

Comparative Evaluation of Two Types of Immersive Art Spaces with 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, indicating a more relaxed and emotionally stable physiological state. These findings highlight the importance of spatial context in shaping 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 how art impacts the body. Clow et al. [3] demonstrated that a brief visit to an art gallery reduced cortisol levels in city 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 panels 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

Two immersive spaces were constructed to compare the physiological effects of different viewing environments during art appreciation. Immersive Space 1 employed mirror displays to create the impression of infinite reflections, while Immersive Space 2 used four large OLED (Organic Light Emitting Diode) panels for a fully enclosed, non-reflective space. Both spaces were of similar size but provided distinct spatial experiences.

Immersive Space 1 offers strong visual complexity and a sense of infinite depth due to the mirror reflections, whereas Immersive Space 2 eliminates self-reflection and provides a calmer, more stable visual environment.

Figures 1 and 2 illustrate the conceptual layouts of Immersive Space 1 and Immersive Space 2, respectively. For a detailed description of the design and construction of these spaces, please refer to our companion paper on psychological evaluations [5].

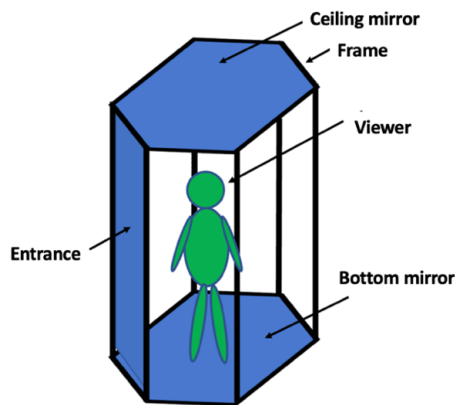


Fig. 1 Conceptual diagram of Immersive Space 1

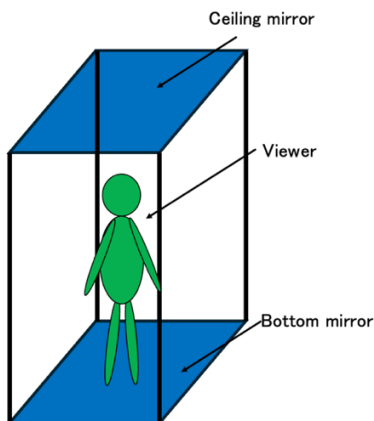


Fig. 2 Conceptual diagram of the Immersive Space 2

3. Experiment Comparing the Immersive Spaces 1 and 2 by Measuring and Analyzing Physiological Data

3.1 Concept of the Evaluation Experiment

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

Immersive spaces 1 and 2 are almost the same size, surrounded by displays. The difference in the characteristics of Immersive Space 1, which is constructed with mirror displays, and Immersive Space 2, which is constructed with large displays, gives different impressions to people while viewing art and other content in the immersive space. By comparing physiological data in these two immersive spaces with such different characteristics, it is possible to understand the effects of different environments on 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) [6] 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 study, we used the digital video artwork “Sound of Ikebana,” created by one of the authors, Naoko Tosa, as the primary art stimulus. This artwork visualizes fluid dynamics by applying sound vibrations to paint or other fluids and capturing their dynamic forms with a high-speed camera. The resulting visuals, inspired by Japanese seasonal aesthetics, have been widely applied in experimental settings [7][8]. The content for this experiment was a three-minute video clip (hereafter “Tosa Art”) derived from the Sound of Ikebana. This artwork was selected because it is based on reproducible physical phenomena and can be adjusted by modifying parameters such as fluid type and sound frequency, allowing for consistent and controlled experimental conditions. Figure 3 shows a scene from the Sound of Ikebana.

For detailed descriptions of the creative process and parameter variations, please refer to our previous publications [7][8].



Fig. 3 A scene from “Sound of Ikebana”

3.4 Comparative Content

When conducting evaluation experiments using art content, preparing content for comparison with the art content 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 through psychological experiments, we used geometric figure content whose shape changes to circles and squares in sequence with color as the comparison content with art content [9].

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. 4).

- (1) First, after briefly explaining the purpose and content of the experiment, a subject signed a consent form.
- (2) The subject then moves into the immersive space.
- (3) After moving to the immersive space, the subject performs an initial psychological evaluation using Google Forms.
- (4) Before displaying Content 1, a resting period of 3 minutes 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 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).
- (8) Content 2, with a 3-minute duration, is displayed, and physiological data is measured (“Art” or “Figure” hereafter).

- (9) After viewing Content 2, the subject completes a third psychological evaluation.
- (10) At the end of the experiment, the subject exits the immersive space.

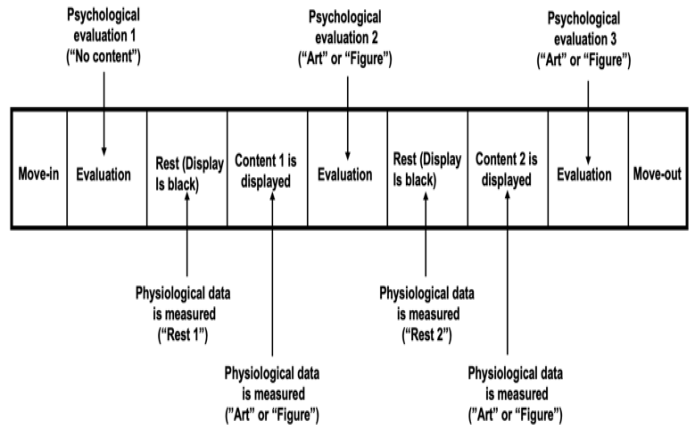


Fig. 4 Experimental procedure

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 measured on 40 subjects, of whom only 22 could successfully measure all three data types. In Immersive Space 2, out of 52 subjects, 39 were successfully measured with all three data types. Since we want to analyze the relationship between the ECG, EEG, and skin potentials, we limited our analysis to subjects for which all three data types could be measured. In this paper, we focus on the ECG data.

4.2 Analysis Methods for ECG Data

Figure 5 shows the basic shape of the ECG data.

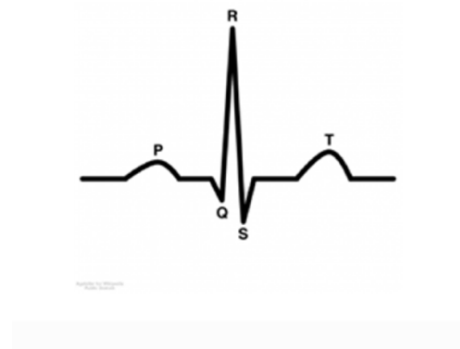


Fig. 5 Shape of ECG

Heart rate variability, the periodic fluctuation of the interval between adjacent R waves (RRI) obtained from this, reflects autonomic nervous 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, in the present study, we averaged the data. 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 affected by the content (Figure or Art) viewed immediately before Rest 2, we excluded them. We used only Rest 1 (hereinafter referred to as Rest) to compare the three conditions of 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 6 through 9 show the results of averaging and further analysis of variance (ANOVA) on subjects for SSDN, RMSSD, pNN50, and HF, which indicate parasympathetic activity.

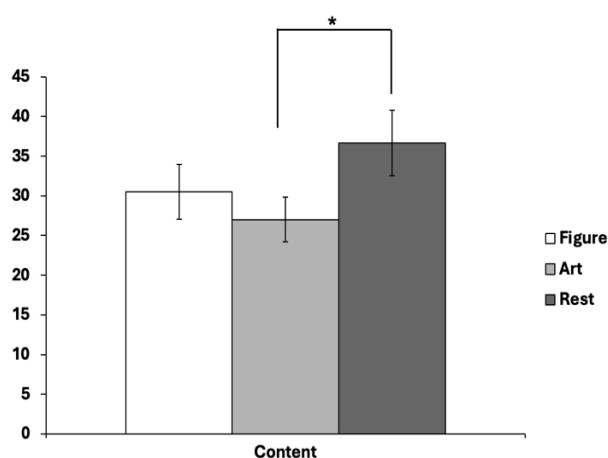


Fig. 6 Mean and ANOVA results for SSDN

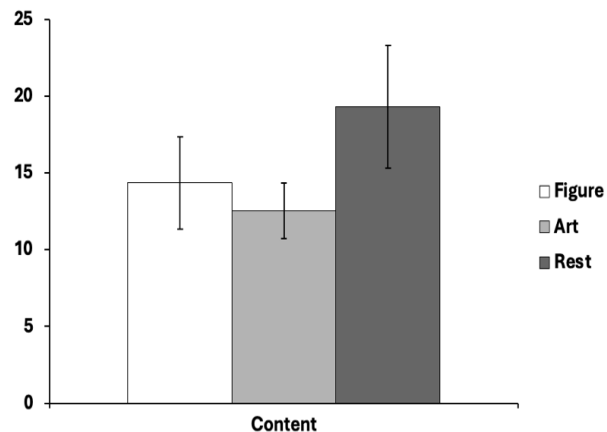


Fig. 7 Mean and ANOVA results for RMSSD

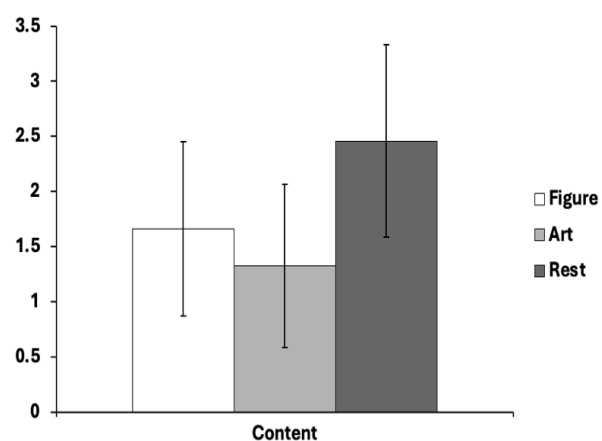


Fig. 8 Mean and ANOVA results for pNN50

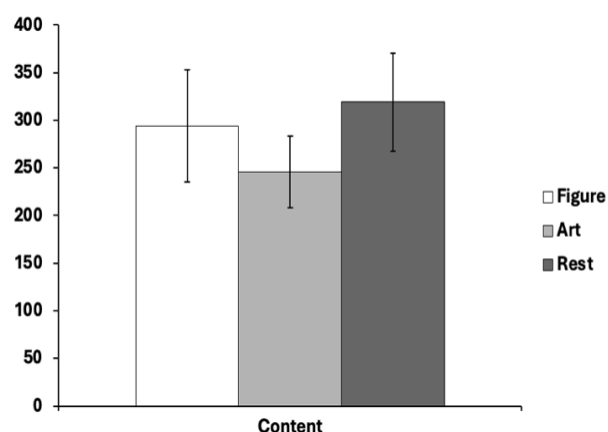


Fig. 9 Mean and ANOVA results for HF

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 relaxation state and mental flexibility. These lower values suggest that subjects were less able to achieve an internal sense of calm and immersion because of the visual complexity and reflection of Immersive Space 1. As a result, parasympathetic activity due to the inherent 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 10 shows the results for LF/HF, which indicates sympathetic activity.

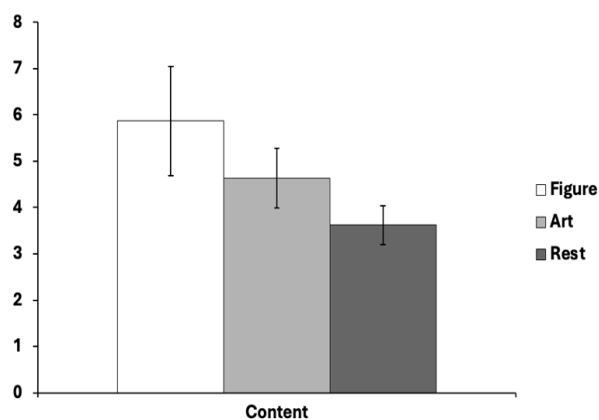


Fig. 10 Mean and ANOVA results for LF/HF

The LF/HF ratio in Art is an intermediate value between Figure and Rest. 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 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, the ANOVA results indicate no significant differences between Art, Figure, and Rest, suggesting considerable individual variation.

4.3.2 Analysis of Immersive Space 2

Figures 11 through 14 show the results of averaging and further analysis of variance (ANOVA) on subjects for SSDN, RMSSD, pNN50, and HF, which indicate parasympathetic activity.

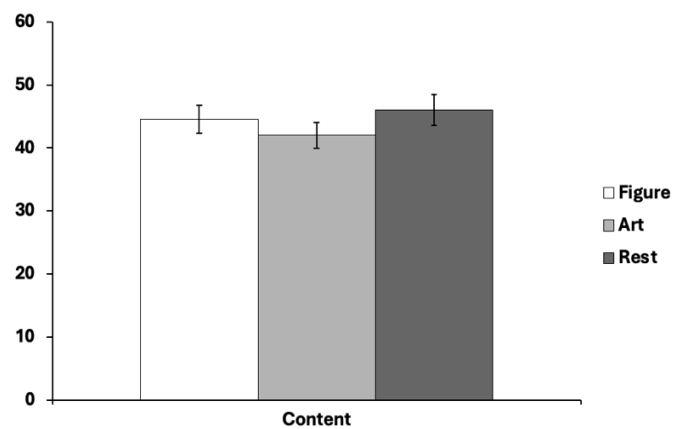


Fig. 11 Mean and ANOVA results for SSDN

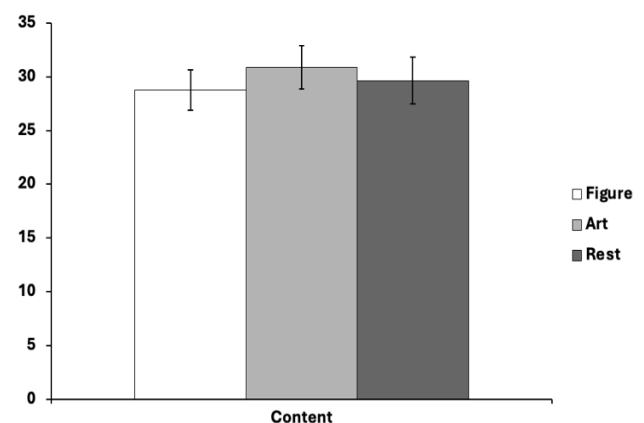


Fig. 12 Mean and ANOVA results for RMSSD

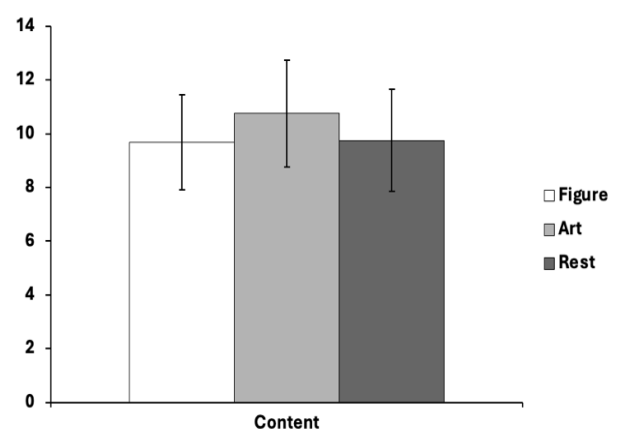


Fig. 13 Mean and ANOVA results for pNN50

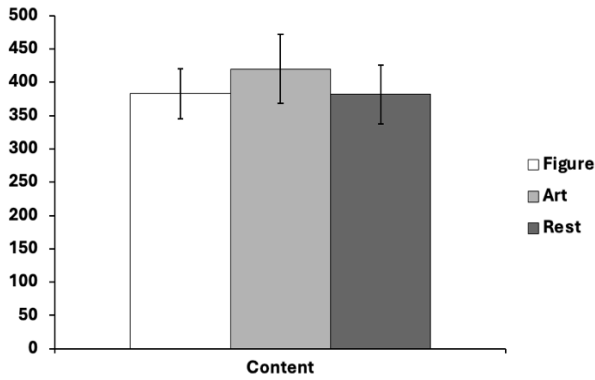


Fig. 14 Mean and ANOVA results for HF

These considerations are as follows.

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 a safe and secure spatial experience. As a result, heart rate flexibly varied, and deep, regulated breathing became possible, indicating that parasympathetic nervous system function was fully activated.

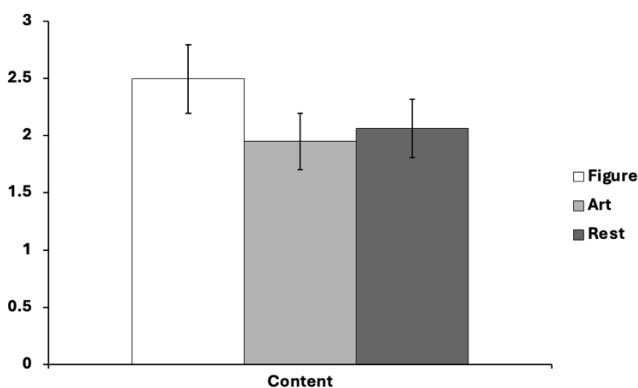


Fig. 15 Mean and variance analysis results for LF/HF

Figure 15 shows results for LF/HF, which indicate sympathetic activity. Below is the discussion.

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 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, similar to Immersive Space 1, the lack of significant differences between Art, Figure, and Rest across all indicators suggests that further detailed analysis, such as individual differences, is necessary.

5 Conclusion

This study explored how different immersive environments influence the physiological state of viewers 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 OLED 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 response to art, even when the same content is presented. 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 [5]. The divergence between physiological and psychological responses is examined in detail in a separate paper submitted by the authors, focusing on the layered nature of aesthetic experience [10].

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