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Comparative Evaluation of Two Immersive Art Spaces Using ECG Data

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ABSTRACT

To better understand the nature of art, this study investigated how different immersive environments influence viewers' physiological responses during art appreciation. We constructed two immersive spaces with distinct spatial characteristics: Immersive Space 1, which incorporates mirror displays to create a sense of infinite reflection, and Immersive Space 2, which is surrounded by large LED displays. While participants viewed a video artwork created by one of the authors, we recorded and analyzed their electrocardiographic (ECG) data.

The results revealed that in Immersive Space 1, both sympathetic and parasympathetic activities were suppressed during art viewing, suggesting a state of heightened arousal and reduced physiological relaxation. In contrast, in Immersive Space 2, parasympathetic activity was dominant, suggesting a more relaxed, emotionally stable physiological state. These findings underscore the significance of spatial context in shaping the embodied aesthetic experience.

Keywords: Art Viewing, Immersive Space, ECG Data Analysis

1. INTRODUCTION

Art has long been regarded as a medium capable of inspiring, comforting, and enriching human experience. In recent decades, this intuitive understanding has been increasingly examined through empirical research, particularly in psychology and neuroscience. Experimental aesthetics, originating with Gustav Fechner in the 19th century, pioneered the quantitative study of aesthetic preference by assessing viewers' reactions to visual stimuli such as symmetry and balance. Subsequent psychological studies have explored how individual factors—such as familiarity, abstraction, and expertise—affect art appreciation. For example, Okada and Inoue [1] showed a general preference for figurative over abstract art. At the same time, Winston and Cupchik [2] found that experts favored fine art, whereas non-experts preferred more accessible imagery.

Beyond subjective evaluations, physiological approaches have been introduced to assess the impact of art on the body. Clow et al. [3] demonstrated that a brief visit to an art gallery reduced cortisol levels in office workers, suggesting that art can help relieve stress. Law et al. [4] reviewed numerous studies using physiological measures—including heart rate, blood pressure, and skin conductance—to assess emotional and stress-related responses to art in settings ranging from galleries to hospitals. However, these studies have focused mainly on generalized calming effects, and relatively few have addressed how the viewing environment might modulate physiological response during art appreciation.

To address this gap, the present study investigates how different immersive spaces affect the autonomic nervous system activity of viewers engaging with art. Two immersive environments were constructed: Immersive Space 1, designed using mirror displays to create a sense of infinite visual depth, and Immersive Space 2, constructed using large LED displays that enclose the viewer entirely with non-reflective visuals. While participants experienced video artwork created by one of the authors, we collected electrocardiographic (ECG) data. We analyzed key indices of heart rate variability, including SDNN, RMSSD, pNN50, HF, and LF/HF, which are commonly used to evaluate parasympathetic and sympathetic nervous system activity.

This study is one of the first to systematically examine the interaction between immersive spatial design and autonomic nervous system activity during art appreciation.

2. IMMERSIVE SPACES FOR ART APPRECIATION

It is considered adequate to view art in a space surrounded by art. We constructed two art-enclosed spaces: an immersive space surrounded by mirror displays and another by large LED displays.

2.1 Immersive Space 1: Immersive Space with Mirror Display

2.1.1 Mirror display

Mirrors are suitable for creating a system that gives the illusion of infinite space. At the same time, a mechanism to display images is necessary. Therefore, we used a mirror display that functions as both a mirror and a display.

Several companies have commercialized mirror displays that combine the functions of a mirror and a display. These are marketed under various names, combining a display with a half-mirror that serves as both a mirror and a glass surface. The authors used a mirror display developed by AGC Corporation and commercialized under the name "Mirroria" [5].

2.1.2 Design and construction of Immersive Space 1

We have already confirmed in psychological experiments that art content has a positive effect on the human mind [6][7]. In this experiment, art content was displayed on large LED displays and mirror displays. Placing people in a more immersive environment may be a practical approach.

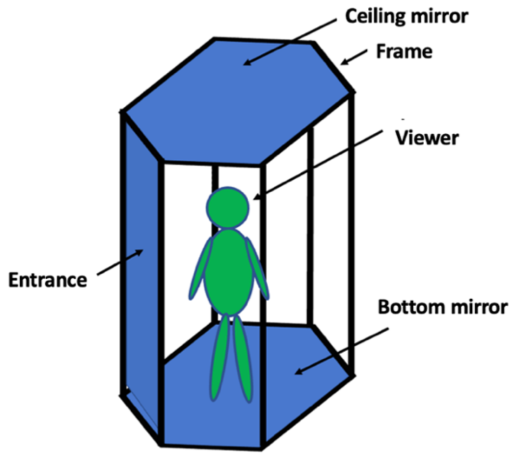

Fig. 1. Conceptual diagram of Immersive Space 1

Therefore, we decided to construct an environment where people are located and surrounded by mirrors, some of which are mirror displays that display art content. A hexagonal space surrounded by rectangular mirrors was constructed. The concept is shown in Fig. 1, where the hexagonal space comprises three mirrors facing each other. It is well known that mirrors create an infinite number of images by reflecting each other. By having three sets of mirrors, people inside the space feel as if countless images of themselves surround them. Furthermore, by using the ceiling and floor as mirrors, one has the sensation of being surrounded by an infinite number of busts of oneself, both above and below. The six mirrors that make up this hexagonal space are the mirror displays that can display images.

2.2 Immersive Space 2: Immersive Space Surrounded by Four LED Displays

2.2.1 Concept of Immersive Space 2

Immersive Space 1 has the following advantages and disadvantages.

Advantages: Due to the mirror effect, a mirror display can create the illusion of an infinite space within a confined area of approximately 1.5m (width) x 1.5m (depth) x 2m (height).
Disadvantages: On the other hand, using mirrors results in an endless series of mirror images of the viewers. Therefore, some viewers may feel less immersed because they can see their image.

Considering these advantages and disadvantages, we decided to construct Immersive Space 2 with the following features and to conduct a comparison experiment with Immersive Space 1.

Features of Immersive Space 2: Large LED displays are used to create a space rather than a mirror display. Since mirrors are not used, one's image is not reflected. Therefore, Immersive Space 1's disadvantage of a reduced sense of immersion can be eliminated. On the one hand, it does not evoke the same sense of being in an endless space as Immersive Space 1 does.

2.2.2 Construction of Immersive Space 2 using OEL displays

Immersive Space 2 is a closed space surrounded by displays on four sides. A 77-inch OEL (Organic Electro-Luminescence) display is used. However, a completely enclosed space surrounded by displays creates a sense of closure, and it is considered mentally challenging for people with claustrophobia to enter. Therefore, we used mirrors for the ceiling and floor to soften the sense of a closed space. A conceptual diagram of Immersive Space 2 is shown in Fig. 2.

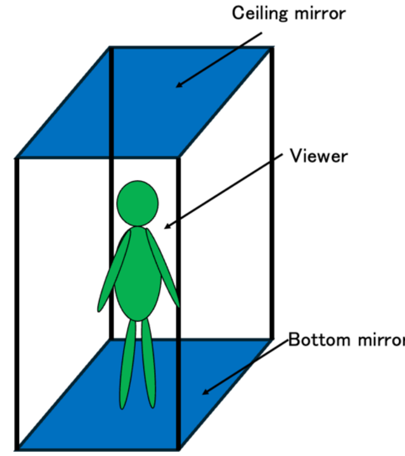

Fig. 2. Conceptual diagram of Immersive Space 2

Since Immersive Spaces 1 and 2 have relative characteristics, as described earlier, it would be interesting to compare them through physiological experiments.

3. EXPERIMENT COMPARING IMMERSIVE SPACES 1 AND 2 BY MEASURING AND ANALYISING PHYSIOLOGICAL DATA

3.1 Concept of the Evaluation Experiment

Physiological data were collected and analyzed to evaluate how viewers feel when art content is displayed in the two immersive spaces.

Immersive Spaces 1 and 2 are almost identical in size and are surrounded by displays. The differences in the characteristics of Immersive Space 1, constructed with mirror displays, and Immersive Space 2, constructed with large displays, create distinct impressions for viewers when viewing art and other content in the spaces. By comparing physiological data from these two immersive spaces, which differ in so many ways, it is possible to understand how different environments affect people's physiology when viewing art. This will shed new light on the problem of what appeals to people when viewing art.

3.2 Measurement of Physiological Data

This research was conducted in collaboration with Kyoto University and Shimadzu Corporation. HuME (Human Metrics Explorer) [8] from Shimadzu was used to measure physiological data. HuME is a physiological measurement system that integrates various wearable devices. In this study, we measured electrocardiograms (ECGs) using the HuME device, electroencephalography (EEG), and skin electrical activity using a commercial device. This paper focuses on the ECG data and its analysis among the measured data.

3.3 Digital Art "Sound of Ikebana" Used as Art Content for the Evaluation Experiment

In this research, we used a video artwork created by one of the authors, Naoko Tosa, as art content. She found that by applying sound vibrations to a fluid, such as paint, and photographing it with a high-speed camera, the fluid forms a shape resembling a flower arrangement. This is an art production using fluid phenomena.

Tosa confirmed that various fluid shapes can be generated by altering the sound's shape, frequency, fluid type, and viscosity [9]. She further edited the resulting video to match the colors of the Japanese seasons and created a digital artwork called "Sound of Ikebana" [10]. Figure 3 shows a scene from the artwork.

Fig. 3. A scene from "Sound of Ikebana"

The art content used in the evaluation experiment was a three-minute video clip (hereinafter referred to as "Tosa Art") cut from the "Sound of Ikebana." The reasons we chose "Sound of Ikebana" as art content, despite the numerous artworks available, are as follows.

(1) Tosa Art was created by filming fluid phenomena with a high-speed camera, suggesting it is based on physical phenomena. Therefore, it is more compatible with the scientific evaluation method than art produced manually by artists.
(2) Since it is based on fluid phenomena, various content variations can be created by changing parameters, such as the type of fluid and the type of sound. It is also compatible with the scientific evaluation method of repeated experiments with different conditions.

Figure 4 shows examples of Tosa Art displayed in Immersive Space 1, and Fig. 5 shows an example of Tosa Art displayed in Immersive Space 2.

Fig. 4. Tosa Art displayed in Immersive Space 1

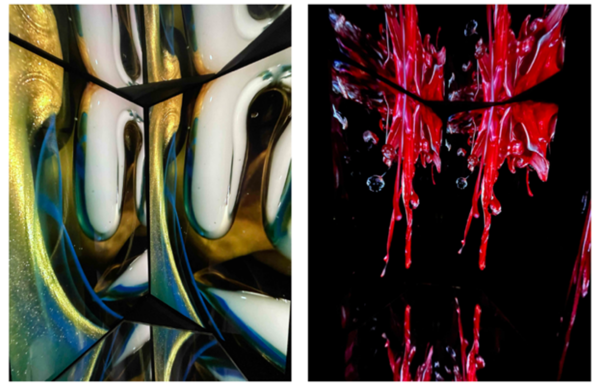

Fig. 5. Tosa Art displayed in Immersive Space 2

3.4 Comparative Content

When conducting evaluation experiments using art content, preparing content for comparison is necessary. We used simple geometric figures such as circles and squares as the comparison content. After conducting preliminary experiments and evaluating multiple geometric figures in psychological experiments, we used geometric figure content whose shapes change from circles to squares in sequence, accompanied by color, as the comparison content alongside art content [11].

Inside Immersive Space 1, even a simple figure can generate a beautiful environment by continuing infinitely back and forth, left and right, and up and down through the mirror effect (Fig. 6).

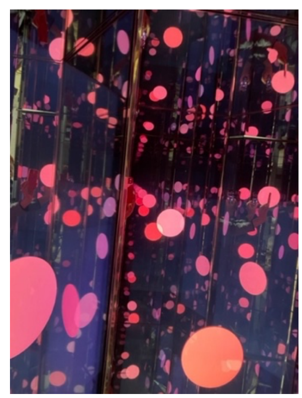

Fig. 6. Displaying a geometric figure (circle) in Immersive Space 1

3.5 Test Subjects

Different subjects evaluated Immersive Spaces 1 and 2. Immersive Space 1 was evaluated by 40 Kyoto University students (32 males, 8 females), and Immersive Space 2 was evaluated by 52 Kyoto University students (28 males and 24 females).

3.6 Experimental Procedure

The experiment process for each subject is as follows (Fig. 7).

(1) First, after the purpose and content of the experiment were briefly explained, the subject signed a consent form.
(2) The subject then moves into the immersive space.
(3) After entering the immersive space, the subject completes an initial psychological evaluation via Google Forms.

(4) Before displaying Content 1, a 3-minute resting period is taken to reset the subject's state. The display is black during this time, and physiological data is measured ("Rest 1" hereafter).
(5) Content 1 with a 3-minute duration is displayed, and physiological data is measured (“Art” or “Figure” hereafter).
(6) After viewing Content 1, the subject completes a second psychological evaluation.
(7) Before Content 2 is displayed, a 3-minute resting period is taken to reset the subject's state. The display is black during this time, and physiological data is measured (“Rest 2” hereafter). Content 2, with a 3-minute duration, is displayed, and physiological data is measured (“Art” or “Figure” hereafter).
(8) After viewing Content 2, the subject completes a third psychological evaluation.
(9) At the end of the experiment, the subject exits the immersive space.

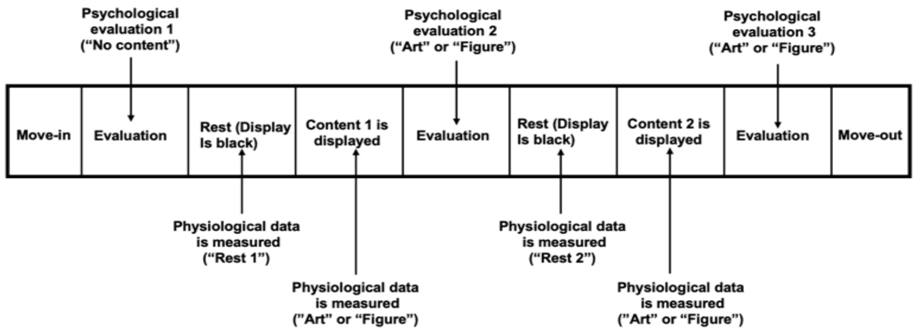

Fig. 7. Experimental procedure

4. ANALYSIS RESULTS OF ECG DATA

4.1 ECG Data Used in the Analysis

This study aimed to clarify the physiological data characteristics of subjects viewing Tosa Art and other content in two different immersive spaces. For Immersive Space 1, physiological data (ECG, EEG, and skin potential) were collected from 40 subjects, of whom 22 successfully measured all three data types. In Immersive Space 2, 39 of 52 subjects were successfully measured with all three data types. To analyze the relationship between the ECG, EEG, and skin potentials, we limited our analysis to subjects for whom all three data types could be measured. In this paper, we focus on the ECG data.

4.2 Analysis Methods for ECG Data

Figure 8 shows the basic shape of the ECG data.

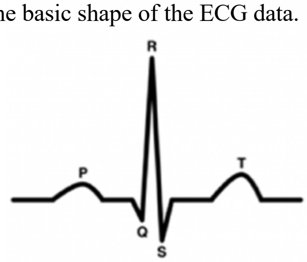

Fig. 8. Shape of ECG data

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

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.
HF: High-frequency component from frequency analysis of RR interval data.
LF/HF: Ratio of the low-frequency component to the high-frequency component.

SDNN, RMSSD, pNN50, and HF are used as indices of parasympathetic activity, while LF/HF is used as an index of sympathetic activity. Although all of these are obtained as time-series data, we averaged the data in the present study to facilitate analysis. We obtained four types of data (Art: ECG data during art viewing; Figure: ECG data during geometric figure viewing; Rest 1: ECG data corresponding to Rest 1; Rest 2: ECG data corresponding to Rest 2) for each subject. In addition, since the ECG data in Rest 2 were influenced by the content (Figure or Art) viewed immediately before Rest 2, we excluded these data. We used only Rest 1 (hereinafter, Rest) to compare the three conditions: Art, Figure, and Rest.

4.3 Qualitative Comparison of Individual Variation Indicators in the Two Immersive Spaces

4.3.1 Analysis of Immersive Space 1

Figures 9 through 12 show the results of averaging and further analysis of variance (ANOVA) on subjects for SSDN, RMSSD, pNN50, and HF, which indicate parasympathetic activity.

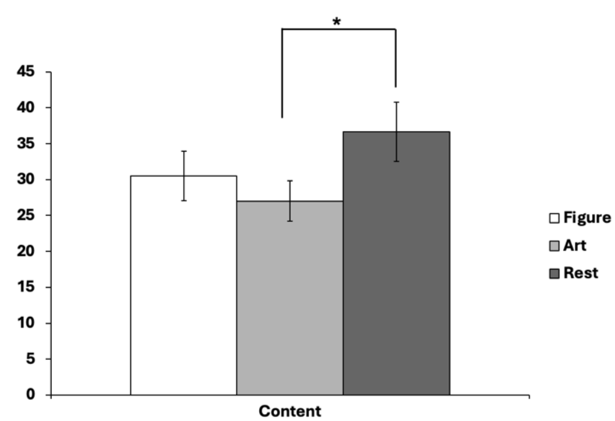

Fig. 9. Mean and ANOVA results for SSDN

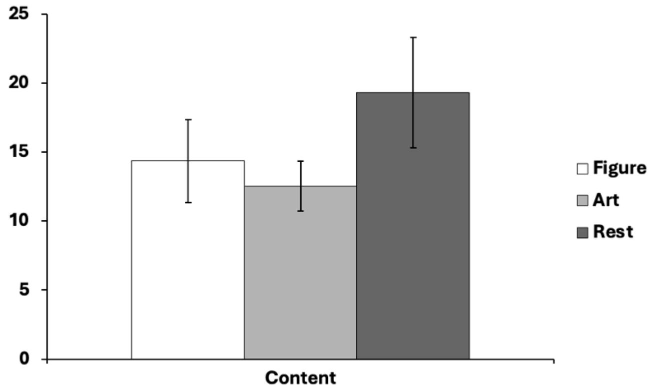

Fig. 10. Mean and ANOVA results for RMSSD

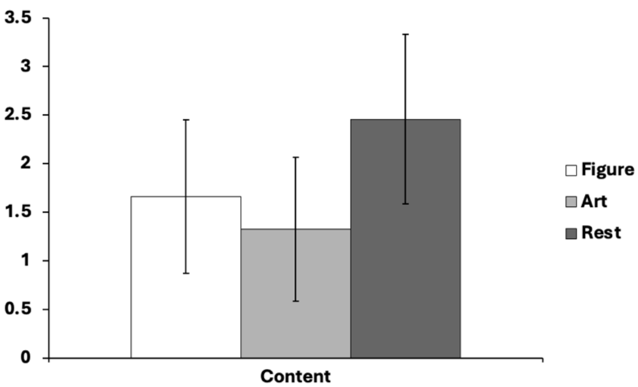

Fig. 11. Mean and ANOVA results for pNN50

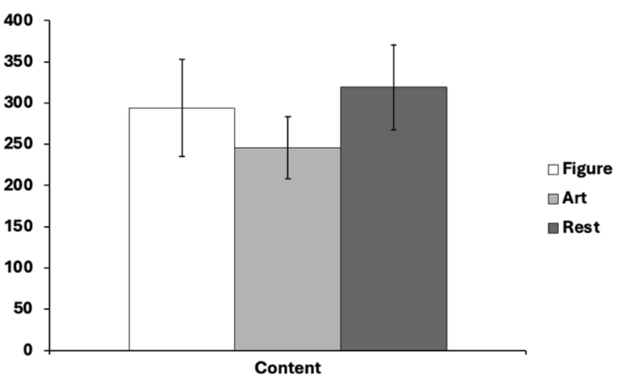

Fig. 12. Mean and ANOVA results for HF

All of them show similar trends. Below are the summarized discussions.

When viewing art in Immersive Space 1, SDNN, RMSSD, pNN50, and HF variability indices are consistently lower for Art than for Figure and Rest. These indices reflect heart rate variability and respiratory variability, and are strongly associated with a relaxed state and mental flexibility. These lower values suggest that subjects were less able to achieve an internal sense of calm and immersion due to the visual complexity and reflective nature of Immersive Space 1. As a result, parasympathetic activity, which is inherent in the healing and emotional immersion of art, may have been suppressed. Although Immersive Space 1 is stimulating in design, it may be a physiologically tense environment.

Figure 13 shows the LF/HF results, which indicate sympathetic activity.

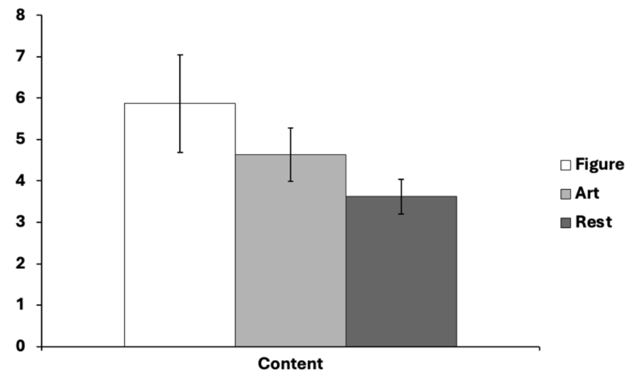

Fig. 13. Mean and ANOVA results for LF/HF

The LF/HF ratio is an intermediate value between Figure and Rest in Art. That is, sympathetic nervous activity is more active than in Rest, approaching a state of tension or arousal, but not as high as during Figure appreciation.

The following are the findings regarding Immersive Space 1 as a whole.

In Immersive Space 1, all parasympathetic indicators related to Art (SDNN, RMSSD, pNN50, HF) were lower than in other conditions. On the other hand, the LF/HF ratio, which indicates sympathetic nervous activity, was higher than in Rest but lower than in the Figure. These findings suggest that the structural characteristics of Immersive Space 1 relatively suppress the introspective and emotional effects inherent in art. In other words, the mirror reflections and visual complexity characteristic of Immersive Space 1 may simultaneously induce physiological relaxation, immersion, arousal, and tension.

On the other hand, most ANOVA results indicate no significant differences among Art, Figure, and Rest, suggesting considerable individual variation.

4.3.2 Analysis of Immersive Space 2

Figs. 14 through 17 show the results of averaging and further analysis of variance (ANOVA) on subjects for SSDN, RMSSD, pNN50, and HF, which indicate parasympathetic activity.

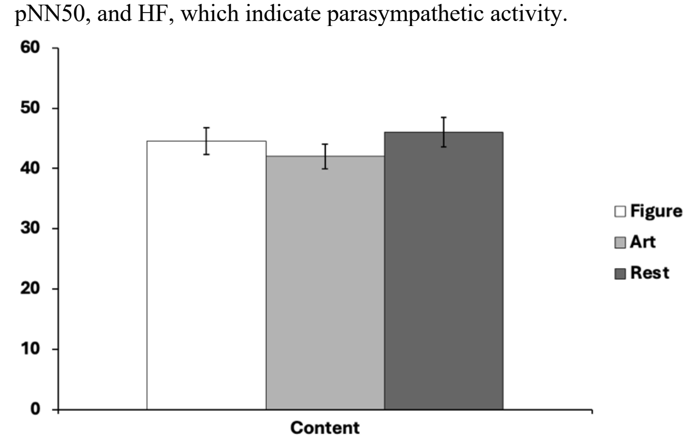

Fig. 14. Mean and ANOVA results for SSDN

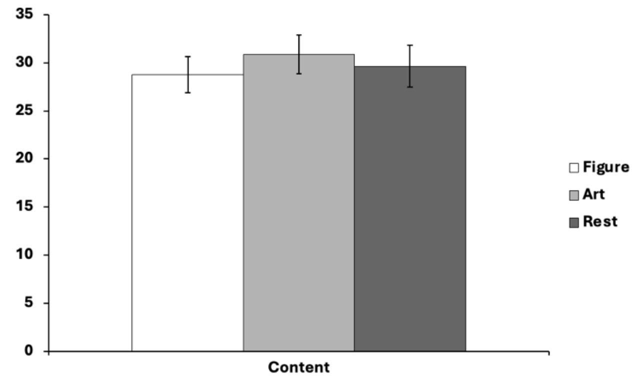

Fig. 15. Mean and ANOVA results for RMSSD

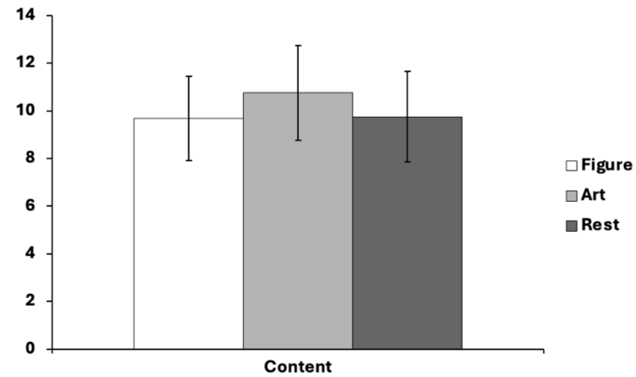

Fig. 16. Mean and ANOVA results for pNN50

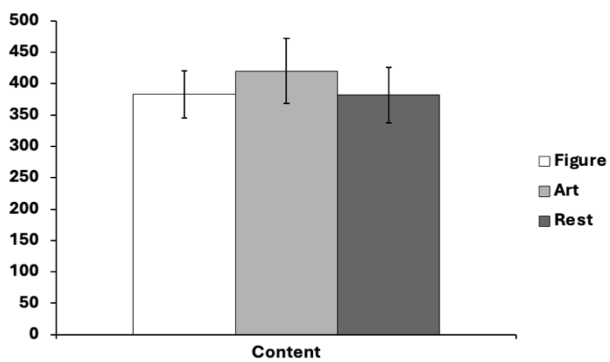

Fig. 17. Mean and ANOVA results for HF

Below are the considerations.

SDNN for Art shows slightly lower values than the Figure and Rest. SDNN reflects overall heart rate variability and is an indicator influenced by the sympathetic and parasympathetic nervous systems. A decrease in this value suggests that art appreciation in Immersive Space 2 may have suppressed long-term heart rate variability and promoted a stable physiological state. This results from reduced external responses due to the state of concentration brought about by integrating immersive images and space.

Regarding RMSSD, pNN50, and HF, all values were higher for Art than for Figure and Rest, indicating that parasympathetic activity was activated during art appreciation in Immersive Space 2. These indicators are associated with respiratory variability and short-term heart rate adjustments and are strongly linked to deep relaxation and emotional stability. Immersive Space 2 integrated visual stimuli with bodily sensations and blocked external stimuli, providing participants with a safe and secure spatial experience. As a result, heart rate varied flexibly, and deep, regulated breathing became possible, indicating that the parasympathetic nervous system function was fully activated.

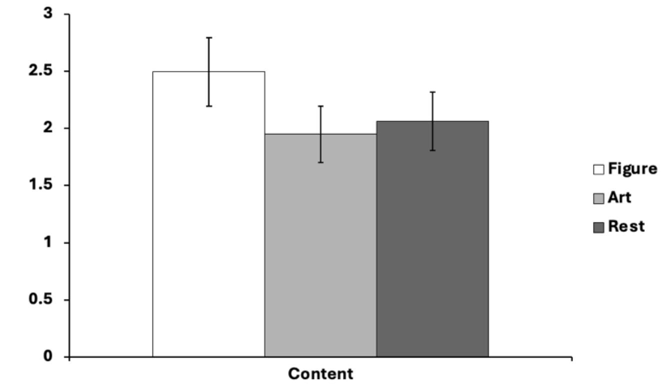

Fig. 18. Mean and variance analysis results for LF/HF

Figure 18 shows LF/HF results, indicating sympathetic activity. Below are the discussions.

LF/HF values are lower for Art than for Figure or Rest. This indicates that parasympathetic nervous activity is dominant during art appreciation, suggesting a reduction in sympathetic nervous activity associated with tension and arousal. Art exhibits significantly lower LF/HF ratios than Figure, suggesting that it may induce deeper psychological immersion and relaxation than simple visual stimuli such as geometric shapes.

The following are considerations regarding the entire Immersive Space 2.

From these data, it can be seen that autonomic nervous activity during art appreciation is in a parasympathetic-dominant balance. Parasympathetic indicators such as RMSSD, pNN50, and HF are generally elevated, while LF/HF is reduced, suggesting that the tension-inducing effects of the sympathetic nervous system are suppressed. In other words, art appreciation provides an experience that is both emotionally stimulating and calming. Such a balance was not observed in Figure or Rest, and in Figure, sympathetic activity was relatively high, possibly due to the need for visual attention. Art in Immersive Space 2 is thought to achieve a balance between moderate internal activity and physiological relaxation.

At the same time, as in Immersive Space 1, the lack of significant differences between Art, Figure, and Rest across all indicators suggests that a more detailed analysis, such as examining individual differences, is necessary.

5. CONCLUSION

This study examined the effects of various immersive environments on viewers' physiological states during art appreciation, using electrocardiographic (ECG) data as the primary measure. Two immersive spaces were constructed: Immersive Space 1, surrounded by mirror displays that create a sense of infinite reflection, and Immersive Space 2, enclosed by large OEL panels to provide a visually absorbing experience.
Our findings indicate that Immersive Space 1 suppressed both sympathetic and parasympathetic activity, suggesting that the

visually complex environment may have induced mild physiological arousal or tension. In contrast, Immersive Space 2 was associated with increased parasympathetic activity and decreased sympathetic activity, reflecting a more relaxed and emotionally balanced physiological state during art viewing.

These results demonstrate that the spatial characteristics of immersive environments can significantly modulate the autonomic nervous system response to art, even when the content is duplicated. While both spaces successfully delivered an immersive experience, their distinct effects on physiological relaxation and arousal highlight the importance of spatial design in shaping embodied aesthetic responses.

Furthermore, although physiological differences were evident between the two environments, psychological evaluations conducted in a related experiment showed no significant differences [12]. The divergence between physiological and psychological responses is examined in detail in a separate paper submitted by the authors to this conference, focusing on the layered nature of aesthetic experience [13].

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