emotions: excitement (around valence 6- 7, arousal 6-7), disgust (around valence 3-4, arousal 6-7), boredom (around valence 3-4, arousal 3-4), and relaxation (around valence 6-7, arousal 3-4).

Table 1: Used Images

emotion	IAPS_number
excitement	1650, 2034, 2300, 4325, 5626, 5629, 6910, 7451, 7570, 8034
	8158, 8163, 8179, 8191, 8206, 8251, 8260, 8341, 8490, 9156
disgust	1050, 1304, 1525, 2730, 3213, 3250, 4664.2, 5973, 6250, 6263
	6300, 6315, 6370, 6550, 8465, 9050, 9600, 9622, 9623, 9630
boredom	2039, 2206, 2312, 2399, 2456, 2490, 2590, 2715, 2753, 4550
	4561, 9000, 9001, 9045, 9046, 9110, 9291, 9331, 9395, 9832
relaxation	1410, 1419, 1601, 1812, 1900, 2274, 2388, 2594, 2791, 5200
	5201, 5711, 5726, 5750, 5764, 5779, 5891, 7325, 7489, 7545

4 Exploratory Experiment

To calculate the HRV index, a measurement time of about 5 minutes is required for each emotion. Since four emotions are measured in this study, the experiment will be long, about 40 minutes, taking into account the resting time to reset the emotions. In a long experiment, the heart rate will reflect boredom or fatigue caused by the experiment, so it is necessary to take a rest period at an optimal location. Therefore, a preliminary experiment was conducted to determine the optimal length of the experiment.

4.1 Experimental Flow and Data Reduction and Analysis

Exploratory experimental flow is shown in Figure 1. 300 s of image gazing consisted of 20 times gazing of 15 s of images. subjects also sat in a recliner chair in a small, dimly lit room and gazed at a 24-inch screen at a distance of 50 cm. In addition, electrocardiograms were measured during the experiment by wearing a Hexoskin smart shirt [14].

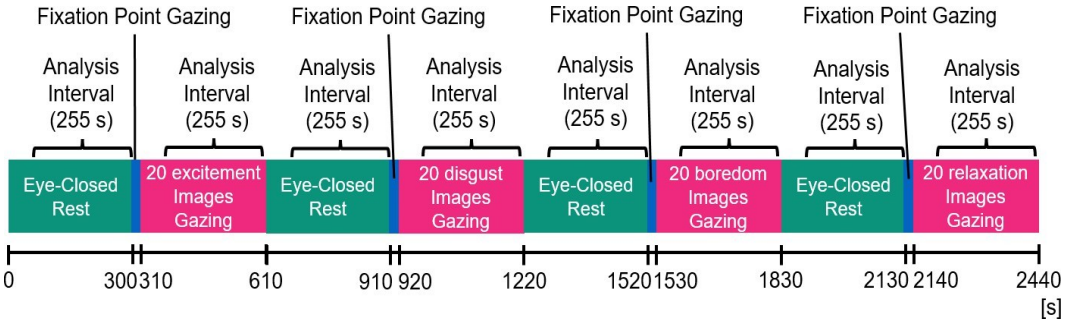


Figure 1: Exploratory Experimental Flow

The HRV index value was calculated from the RRI of 45-300 s among 300 s of eye-closed rest and 300 s of image gazing. Therefore, the number of samples was 8. Then, standardization was performed on the 8 data for each HRV index value for each subject so that the mean was 0 and the variance was 1. Also, the subjects were 14 male university students, of whom 2 subjects with disturbed ECG were excluded. Therefore, the sample size was 12. The HRV indices used are also shown below.

· SDRR…Standard deviation of RRI.

· LF…Total power in the low frequency component (0.04-0.15 Hz) of the RRI.

4.2 Result

SDRR

The box plots of the SDRR results are shown in Figure 2. This figure shows that the SDRR which is an index of the autonomic nervous system tended to be higher after the third resting period (1265-1520 s).

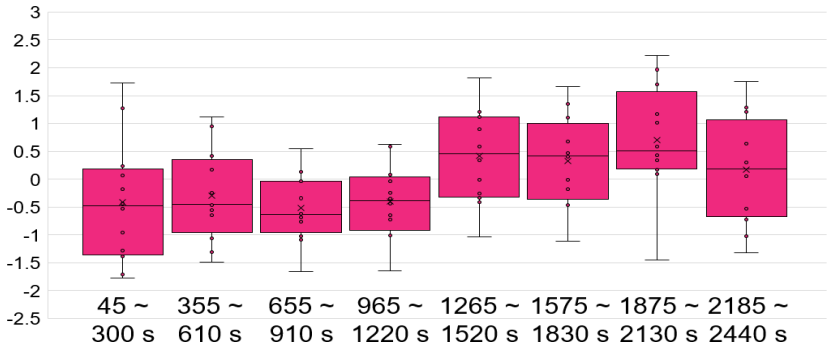


Figure 2: Exploratory Experimental Result (SDRR)

LF

A boxplot of the LF results is shown in Figure 3. This figure shows that LF which is an index of the parasympathetic nervous system tended to be higher after gazing at the boredom image (1575-1830 s).

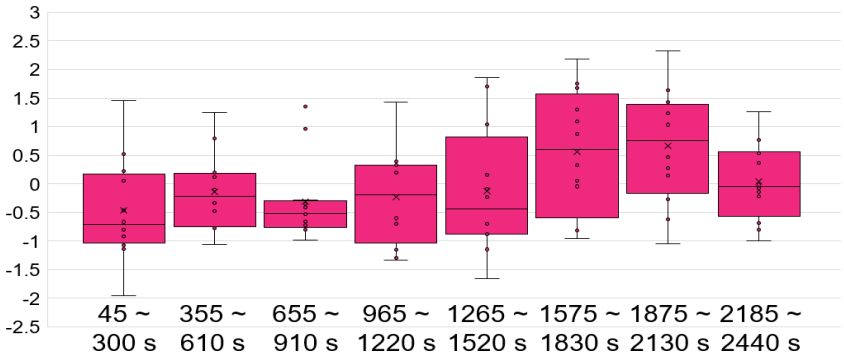


Figure 3: Exploratory Experimental Result (LF)

Overall Analysis

SDRR tended to be higher after the third resting period (1265-1520 s), and LF tended to be higher after the presentation of boredom images (1575-1830 s). This result thought to be attributed to the fact that the heart rate reflected the boredom and fatigue evoked by long experiment. This suggests that the experiment duration should be kept within 1220 s.

5 Experiment

Experiments were conducted with the aim of identifying HRV indices that are effective in detecting emotions evoked by image stimuli.

5.1 Experimental Flow and Data Reduction and Analysis

Based on the results of the exploratory experiment, the flow shown in Figure 4 was considered as one trial. In the first trial, the subjects gazed at the images in the order of 20 images of excitement and 20 images of disgust, and in the second trial, they gazed at the images in the order of 20

images of boredom and 20 images of relaxation. 300 s of image gazing consisted of 20 times gazing of 15 s of images. subjects also sat in a recliner chair in a small, dimly lit room and gazed at a 24-inch screen at a distance of 50 cm. In addition, electrocardiograms were measured during the experiment by wearing a Hexoskin smart shirt [14].

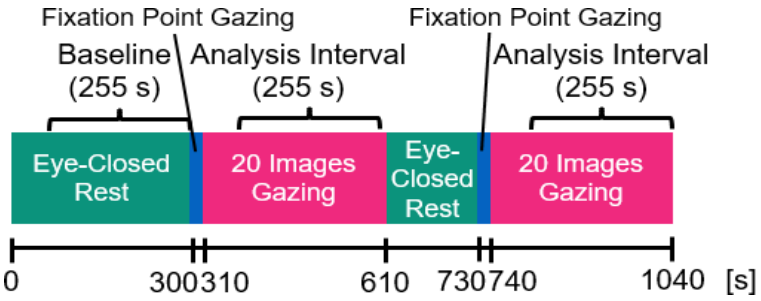


Figure 4: One Trial Flow of Experiment

The HRV index value of 45-300 s out of 300 s of eye-closed rest was used as the baseline, and the HRV index value of 45-300 s out of 300 s of image gazing minus the baseline was used for analysis. Therefore, the number of samples was 4. Then, standardization was performed on the four data for each HRV index value for each subject so that the mean was 0 and the variance was 1. In addition, Wilcoxon signed rank tests were performed for all four groups of excitement, disgust, boredom, and relaxation between the two groups. Also, the subjects were 17 male college students, of whom 1 subject with disturbed ECG was excluded. Therefore, the sample size was 16. The HRV indices used are also shown below.

Time Domain indices

· Mean…Mean value of RRI.

· rMSSD…root-mean-square of sequential differences in RRI.

· pNN50…Percentage difference between adjacent RRIs exceeding 50 ms.

· SDRR…Standard deviation of RRI.

Frequency Analysis indices

The RRI time series data were resampled at a sampling frequency of 1 Hz, and frequency analysis was performed on the cubic spline complemented data.

· LF…Total power in low frequency component (0.04-0.15Hz).

· HF…Total power in high frequency component (0.15-0.40Hz).

· LF/HF…LF/HF.

Non-linear (Lorenz plot) indices

An analysis method that represents RRI time-series data as a nonlinear plot and captures the activity of the autonomic nervous system based on the scatter of the distribution. Successive RR intervals are represented by I1, I2, I3, . . . , In. For each k = 1, 2,..., n− 1, we plot the point (Ik, Ik+1), which represents the relationship between consecutive intervals [7].

· L…Standard deviation of the scatter with respect to the axis parallel to the main diagonal of the plotted points.

· T…Standard deviation of the scatter with respect to the axis perpendicular to the main diagonal of the plotted points.

· CVI…log10(L*T).

· CSI…L/T.

5.2 Result

5.2.1 Time domain indices

The results are shown in Figure 5.

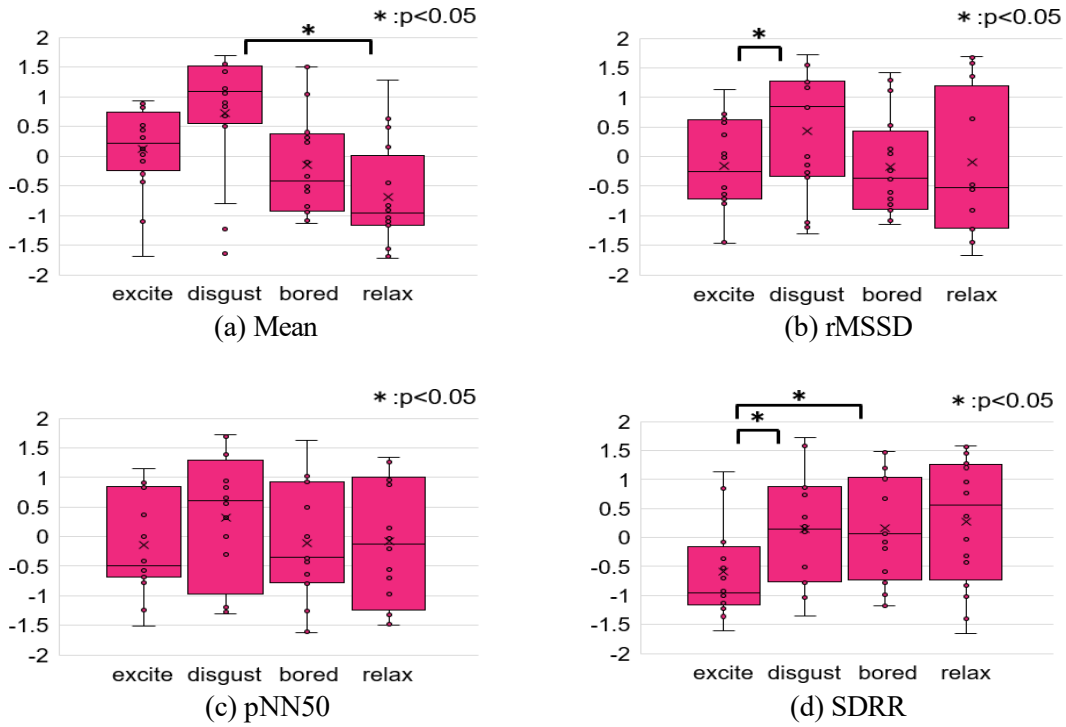


Figure 5: Result of Time Domain Indices

Mean

Significant differences were found for Mean at the 5% level between disgust and relaxation. Also, Mean tends to be higher than other emotions when it is disgust. Disgust images are unpleasant images with high arousal. A related study [11] reported a rapid initial decrease in heart rate immediately after the presentation of unpleasant images, and this experiment, in which images were presented in succession, also resulted in a decrease in heart rate (increase in Mean).

The change over time in the RRI of subject 4 shown in Figure 6 indicates that there is a change in which the RRI increases rapidly immediately after disgust images presentation. In order to evaluate this response, we calculated the mean of the RRIs for the two groups of subjects, "7.5 s after disgust images presentation" and "7.5 s to 15 s after disgust images presentation", for each subject at the time of aversion disgust images presentation, and performed a Wilcoxon signed-rank test. The number of samples was 2 and the sample size was 16. The results confirmed a significant difference at a significance level of 1%. This suggests that the increase in RRI due to the unpleasant images is transient.

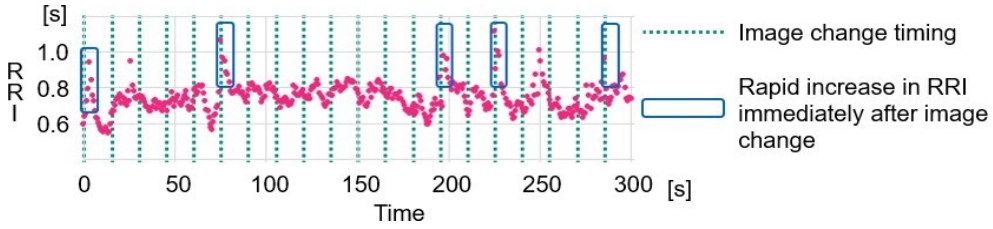


Figure 6: Change in RRI over 300 s (S4)

rMSSD

A Significant difference was found for rMSSD at the 5% level between excitement and disgust. Also, rMSSD tends to be higher than other emotions when it is disgust. Because rMSSD reflects the squared difference between adjacent RRIs, it is thought to strongly reflect the degree of abrupt change in RRIs shown in Figure 6.

pNN50

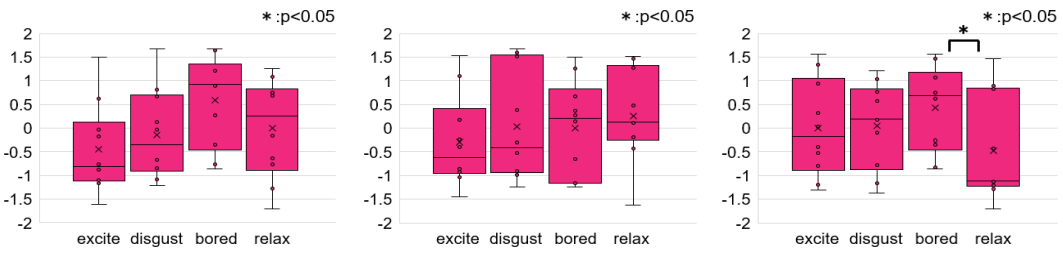
Significant differences were not found. pNN50, like rMSSD, is used as an index of the parasympathetic nervous system, but pNN50 does not reflect the extent to which 50 ms was exceeded. Therefore, pNN50 is thought to be less sensitive to disgust than the rMSSD, which reflects the degree of abrupt change as shown in Figure 6.

SDRR

Significant differences were found for SDRR at the 5% level for excitement and disgust, and excitement and boredom. Also, SDRR tends to be lower than other emotions when it is excitement. The SDRR was lower for excitement than for the other emotions. The reasons for this are that the heart rate changed rapidly when disgust images were shown in Figure 6, and the sympathetic nervous system was activated and the heart rate changed due to stress caused by continuous gazing of boredom images.

5.2.2 Frequency analysis indices

The LF and HF indices defined in this study are based on the assumption that the blood pressure cycle and respiratory cycle fall within the range of 0.04-0.15 Hz and 0.15-0.40 Hz, respectively. In particular, respiration can be voluntarily controlled, and we confirmed that subjects who did not fall within the range. Therefore, frequency analysis was performed on 10 subjects whose respiration rate per minute measured by Hexoskin was always 9 or higher. The results are shown in Figure 7.



(a) LF (b) HF (c) LF/HF

Figure 7: Result of Frequency Domain Indices

LF
Significant differences were not found.
HF
Significant differences were not found.
LF/HF
A significant difference was found for LF/HF at the 5% level between boredom and relaxation. LF reflects the blood pressure variability due to Mayer waves transmitted to HRV when the sympathetic nervous system is active. Therefore, the higher the sympathetic nervous system activity and the longer the active time, the more LF increases. In this study, LF is thought to have increased due to the continuous stress evoked by boredom images. Also, HF reflects respiratory variability transmitted to HRV during parasympathetic nervous system activity. Therefore, the higher the activity of the parasympathetic nervous system and the longer the active time, the more HF increases. In this study, HF is thought to have increased due to the continuous relaxation effect evoked by relaxation images. As a result, it is thought that when boredom, LF/HF increased due to an increase in LF, and when at relaxation, LF/HF decreased due to an increase in HF.

5.2.3 Non-linear (Lorenz plot) indices

The results are shown in Figure 8.

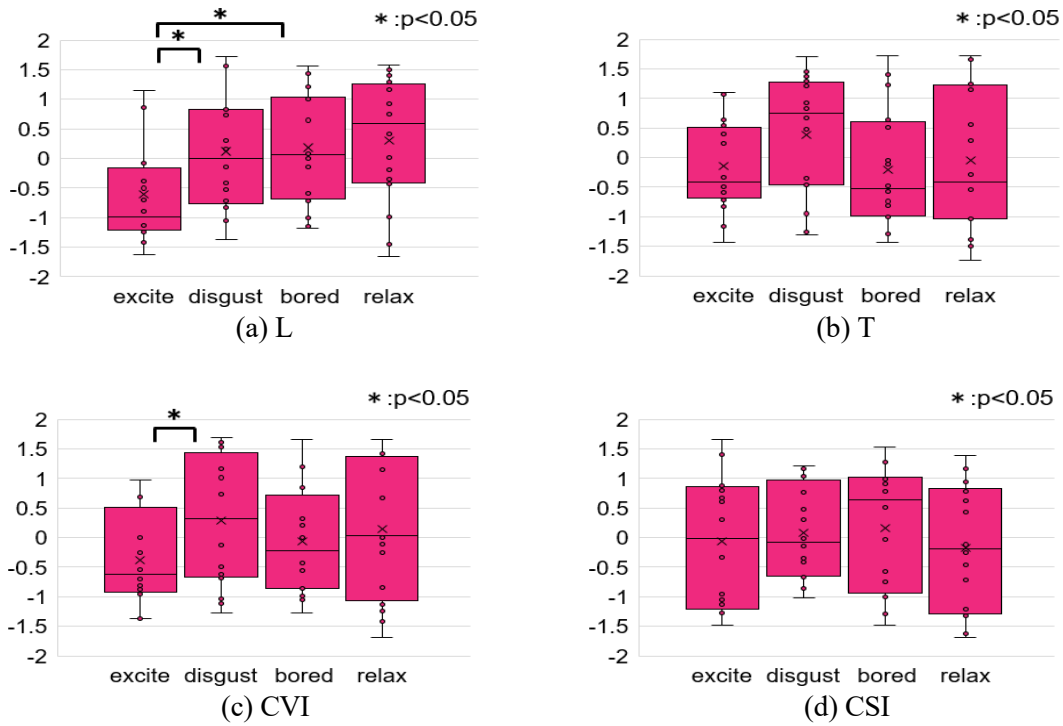


Figure 8: Result of Non-linear (Lorenz plot) Indices

L
Significant differences were found for L at the 5% level for excitement and disgust, and excitement and boredom. Also, L tends to be lower than other emotions when it is excitement. L is an index calculated using a Lorentz plot of the degree of variation in RRI in

the analysis interval. Therefore, it is thought that L is increased for the same reason as SDRR.

T

Significant differences were not found.

CVI

A significant difference was found for CVI at the 5% level between excitement and disgust. Since CVI is the product of L and T, the reason is thought to be that the CVI was greatly influenced by L.

CSI

Significant differences were not found.

5.2.4 Overall Analysis

Mean and rMSSD were shown to be effective in detecting disgust. Because Mean reflects a decrease in heart rate at the time of disgust images presentation, and rMSSD reflects a rapid change in RRI at the time of disgust images presentation. In addition, these indices are thought to be indices that highly reflect the decrease in RRI which related studies were shown.

SDRR and L were shown to be effective in detecting excitement. Because the auto- nomic nervous system is less active during excitement images presentation than during other images presentation, and the RRI fluctuated less. Also, the related study showed that RRI changes when gazing at pleasant images, but this was not consistent with the results of the experiment. This is thought to be because the excited images used in this experiment are relatively low arousal (6-7) in the high arousal (6-9) pleasant images. The images in which strong RRI fluctuations occurred in related studies were mainly erotic images, and such images were not included in this experiment.

LF/HF was shown to be useful in classifying boredom and relaxation. LF is the index that reflects the blood pressure cycle transmitted via the sympathetic nervous system to HRV. HF is the index that reflects the respiratory cycle transmitted via the parasympathetic nervous system to HRV. Therefore, the higher the activation of the sympathetic nervous system and the longer the active time, the higher the LF, and the higher the activation of the parasympathetic nervous system and the longer the active time, the higher the HF. In the experiment, LF increased as a result of feeling stress for a longer period of time with boredom images, and HF increased as a result of feeling relaxation for a longer period of time with relaxation images, considering that a significant difference was found.

Other results showed that CVI was effective in classifying excitement and disgust.

6 Conclusion

In this study, we investigated HRV indices that are useful for emotion estimation evoked by long-term visual stimuli. We constructed an experimental system in which the same emotion is continuously evoked by gazing at images with consistent emotional evaluation values. In a preliminary experiment, we investigated the time during which boredom and fatigue from long experiment did not affect the HRV. The results suggested that the experiment duration should be kept within 1220 s. In this experiment, we analyzed 11 HRV indices for their effectiveness in estimating emotions. The results showed that SDRR and L were effective in detecting excitement, Mean and rMSSD in detecting disgust, and LF/HF in classifying boredom and relaxation. These results are expected to serve as a basis for emotion estimation in situations where people

are exposed to visual stimuli for long periods of time, such as when viewing videos or scenery.

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