Evaluation of Viewers' Physiological State by ECG Data while Viewing Art in An Immersive Space

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ABSTRACT

Many previous studies have shown that art appreciation relaxes the human mind and reduces stress. We also hypothesized that art appreciation positively affects viewers' motivation and creativity and started research to confirm this. Firstly, an immersive environment was constructed based on the idea that viewing art in an immersive environment that provides a sense of endless space can maximize the effects of art appreciation. Then, we conducted a psychological evaluation using subjects while viewing art in this environment and obtained evaluation results showing that the subjects' motivation and creativity improved. As a next step, we aim to measure and analyze physiological data to obtain data to support psychological evaluation. In this paper, after briefly describing the configuration of the immersive environment, we report on the results of analyzing electrocardiographic (ECG) data when art content is compared with geometric figure content and no content using the environment.

1 Introduction

Art can enrich people's minds, heal their hearts, inspire them, etc. As an extension of this, we decided to evaluate the effect of art viewing on the human mind in an environment suitable for art appreciation. The video art of Naoko Tosa (Tosa Art), one of the authors, was used as art content. Tosa Art uses technology to extract the beauty hidden in natural phenomena and turn it into video art, characterized by its abstract and organic forms. Many people who have viewed Tosa Art have commented that it enhanced their creativity.

To measure the higher-order effects of art appreciation, such as improving creativity, it is necessary to construct an immersive space suitable for art appreciation and have the subjects appreciate the art in the space. We constructed a space surrounded by mirror displays to give subjects the feeling of being in an infinite space.

There are two evaluation methods for art viewing: psychological evaluation and measurement and analysis of physiological data. It is expected that the complex process of art appreciation will be better understood by combining two evaluation methods: psychological evaluation and physiological data measurement. We aim to clarify how people experience art appreciation in an immersive environment by simultaneously conducting psychological assessment and physiological data measurement, analyzing their results, and analyzing the relationship between psychological evaluation and physiological data. Since we have already presented the psychological evaluation results at several international conferences [1], this paper focuses on analyzing physiological data, specifically electrocardiographic (ECG) data, and describes the process and results.

2 Digital Art "Sound of Ikebana"

One of the authors, Naoko Tosa, has discovered that by applying sound vibrations to a fluid such as paint and photographing it with a high-speed camera, the fluid creates a shape similar to that of Ikebana, a Japanese flower arrangement. She confirmed that various fluid shapes could be generated by changing the shape of the sound, its frequency, the type of fluid, and viscosity. She further edited the resulting video to match the colors of the Japanese seasons and created a digital artwork called "Sound of Ikebana [2]". Figure 1 shows a scene from the work.

Fig. 1 A scene from "Sound of Ikebana."

Many people who have viewed Tosa's art content have commented that they feel their creativity is enhanced. Such an effect will likely be demonstrated in a space providing infinite immersion. Based on this idea, we designed and constructed a space that provides a sense of infinite immersion.

3 Design and Construction of an Immersive Space Using Mirror Displays

Mirrors are suitable for constructing a system that gives the impression of infinite space. At the same time, a display system is necessary to display images. Here, we decided to use a mirror display that functions as both a mirror and a display.

We designed and constructed an environment in which mirrors surround people, and part of the mirrors are the mirror displays, and art contents are displayed there. A hexagonal space surrounded by rectangular mirrors was constructed. The concept is shown in Fig. 2, where the

hexagonal space comprises three sets of mirrors facing each other. It is well known that mirrors facing each other create infinite images by mutually reflecting each other. By having three sets of mirrors, a person inside feels as if he/she is surrounded by countless mirror images of himself/herself. Furthermore, by using the ceiling and floor as mirrors, one feels as if one is surrounded by an infinite number of busts of oneself, both above and below.

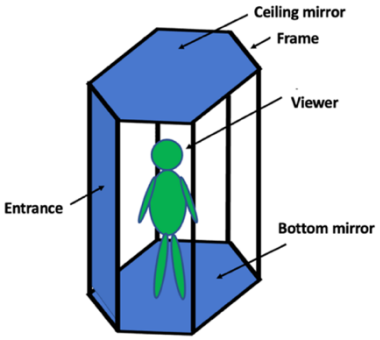

Fig. 2 Conceptual diagram of immersive space.

Inside this device, even a simple figure can generate an environment of beauty by continuing back and forth, left and right, and up and down indefinitely. Figure 3 shows an example of displaying art content produced by Tosa.

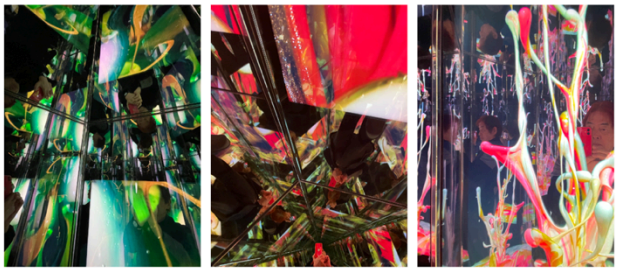

Fig. 3 Examples of art content visible within the immersive space.

4 Content Evaluation in the Immersive Space

4.1 Evaluation concept

The immersive space mentioned above gives the person inside the space the feeling of being in an infinitely expanding space. We plan to evaluate various art contents in this immersive space. As a first step, we used “Sound of Ikebana” by Naoko Tosa, one of the authors, as the main content. The reasons for this are as follows.

(1) Tosa’s art is generated using a high-speed camera to capture fluid phenomena. In other words, it is based on physical phenomena. Therefore, it is more compatible with the scientific evaluation method than art created manually by artists.

(2) Since it is based on fluid phenomena, various variations can be created by changing parameters, such as the type of fluid and the type of sound. In this respect, it is also compatible with the scientific evaluation method of changing conditions.

To evaluate the effect of art viewing, we simultaneously carried out psychological evaluation and measured physiological data in our experiment. This paper describes the initial analysis of the ECG data.

4.2 Measurement of physiological data

To measure physiological data, we used a device called HuME (Human Metrics Explorer) [3][4] from Shimadzu Corporation. HuME is a sensory measurement platform capable of complex measurements of electrocardiogram (ECG), electroencephalogram (EEG), skin potentials, sweating, gaze, etc. This paper focuses on the ECG data.

4.3 Contents

(1) Art content

The art content used was "Sound of Ikebana" by Naoko Tosa, one of the authors of the reason mentioned in 4.1.

(2) Geometric figure contents for comparison

Geometric figures are used as the content for comparison with the art content. The geometrical figure contents are simple shapes such as circles, squares, etc., and simple effects such as rotation and color change with time are added. These color and shape changes were synchronized with changes in the art content as much as possible. The three types of geometric figures we have selected are below.

Geometric Figure 1: The shape is a circle and only the color changes over time.

Geometric Figure 2: The shape changes to a circle and a square in sequence, along with colors.

Geometric Figure 3: The square shape rotates, and the color changes with time, as in Geometric Figures 1 and 2.

Preliminary experiments have revealed no significant differences in comparisons between these geometric figures [1]. We decided to use Geometric Figure 2 (“Figure”) to be compared with Tosa’s art (“Art”).

4.4 Subjects

Forty Kyoto University students were used as subjects. The students were given a thorough explanation of the experiment and asked to sign a consent form.

4.5 Experimental procedure

The procedure of each subject's psychological evaluation and physiological data measurement is described below.

Move: A subject moves into the immersive space.

Assessment 1: The subject completes an initial psychological evaluation.

Rest 1: No content is displayed to reset the subject's state. Physiological data measurement is performed.

Content 1: Art or Figures are displayed. Physiological data measurement is performed at the same time.

Assessment 2: The subject completes a second psychological evaluation.

Rest 2: No content is displayed to reset the subject's state. Physiological data measurement is performed.

Content 2: Art or Figure is displayed. If Content 1 is Art, Figure is displayed; if Content 1 is Figure, Art is displayed. Physiological data measurement is performed at the same time.

Assessment 3: The subject completes a third psychological evaluation.

Move: The subject exits the immersive space.

5 Results of ECG Data Analysis

5.1 Physiological data measurement

This study aimed to clarify the characteristics of Tosa's art by comparing geometric figures with Tosa'a art. Forty subjects were measured for physiological data (ECG, EEG, and skin potentials), but only 22 could successfully measure all three data types. Since we want to analyze the relationship between the ECG, EEG, and skin potentials, we focused our analysis on the 22 subjects for which all three data types could be measured. In this paper, we focus on the ECG data.

5.2 Analysis methods for ECG data

Figure 4 shows the typical shape of the ECG.

Fig. 4 Shape of ECG.

Heart rate variability, the periodic interval fluctuation between adjacent R waves (RRI), reflects autonomic nervous system activity. Therefore, we focused on the following heart rate variability indices obtained from the ECG data of 22 subjects.

RRI: RR interval.

SDNN: Standard deviation of RR interval.

RMSSD: Root mean square of the difference between adjacent RR intervals.

pNN50: Ratio of difference between adjacent RRIs exceeding 50 msec.

LF: Low-frequency component from frequency analysis of RR interval data.

HF: High-frequency component from frequency analysis of RR interval data.

LF/HF: Ratio of low-frequency component to high-frequency component.

SDNN, RMSSD, pNN50, and HF are used as indices of parasympathetic nerve activity, while LF/HF is used as an index of sympathetic nerve activity. All of these can be obtained as time series data. However, in the present study, averaged values were compared for the four types of content presented for 3 minutes (Figure, Art, Rest 1: no content corresponding to Rest 1, Rest 2: no content corresponding to Rest 2).

5.3 Results of heart rate variability index analysis

Graphs comparing the contents of Figure, Art, Rest1, and Rest2 for the above five heart rate variability indices, SDNN, RMSSD, pNN50, HF, and LF/HF, are shown in Figs. 5 through 9. An analysis of variance (ANOVA) was performed to see if the differences between Figure, Art, Rest1, and Rest2 were significant, and the results are also overlapped on Figs. 5 through 9. Interpretations for each figure are given below.

Figure 5: For SDNN, the value of Art is lower than for Figure, Rest1 and Rest2. The analysis of variance also shows that the main effect on content is significant ($F(3, 63)=5.87$, $p=.002$). Multiple comparisons reveal a significant difference between Art and Rest1 and Rest2 at the 5% level. These results suggest the following.

The lower SDNN for Art suggests that parasympathetic nerve activity is suppressed while the subjects are viewing Art, suggesting that the subjects are in a state of arousal or excitement. SDNN is high during Rest1, 2, indicating that parasympathetic nerve activity is dominant and the subject is relaxed. SDNN for Figure is located between Art and Rest1, 2, indicating that the subjects are between resting and viewing Art when viewing Figure.

Figure 6: RMSSD reflects short-term heart rate variability and is considered an indicator of parasympathetic nerve activity. RMSSD for Art is low, and RMSSD for Figure is higher than Art and lies between Art and Rest1, 2. The analysis of variance results show that the main effect for content is marginally significant ($F(3, 63)=3.23$, $p=.064$). Looking at differences between content, the difference between Art and Rest1, 2 is insignificant, but low values are obtained for the difference between Art and Rest1 ($p=.047$) and Art and Rest2 ($p=.033$). The lower RMSSD during Art viewing indicates that short-term heart rate variability is suppressed.

Figure 7: Also, for pNN50, Art has a lower value, while pNN50 for Figure is higher than Art but lower than Rest1, 2. The analysis of variance results show that the main effect on content is significant ($F(3, 63)=3.11$, $p=.043$). However, the multiple analysis results show no significant differences among the contents due to the large variance.

Figure 8: For LF, the trend is similar to Figs. 5 through 7 in the sense that the value of Art is low. However, the main effect on content is insignificant ($F(3, 63)=1.81$, $p=.165$).

These results can be interpreted as follows: SDNN, RMSSD, pNN50, and HF indicate that parasympathetic nerve activities were low during Art viewing, suggesting that the subjects were not relaxed or in a state of arousal or excitement. On the other hand, when viewing Figure, they were shown to be more relaxed than in Art but less relaxed than in Rest.

Figure 9: The following results were obtained for LF/HF. During Rest1, the low LF/HF values indicate that sympathetic nerve activity is suppressed. This means that the subjects were in a relaxed state. LF/HF values are slightly higher during Art viewing than in Rest1. This indicates that viewing art induces a state of arousal and excitement similar to the resting state of the subjects. When viewing Figure. LF/HF values are higher than when viewing Art, indicating that sympathetic nerve activity is stronger than when viewing Art. During Rest2, LF/HF values are much higher than Rest1. This indicates that the anticipation and excitement for the following content continues even after the content presentation ends, suggesting that sympathetic nerve activity continues.

The analysis of variance results show that the main effect of content is significant ($F(3, 63)=3.41$, $p=.028$). However, the multiple analysis results show no significant differences in content, which may be due to the significant variance.

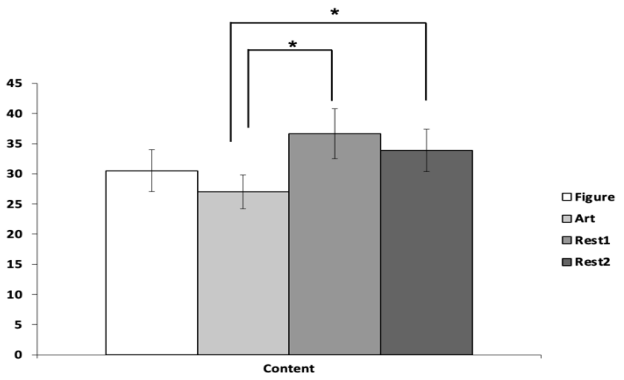

Fig. 5 Mean and variance analysis results for SDNN.

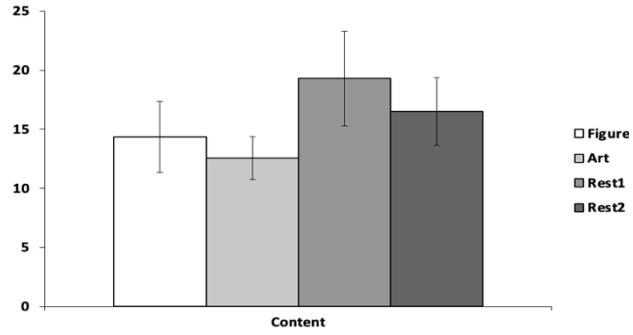

Fig. 6 Mean and variance analysis results for the four content types for RMSSD.

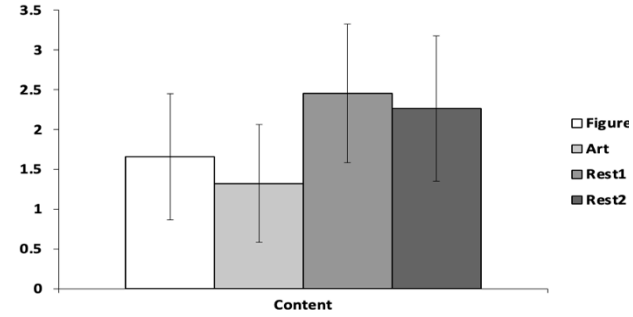

Fig. 7 Mean and variance analysis results for the four content types for pNN50.

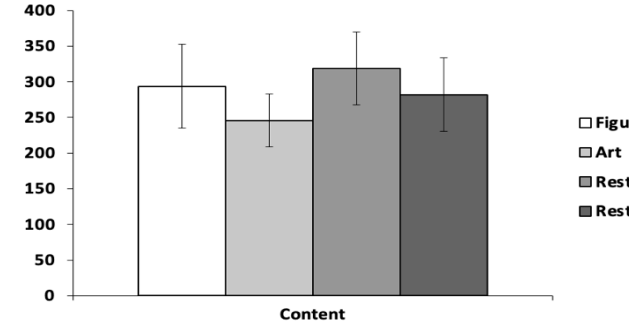

Fig. 8 Mean and variance analysis results for four types of content targeting HF.

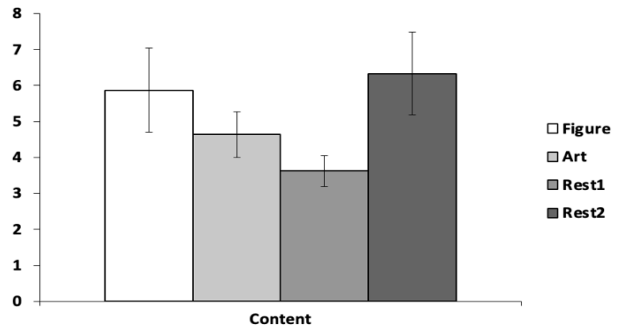

Fig. 9 Mean and variance analysis results for four content types for LF/HF.

In summary, Figs. 5 through 9 can be interpreted as follows. Figures 5 through 8 show parasympathetic nerve activity was suppressed during Art appreciation. Figure 9 shows that sympathetic nerve activity was also suppressed during Art appreciation, with a slight increase compared to the resting state (Rest1). In other words, sympathetic and parasympathetic nerve activities were suppressed during Art appreciation. Since sympathetic and parasympathetic nerve activities usually move in opposite directions, the combination of low activity of either nerve system indicates low activity of both autonomic nerve systems. This is seen, for example, during deep sleep or in the presence of certain neurological disorders. It is usually interpreted that in this state, overall autonomic regulation may be reduced, and various functions of the body may not be adequately coordinated.

In contrast, this study's results were obtained when healthy subjects viewed art in an immersive space. The results suggest that art appreciation may induce a particular condition in people.

6 Conclusion

Our research aims to understand how subjects are affected when viewing art, specifically video art created by Naoko Tosa, one of the authors, in an immersive space. We conducted psychological experiments and physiological data measurements simultaneously to analyze their relationship. We have already conducted a detailed analysis of the psychological evaluation results and obtained the exciting result that viewing Tosa's art in an immersive space stimulates people's minds and arouses their creativity [1].

Since physiological data measurement was conducted simultaneously, in this paper, we focused on the ECG data and analyzed the heart rate variability under four conditions: when art content is presented, when geometric figure content is presented, and when no content is presented twice.

The results show that sympathetic and parasympathetic nerve activities were suppressed during art presentation. This experiment, in which healthy subjects viewed art in an immersive space, revealed the possibility that art viewing may uniquely affect people's minds and bodies. This point should be further investigated in the future. At the same time, the results obtained during art viewing showed substantial differences between individuals. This result indicates that a detailed analysis of the data for each subject is

needed.

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