

Construction of Immersive Art Space Using Mirror Display and Its Evaluation Through Heart Rate Measurements

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Abstract

This study, conducted at Kyoto University, explores the construction of an immersive art space using a mirror display and evaluates its impact through heart rate measurements. The research integrates Naoko Tosa's media art, which captures the hidden beauty in nature, into an immersive space surrounded by mirrors. This unique setting aims to blur the boundaries between art and viewer, offering a more natural and less device-dependent immersive art experience.

The study involved 43 Kyoto University students, with ECG data collected during normal and art viewing states. Using Poincaré plots, the study analyzed changes in heart rate variability and other physiological markers. The results showed significant emotional and physiological changes in viewers, with approximately half experiencing clear immersion in the art pieces.

This research contributes to the field of immersive art experiences by employing Naoko Tosa's unique aesthetic and scientific approach to art and using innovative mirror display technology. It offers insights into the psychological and physiological effects of art on viewers, with potential applications in various fields. However, the study acknowledges the need for caution in generalizing results and the importance of further research in diverse settings.

Key Word

Immersive Art, Mirror Display Technology, Heart Rate Variability (HRV), Physiological Data Analysis, Art and Emotion, ECG (Electrocardiogram) Data, Poincaré Plots, Viewer Immersion Experience, Art and Technology Integration

1. Introduction

1.1 Research Background

In contemporary immersive art experiences, advanced technologies such as virtual reality (VR) and augmented reality (AR) enable artists to access new creative methodologies beyond traditional physical constraints. Utilizing such technologies, the form of art expression transforms into multidimensional, dynamic, and interactive modalities.

However, implementing immersive art experiences using VR and AR necessitates the use of specific devices, which can be obtrusive and restrict movement, requiring a degree of acclimatization to the devices for a truly immersive experience. Therefore, we hypothesize that spaces themselves, transformed by art, can more naturally blur the boundaries between space and individuals. Such spaces, diminishing the demarcation between art and the viewer, become a crucial element in fostering new forms of art and expanding the horizons of creativity. Immersive art experiences are believed to initiate a new wave of creativity in the realm of art, offering innovative experiences for both artists and observers.

Furthermore, immersive art experiences hold various significant social implications. For instance, in educational settings, utilizing such experiences enables learners to engage in experiential learning, which is not achievable through traditional textbooks and lectures. This approach can enhance motivation for learning, deepening understanding of art and stimulating interest in culture and history. Immersive art experiences are also beneficial in promoting cultural inclusivity. They provide new forms of art access to people from diverse cultural backgrounds, facilitating shared experiences that transcend cultural barriers and deepen cross-cultural understanding.

However, to apply these immersive art experiences to solve societal challenges, more participant data is needed. This study creates a unique space using a mirror display to facilitate immersive art experiences for participants, collecting and analyzing their physiological data.

The art content utilized in this research is the media art of Naoko Tosa. Tosa's art, known for capturing the hidden beauty in nature and providing viewers with a sense of infinite space, is considered highly suitable for creating the desired immersive art experience. Through this study, we aim to analyze the changes in states experienced by viewers during immersive art experiences compared to normal conditions. Anticipating the potential changes in viewers, we aspire to contribute to applications in various fields.

1.2 Outline

In this study, Chapter 2 will delve into Tosa Art, recent research on immersive art experiences, physiological data analysis of art experiences, and the relationship between art and emotions. It will discuss how this research addresses existing gaps in the literature and aims to provide new insights. Chapter 3 will touch upon the research methodology. This includes details about the mirror display used in the experiments, the experimental procedures, information about the participants, the data collected, and the methods used for data analysis. Chapter 4, the results section, will present the data, perform statistical analysis, and discuss the observed trends and patterns. Chapter 5 is the discussion part, where the interpretation of results, their relation to the literature review, and the significance and impact of the research will be explored. Finally, Chapter 6, the conclusion part, will discuss the study's main findings, limitations, and proposals for future research.

2. Literature Review

2.1 Tosa Art

One of the authors, Naoko Tosa, is renowned for her creation of media art utilizing cutting-edge technology. Her works specialize in capturing the hidden beauty within natural and physical phenomena using high-speed cameras (Tosa, 2016). She has a particular interest in the behavior of fluids, visualizing movements not typically visible to the naked eye by capturing their dynamics with high-speed cameras. This field, known as fluid dynamics, has been the subject of extensive academic research. The visualization of fluid motion fascinates many due to its beautiful movements, attracting attention not only from a scientific perspective but also an artistic one (Tosa, 2023; Pamg, 2017).

Tosa's work distinguishes itself from the broader research in fluid dynamics. While general studies on fluid visualization focus on capturing stable fluid behavior, Tosa challenges herself to capture the art in unstable and unpredictable fluid movements. Through this approach, she provides viewers with a novel visual experience, expressing the deep beauty and complexity hidden in fluid motions. Her work blurs the boundaries between science and art, demonstrating how these two fields can interact.

The reason for selecting Naoko Tosa's media art in this study is due to the unique aesthetic and scientific background of her work, which we believe is highly suitable for research in immersive art experiences. Her work captures the beauty hidden in natural phenomena, offering viewers a sense of infinite space and deep emotion. These characteristics play a crucial role in the creation of immersive art experiences that this study aims to achieve. Through Tosa's work, viewers can discover new aspects of natural phenomena and enjoy a unique experience born from the fusion of art and science. Such experiences are thought to

expand viewers' perceptions and deepen the understanding of the impact of immersive art experiences.

2.2 Immersive Art Experience

Immersive art experiences refer to situations where viewers deeply interact with artworks and exhibitions. This field, situated at the intersection of art, technology, and psychology, has evolved significantly with recent technological advancements. This section explores prior research on immersive art experiences, elucidating their historical development and significance in research. The concept of immersive art experiences is believed to have originated from installation art in the 1960s. Kaprow (1966) explored the immersive aspects of art experiences through 'Happenings' that emphasized the interaction between the environment and the viewer (Kaprow, 1966). These early experiments aimed to remove physical barriers between the artwork and the viewer, integrating the viewer into the art. Entering the 1990s, with technological advancements, the concept of immersive art took on a new dimension. Marín-Morales (2019) notes that with the introduction of virtual reality (VR) technology, artists could immerse viewers in entirely different environments (Marín-Morales, 2019). This transition allowed art experiences to evolve from purely visual to multisensory. The new concept of immersive art is considered to have a significant impact on individuals, and since then, psychological aspects of how immersive art experiences affect viewers' cognition and emotions have been actively studied. Grau (2003) researched how VR-based artworks alter viewers' emotional responses, showing that immersive art evokes strong emotional reactions in viewers (Grau, 2003).

Currently, immersive art experiences are becoming even more diverse. Recent studies incorporate augmented reality (AR) and interactive installations, allowing viewers to interact more dynamically with artworks. Guerra-Tamez (2023) discovered that interactive artworks stimulate viewers' creativity and inquisitiveness. The research on immersive art experiences goes beyond traditional understandings of art, delving deeply into the impacts of art on human emotions, cognition, and society (Guerra-Tamez, 2023). This field, promoting the fusion of art and science, holds the power to fundamentally change our perception of art by exploring new creative possibilities (Guerra-Tamez, 2023). However, there are still many challenges in providing pure immersive art experiences. One such challenge is the constraints associated with device wear. The use of VR or AR devices can affect viewers' movements and sensory experiences. Ito (2021) studied the physical discomfort and unease felt by viewers when wearing head-mounted displays (HMDs), noting how this can impact the quality of immersive experiences (Ito, 2021). The weight, size, and the hassle of wearing these devices can also act as barriers to immersive

experiences. Kim & Lee (2019) state that first-time users of VR devices need time to become accustomed to the operation, and initial discomfort during this phase can degrade the quality of the experience (Kim & Lee, 2019). This acclimatization process is an important consideration when using such devices. The ongoing trial and error in modern technology to achieve complete immersive art experiences is noteworthy. Pyun (2022) is advancing research to improve the quality of immersive experiences through the development of lighter and more comfortable devices and interface improvements. Research is also being conducted on alternative methods to realize immersive experiences without devices, with the hope that more natural immersive experiences will be possible in the future (Pyun, 2022). This study addresses gaps in existing research on immersive art experiences with our newly developed device. We analyze the impact of the immersive space created using the mirror display on viewers, contributing to the realization of complete immersive art experiences and their application in various fields.

2.3 Analysis of physiological data

The analysis of physiological data is a crucial means of quantitatively assessing the impact of immersive art experiences. This analysis can elucidate how viewers' experiences affect them psychologically and physiologically. However, collecting and analyzing physiological data presents challenges due to its complexity and the precision required. Particularly, time-series analysis is essential for accurately capturing data variations and understanding the dynamic changes in viewers' responses. Collecting physiological data is one of the more challenging aspects of research due to its complexity and the precision required. According to Smith et al. (2018), physiological data such as heart rate and skin conductance can vary significantly due to environmental factors and the individual's physiological and psychological state (Smith et al., 2018). Therefore, rigorous experimental design and advanced measurement techniques are essential for accurate data collection and analysis. In this study, we conducted advanced ECG (Electrocardiogram) measurements with the cooperation of Shimadzu Corporation. Shimadzu is a company highly regarded in the field of precision measurement instruments, and its technological expertise greatly contributed to the accuracy of our research. Specifically, Shimadzu's ECG measuring instruments can capture minute changes in electrocardiograms with high precision, making them ideal for tracking in detail how participants respond to immersive art experiences. The use of these advanced measuring instruments allowed us to capture participants' psychological and physiological responses more accurately, unaffected by environmental changes or individual differences. On the other hand, time-series analysis of physiological data is crucial to capture the dynamic changes in psychological and

physiological responses of viewers and to understand how these changes relate to specific elements of the experience. For instance, a study by Matthews et al. (2016) used HRV analysis to track the autonomic nervous system's responses of viewers when they were in specific stress or emotional states over time. This research clarified how viewers' emotional responses and stress levels are related to particular elements of their experience. While time-series analysis can reveal the relationship between specific elements and changes in viewers, it also presents difficulties in handling due to the complexity, diversity, noise, and the amount of data involved. Moreover, physiological data are susceptible to influences from stress, emotional states, physical activity, and even daily activities like sleep and diet, requiring careful analysis to accurately discern the dynamic changes in psychological and physiological responses of viewers in relation to specific elements of the experience. In this study, we chose to use Poincaré plots to comprehensively analyze the RRI (R-R interval, i.e., the interval between heartbeats) as time-series data.

2.4 Identifying Research Gap

Based on the foregoing, this study addresses gaps in previous research in the following ways. Primarily, by utilizing the media art of Naoko Tosa, we focus on filling the gaps in research on immersive art experiences. Tosa's work is known for capturing the hidden beauty in natural phenomena, providing viewers with a sense of infinite space and profound emotion, playing a vital role in creating immersive art experiences. Previous studies have lacked research on immersive experiences using art with such unique aesthetics and scientific background. Additionally, in response to the challenges of realizing complete immersive art experiences with modern technology, this study employs a newly developed mirror display space. Using this innovative device adds a new dimension to the research on immersive art experiences and allows for a comprehensive analysis of the impact on viewers. This contributes to a deeper understanding of how art experiences affect viewers' psychological and physiological responses, aiming to expand the potential applications of immersive art experiences. Furthermore, in the analysis of physiological data, we conduct a comprehensive analysis of time-series data, keeping in mind the complexities, diversity, and noise issues associated with such data. Using Poincaré plots for the time-series analysis of the R-R intervals (RRI), we aim to understand the physiological responses of viewers. Thus, this study overcomes the gaps in research on immersive art experiences, aiming to provide new insights.

3. Methodology

3.1 Research Design

This study analyzes the changes that occur in viewers undergoing immersive art experiences compared to their normal state, using ECG (Electrocardiogram) data. We proceeded with the analysis under the hypothesis that significant changes would be observed in the viewers' heart rate and ECG data during the immersive art experience compared to their normal state. In this study, we opted to avoid the use of common headsets in VR or AR, and instead employed a mirror display space to provide a deeper immersive art experience. To further explore the potential of creativity in art, we developed a special immersive space surrounded by mirrors. The mirror display, which combines the functions of mirrors and display screens, has been commercialized by several companies. The one we used is developed by AGC Inc. and commercialized under the name "Mirroria" [Mirroria]. A key feature of this display is its use of the company's glass manufacturing technology to achieve a half-mirror reflectance rate of about 65%, equivalent to that of a regular mirror. Part of this space functions as a display screen. As shown in Figure 2, this hexagonal space is fitted with three sets of opposing mirrors, creating the illusion of infinite reflections. Covering the ceiling and floor with mirrors further amplifies this effect. The six main mirrors installed in this space have the capability to display images, and as shown in Figure 2, their vertical length exceeds the actual display area. By adjusting the display position, it is possible to prevent overlapping of images while maintaining the illusion of infinite reflections. Initially, data was collected during a normal three-minute period, followed by a three-minute viewing of Tosa Art within this space, and ECG data was measured for each period.

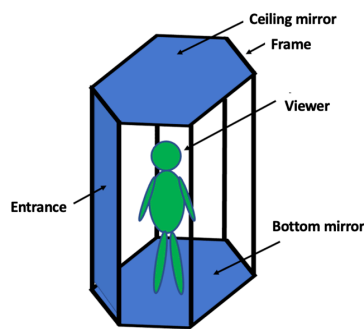


Figure 1: Conceptual diagram of immersed space

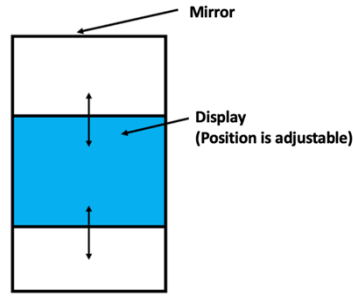


Figure 2: Configuration of individual mirror displays

3.2 Data collection method

In this study, we collected Electrocardiogram (ECG) data from 43 students at Kyoto University. The process involved data collection in two different states for each participant: a normal state (baseline) and while viewing an art piece. Data collection for each state lasted for three minutes, meticulously recording variations in heart rate and ECG.

During the data collection process, participants were fitted with ECG measuring devices, and data was gathered in a relaxed environment to capture physiological responses both during baseline and while observing the art piece. Careful preparation and meticulous measurement were conducted to ensure the comfort of the participants and the accuracy of the data.

After data collection, an analysis based on the quality, completeness, and reliability of the data revealed that the data from 22 out of the 43 participants were accurate and analyzable. Therefore, the final analysis was conducted based on the ECG data of these 22 participants.

3.3 Analytical method

In this study, RRI (R-R Interval) data were extracted from the collected ECG data, and the initial step involved creating Poincaré plots. In these plots, RRI_i (the R-R interval at a given time point) was plotted on the x-axis, and RRI_{i+1} (the R-R interval at the next time point) on the y-axis. This method was applied to the entire dataset. For this analysis, instead of using statistical methods like t-tests on the entire dataset, we focused on classifying and observing trends based on individual data characteristics. This approach was chosen because physiological data can vary significantly due to individual characteristics, health status, age, and gender, making it challenging to adequately consider these personal differences when analyzing the entire dataset collectively. Therefore, detailed analysis was conducted on each participant's Poincaré plot. Initially, SD1 (the standard deviation of the short axis) and SD2 (the standard deviation of the long axis) were calculated, indicating short-term heart rate

variability and long-term variability, respectively, and are associated with parasympathetic activity and autonomic nervous system regulation capabilities. Additionally, measures such as variance (X-axis), variance (Y-axis), density, central position, and branching structure were calculated. These metrics were evaluated based on the rate of change relative to the resting (rest) state, from which the state of the Poincaré plots was determined, facilitating the classification and interpretation of results.

4. Result

4.1 Presentation of collected data

In this study, immersive art experiences using a mirror display were conducted with 43 students from Kyoto University. During these experiences, participants viewed art pieces by Naoko Tosa in a unique space combining mirror and display functionalities. To measure participants' physiological responses, ECG (electrocardiogram) data were recorded for 3 minutes each during both rest and viewing periods. From this data, an analysis was conducted to determine how participants' physiological states changed during the immersive art experience.

Upon data validation, it was found that only ECG data from 22 participants were suitable for analysis due to issues such as noise. Particularly, the analysis focused on RRI (R-R interval), which represents the time interval between R waves, the most prominent part of the ECG waveform, indicating cardiac contractions (the heart pumping blood throughout the body).

RRI variability, also known as heart rate variability (HRV), is widely used as an indicator of autonomic nervous system balance. High HRV generally indicates a healthy autonomic nervous system, while low HRV suggests stress. Given that this characteristic aligns with the objectives of this study, RRI was adopted as the focus of analysis.

As a result, RRI data were obtained for 22 participants for both rest and art viewing periods, each lasting 3 minutes, as depicted in Figure 3.

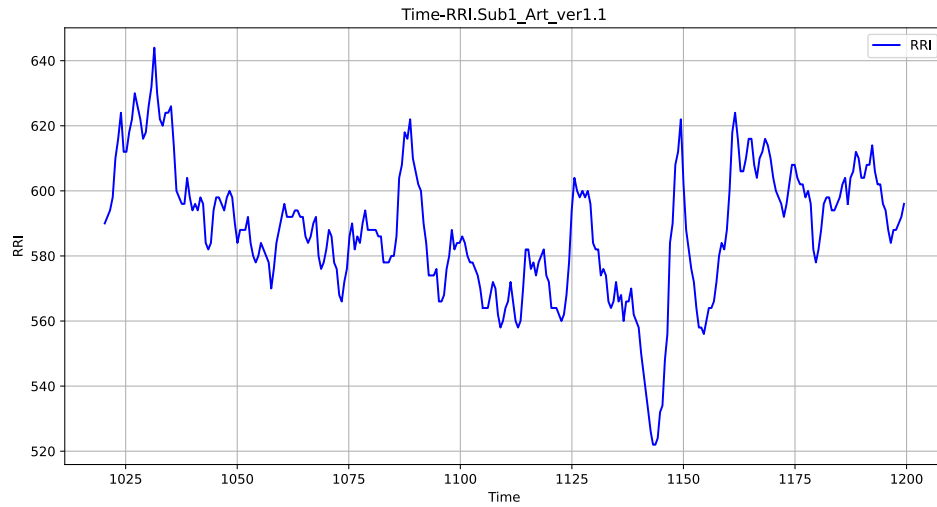


Figure 3:RRI time series data

4.2 Statistical analysis and visualization

In this study, we utilized Poincaré plots to analyze the nonlinear characteristics of RRI (R-R interval). While Poincaré plots have limitations in capturing dynamic changes at specific time points or direct associations with specific elements of an experience, they are highly effective in interpreting particular shapes or patterns of heart rate variability. Moreover, this method enables analysis that accounts for individual differences among participants. The collected RRI data from 22 participants were transformed into Poincaré plots, as shown in Figure 4, and the results were analyzed accordingly.

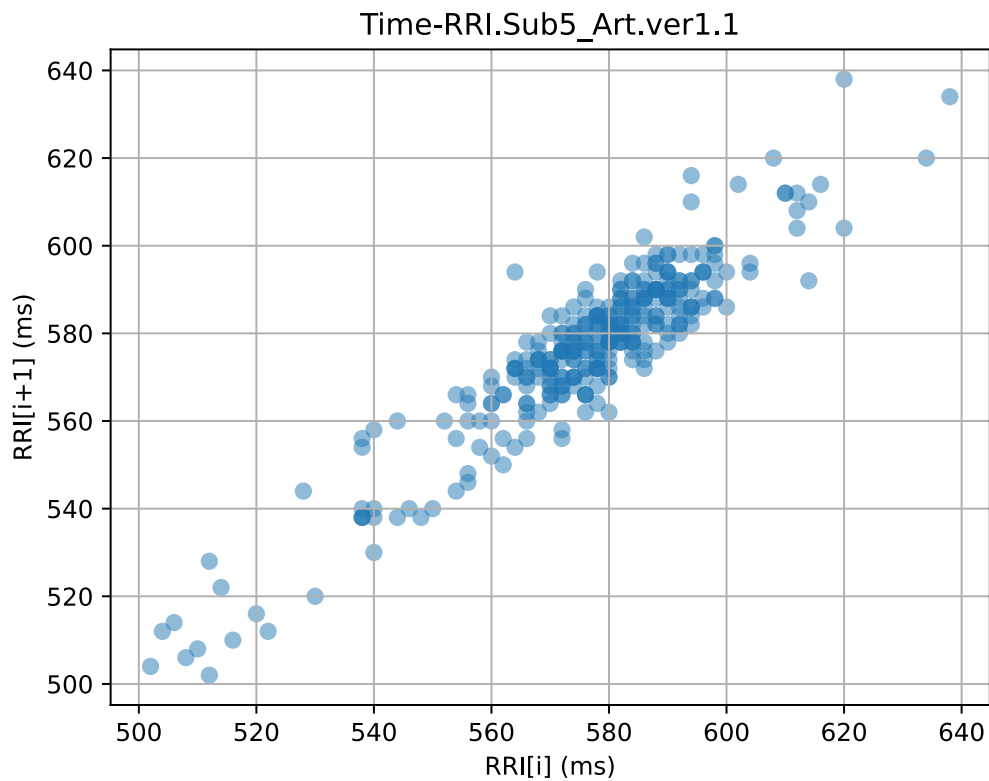


Figure 4 : Poincaré plot

The data extracted from Poincaré plots of each participant in this study encompassed eight parameters: SD1 (standard deviation of short-axis) reflecting short-term fluctuations of heartbeats predominantly influenced by parasympathetic activity, SD2 (standard deviation of long-axis) indicating longer-term variations in heartbeats primarily representing autonomic regulatory capacity, variance (X-axis), variance (Y-axis), density, centroid position (x-coordinate & y-coordinate), and branching structure. These metrics were evaluated in terms of changes from the resting state, focusing on the rate of change from baseline conditions.

Variance, depicting the range of heart rate variability, suggests significant emotional fluctuations if it spreads widely, while a smaller variance may enhance the regularity of heartbeats, potentially stabilizing them. Density indicates variations in heart rate variability (HRV) responses, where high density implies relatively consistent heart rate intervals, possibly reflecting stable emotional or cognitive responses, or a subdued state. Conversely, low density suggests significant fluctuations in heart rate intervals, indicative of strong emotional or cognitive reactions.

Centroid coordinates represent the average of consecutive heart rate intervals (R-R intervals).

A higher centroid position (i.e., longer average R-R intervals) implies longer average heart rate intervals (slower heartbeats) and greater variability between consecutive heart rate intervals, potentially indicating increased parasympathetic activity reflective of relaxation or a relaxed state. Conversely, a lower centroid position (shorter average R-R intervals) implies shorter average heart rate intervals (faster heartbeats) and reduced variability between consecutive heart rate intervals, suggesting increased sympathetic activity.

Lastly, an increase in branching structure on the Poincaré plot (i.e., more diverse points appearing) signifies increased complexity in heart rate variability, potentially indicating heightened emotional responses or mental activity. Conversely, a decrease in branching structure on the Poincaré plot (i.e., fewer different points appearing) suggests a relaxing effect and increased regularity in heart rate, possibly reflecting a state of relaxation.

Figures 5 to 10 depict the rate of change from the resting state for each parameter across all participants. Scatter plots were utilized for variance and centroid coordinates, showing the x-coordinate and y-coordinate relationships, respectively.

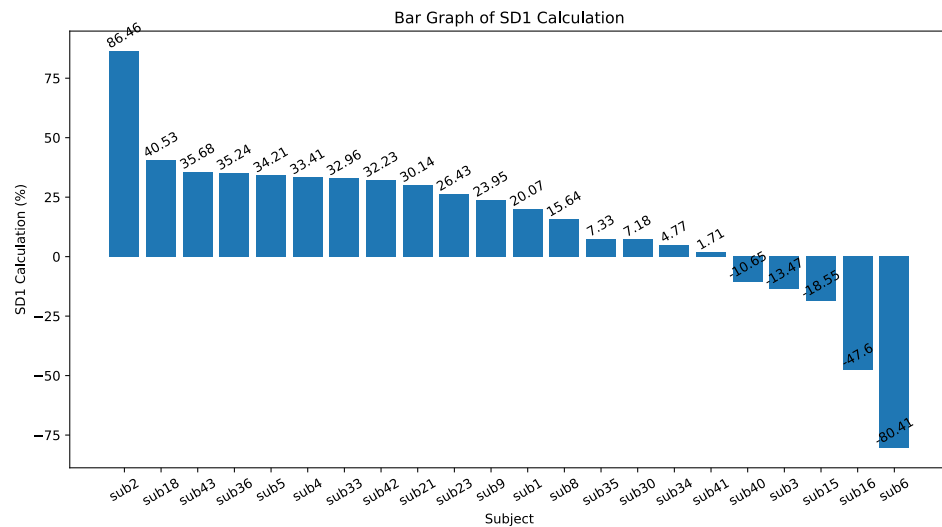


Figure 5: Change in SD1 from Rest to Art Observation

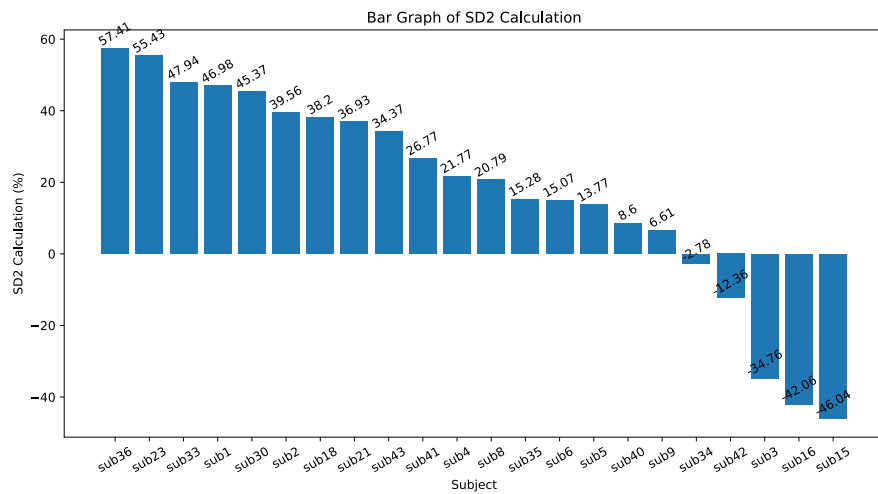


Figure 6: Change in SD2 from Rest to Art Observation

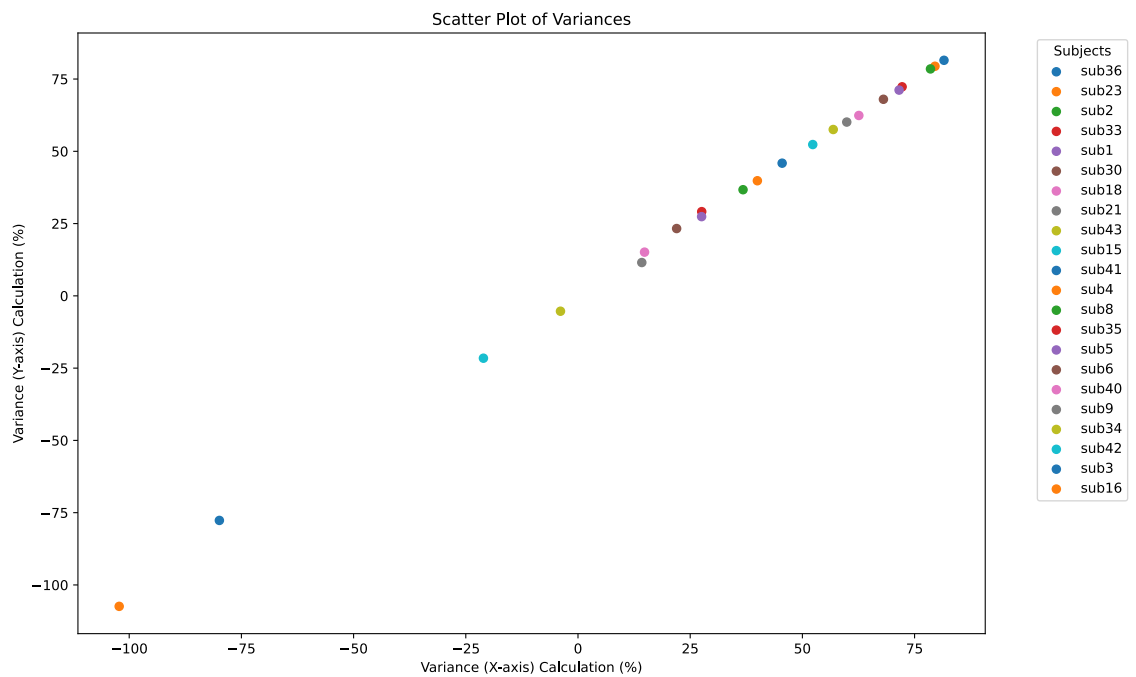


Figure 7: Change in variances from Rest to Art Observation

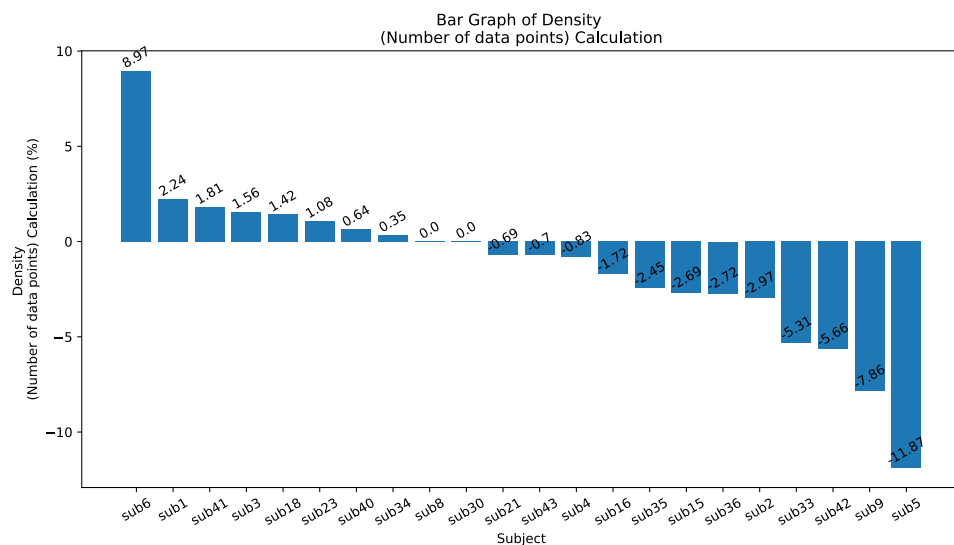


Figure 8: Change in density from Rest to Art Observation

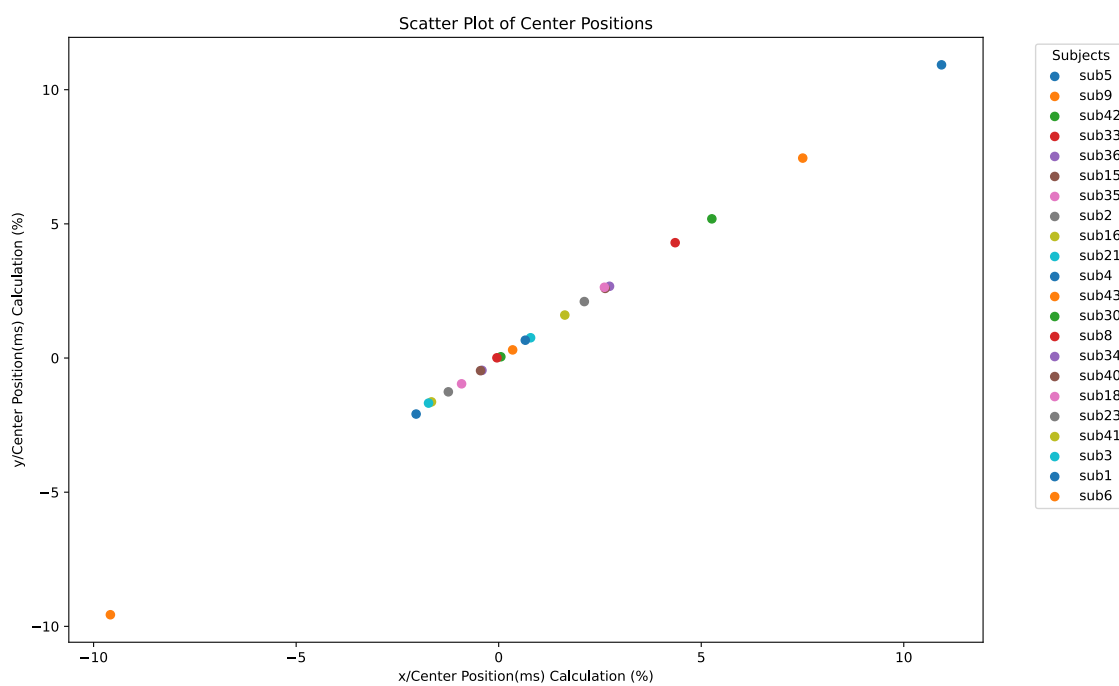


Figure 9: Change in Center Positions from Rest to Art Observation

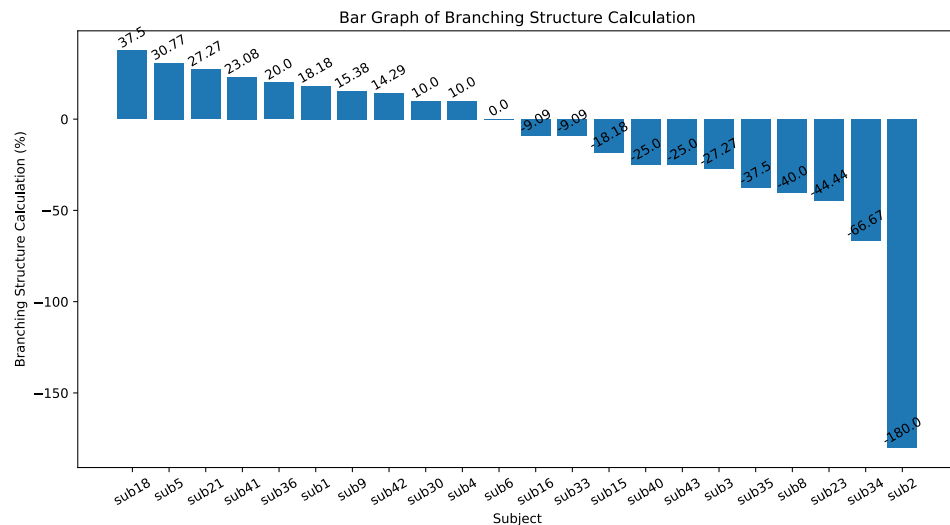


Figure 10 :Change in Branching Structure from Rest to Art Observation

4.3 Description of observed trends and patterns

As a general trend, it cannot be denied that various factors such as the psychological state and physical characteristics of individual participants, personal preferences and experiences with art, as well as the daily physiological and mental state, may influence the outcomes. However, notable differences were observed in the comparison between the resting state (rest) and the art appreciation state (art). Specifically, for instance, in both SD1 and SD2, 15 out of the total 22 participants showed an increase compared to the resting state. Furthermore, distortions in the rate of change for SD1 and SD2 were observed in four participants. Specifically, two participants exhibited negative SD1 and positive SD2 values: participant sub6 (SD1: -47.6, SD2: 15.07) and participant sub40 (SD1: -10.65, SD2: 8.6). Conversely, two participants displayed positive SD1 and negative SD2 values: participant sub42 (SD1: 32.23, SD2: -12.36) and participant sub34 (SD1: 4.77, SD2: -2.78). Additionally, three participants showed negative values for both SD1 and SD2: participants sub3, sub15, and sub16. Analyzing the results regarding variance, participant sub43 showed minimal change, while decreases in variance were observed in participants sub3, sub16, and sub42. Significant increases were noted in the remaining 18 participants. Next, the analysis of density changes on the Poincaré plot revealed that eight participants demonstrated an increase in density compared to the resting state, two participants showed no change, and the remaining 12 participants exhibited a decrease. Considering changes of less than 1% as negligible, seven participants showed no change, six increased, and nine decreased. Subsequently, a detailed examination of centroid position changes on the Poincaré plot was conducted. Scatter plots were created with the change rates of x-coordinate plotted on the x-

axis and the change rates of y-coordinate plotted on the y-axis. This analysis revealed that the increase or decrease rates of x-coordinate and y-coordinate were nearly identical. Considering changes of less than 1% as negligible, eight participants showed minimal change, nine exhibited an increase, and five demonstrated a decrease. Finally, the results regarding branching structure on the Poincaré plot were examined. The analysis of branching structure showed an increase in ten participants compared to the resting state. However, participant sub6 did not show significant changes between the resting and art appreciation states. Furthermore, decreases compared to the resting state were observed in eleven other participants, with participant sub2 showing a particularly large decrease of -180% compared to others.

5. Discussion

5.1 Interpretation of results

The results of this study suggest several important points regarding the influence of art appreciation on the psychological and physiological states of the viewers. First, focusing on the indices of heart rate variability, SD1 and SD2, it was observed that 15 participants showed an increase in both SD1 and SD2 during art appreciation compared to the resting state. SD1 represents short-term fluctuations in heart rate, while SD2 reflects the magnitude of long-term heart rate variability. This suggests that approximately 68% of the participants exhibited strong emotional responses such as joy, surprise, excitement, or anxiety to artworks both in the short and long term. Furthermore, three participants who showed negative values for both SD1 and SD2 were found to be relaxed both in the short and long term during art appreciation. Additionally, among the four participants where distortions in the rate of change for SD1 and SD2 were observed, those with positive SD1 and negative SD2 tended to be relaxed in the long term despite experiencing intense emotions in the short term, while those with negative SD1 and positive SD2 tended to be relaxed in the short term but experienced intense emotions in the long term.

Regarding the changes in variance on the Poincaré plot, which indicates the spread of RR interval (RRI) data and helps understand the characteristics of heart rate variability, an increase in variance was observed in 18 participants. These viewers may be showing strong emotional reactions to artworks or being emotionally aroused. On the other hand, three participants (sub3, sub16, sub42) showed a decrease in variance, indicating that their RR interval data points were relatively concentrated on the Poincaré plot, suggesting minimal heart rate variability and implying emotional stability or a relaxed psychological state while appreciating art. These participants exhibited negative values for both SD1 and SD2, supporting the notion of a relaxed state during art appreciation.

Concerning changes in density, high density suggests relatively constant heart rate intervals and stable emotional and cognitive responses, while low density implies significant fluctuations in heart rate intervals and intense emotional or cognitive responses. When considering changes of less than 1% as negligible, seven participants showed no change, six increased, and nine decreased in density. Notably, participants with increased density, especially participant sub6, exhibited a significantly large increase. This suggests a relaxed state during art appreciation, as evidenced by a substantial decrease in SD1, representing short-term heart rate variability, compared to other participants.

Conversely, the decrease rate showed greater changes than the increase rate, indicating that artworks may induce strong emotional or cognitive responses. Particularly, those who experienced a decrease in density suggested significant emotional or cognitive fluctuations during art appreciation, implying that artworks may evoke profound emotional experiences in viewers.

Regarding changes in the centroid position on the Poincaré plot, it was evident that the change rates of x-coordinate and y-coordinate were nearly identical. This suggests a consistent influence of art appreciation on the balance of heart rate variability. Specifically, when the centroid position moves to the upper right on the scatter plot, indicating longer average heart rate intervals (slower heart rate) and larger differences in consecutive heart rate intervals, viewers may be relaxed but experiencing emotional responses or short-term stress reactions simultaneously. Conversely, moving the centroid position to the lower left suggests shorter average heart rate intervals (faster heart rate) and smaller differences in consecutive heart rate intervals, indicating that viewers may feel stressed and excited but exhibit relatively little short-term heart rate variability, suggesting emotional stability. Analyzing the scatter plot positions, eight participants showed minimal change, while nine moved to the upper right and five moved to the lower left. Particularly, participants with a significant decrease in density (e.g., sub5, sub9, sub42) moved significantly to the upper right, indicating large momentary emotional fluctuations.

Finally, the analysis of branching structure on the Poincaré plot suggests that complex branching structures indicate diverse and unpredictable changes in heart rate intervals. Such complexity may imply healthy cardiac function and adaptive autonomic nervous system responses. The presence of complex branching structures during art appreciation suggests that viewers may exhibit emotionally rich responses and vigorous cognitive activities, reflecting deep emotional experiences or immersion induced by artworks. Conversely, participants with simple or linear branching structures may indicate relatively regular and predictable heart rate variability, suggesting a relatively stable emotional state or consistent emotional responses during art appreciation. Among the 22 participants, 10 showed an

increase in branching structures compared to the resting state, while 11 showed a decrease, with participant sub2 exhibiting a particularly significant decrease compared to others. These results serve as important indicators of immersion experience, suggesting that immersion in Tosa art with its intricate movements induces diverse emotional fluctuations. In just three minutes of art appreciation, nearly half of the participants experienced an increase and complexity in branching structures, indicating that the mirror display space created in this study could provide an excellent immersive experience.

subject	immersive experience	emotional condition	emotional stability	SD1	SD2	Variances	Density	Center Position
sub1	Immersion	Excited	Stable	Increase	Increase	Increase	Increase	left-lower
sub2		Excited	Stable	Increase	Increase	Increase	Decrease	right-upper
sub3		Relax	Fluctuating	Decrease	Decrease	Decrease	Increase	left-lower
sub4	Immersion	Excited	Stable	Increase	Increase	Increase	Almost no change	Almost no change
sub5	Immersion	Excited	Stable	Increase	Increase	Increase	Decrease	right-upper
sub6		Excited	Stable	Decrease	Increase	Increase	Increase	left-lower
sub8		Excited	Stable	Increase	Increase	Increase	Almost no change	Almost no change
sub9	Immersion	Excited	Stable	Increase	Increase	Increase	Decrease	right-upper
sub15		Excited	Fluctuating	Decrease	Decrease	Increase	Decrease	right-upper
sub16		Relax	Fluctuating	Decrease	Decrease	Decrease	Decrease	right-upper
sub18	Immersion	Excited	Stable	Increase	Increase	Increase	Increase	Almost no change
sub21	Immersion	Excited	Stable	Increase	Increase	Increase	Almost no change	Almost no change
sub23		Excited	Stable	Increase	Increase	Increase	Increase	left-lower
sub30	Immersion	Excited	Stable	Increase	Increase	Increase	Almost no change	Almost no change
sub33		Excited	Stable	Increase	Increase	Increase	Decrease	right-upper
sub34		Relax	Fluctuating	Increase	Decrease	Decrease	Almost no change	Almost no change
sub35		Excited	Stable	Increase	Increase	Increase	Decrease	right-upper
sub36	Immersion	Excited	Stable	Increase	Increase	Increase	Decrease	right-upper
sub40		Excited	Stable	Decrease	Increase	Increase	Almost no change	Almost no change
sub41	Immersion	Excited	Stable	Increase	Increase	Increase	Increase	left-lower
sub42	Immersion	Relax	Fluctuating	Increase	Decrease	Decrease	Decrease	right-upper
sub43		Excited	Stable	Increase	Increase	Increase	Almost no change	Almost no change

Table 1 :Summary Table of Participant's State Changes Due to Art Observation

The experiment using the artworks of Naoko Tosa provided important insights into the changes in emotions and immersion states among the participants. While individual differences were observed, it was confirmed that the majority of participants experienced significant emotional changes. This indicates the profound emotional impact that Tosa's artworks have on the viewers. Furthermore, the analysis of branching structures based on the Poincaré plot revealed that approximately half of the participants were in a clear state of immersion. This suggests that participants were deeply immersed in the artworks and strongly responsive to the emotional and cognitive fluctuations induced by the artworks. Such immersion underscores the depth of influence that the unique aesthetics and expressive power of artworks exert on the psychological and physiological responses of viewers, providing valuable insights into research on immersive art experiences. Overall, this study offers a new perspective for understanding the impact of art appreciation on the emotions and psychological states of viewers, potentially serving as a valuable foundation for future research and applications in

the field of art experiences.

5.2 Relation of Results to the Literature Review

This study makes significant contributions to addressing gaps in previous research on immersive art experiences in the following ways. Firstly, by utilizing the media art of Naoko Tosa, this research offers a novel perspective to the study of immersive art experiences by employing Tosa's artworks, which capture the hidden beauty within natural phenomena, thereby filling a gap in research that has overlooked experiences involving such unique aesthetics and scientific background. This approach sheds light on the process by which viewers deeply immerse themselves in artworks and the emotional impact thereof. Secondly, the use of the newly developed mirror display space addresses technical challenges towards achieving a fully immersive art experience, thereby adding a new dimension to the research. By employing this device, comprehensive analysis of viewers' emotional and physiological responses was facilitated, demonstrating technological advancements in the study of immersive art experiences. Furthermore, the application of time-series analysis of physiological data enhanced understanding of viewers' physiological responses by utilizing Poincaré plots on the time-series data of heart rate intervals (RRI). This deepened understanding of the influence of art appreciation on viewers' psychological and physiological states, thereby expanding the potential applications of immersive art experiences. Through these elements, this study overcomes gaps in previous research on immersive art experiences and offers a profound understanding of the impact of art appreciation on viewers, along with new possibilities for application.

6. Conclusion

This study provides important insights into the psychological and physiological effects of immersive art experiences using the media art of Naoko Tosa. Specifically, it was found that the majority of participants experienced significant emotional changes in response to the art pieces, with approximately half experiencing a clear state of immersion. Furthermore, the use of a newly developed mirror display space was shown to be effective in deeply exploring viewers' emotional and physiological responses. Additionally, the application of time-series analysis of heart rate intervals using Poincaré plots allowed for a more detailed understanding of the stability and variability of viewers' emotions. However, as this study is based on specific art pieces and a limited participant pool, caution is needed in generalizing the results. Moreover, the evaluation of emotional changes and immersion status relies on subjective interpretation, highlighting the need for further development of objective measurement methods. Additionally, the research setting and cultural background may influence the results, warranting additional studies in different

environments and cultures. Future research should aim to generalize the results of this study by including various art pieces and participants with different cultural backgrounds. Moreover, the development and application of more objective and precise measurement methods are necessary for evaluating emotional changes and immersion status. Further research is also needed to deepen understanding of how the characteristics of art pieces and individual differences in viewers may influence emotional and physiological responses. This broader understanding could lead to the development of new applications for art experiences.

Reference

1. Cristobal Rodolfo Guerra-Tamez, "The Impact of Immersion through Virtual Reality in the Learning Experiences of Art and Design Students: The Mediating Effect of the Flow Experience." *Education Sciences* 13, no. 2 (2023): 185
2. Grau, Oliver. "Virtual Art: From Illusion to Immersion." Cambridge, MA: MIT Press, 2003.
3. Ito, Kodai, Mitsunori Tada, Hiroyasu Ujike, and Keiichiro Hyodo. "Effects of the Weight and Balance of Head-Mounted Displays on Physical Load." *Applied Sciences* 11, no. 15 (2021): 6802. DOI: 10.3390/app11156802.
4. Kaprow, Allan. "Assemblages, Environments, and Happenings." New York: Harry N. Abrams, Inc., 1966.
5. Kim, Jihye, and Sangsu Lee. "A Study on the Immersive Experience in Virtual Reality: Focused on the First Time User." *International Journal of Virtual Reality* 19, no. 1 (2019): 65-74.
6. Marín-Morales, Javier, Juan L. Higuera-Trujillo, Alberto Greco, Jaime Guixeres, Carmen Llinares, Claudio Gentili, et al. "Real vs. immersive-virtual emotional experience: Analysis of psycho-physiological patterns in a free exploration of an art museum." *PLoS ONE* 14, no. 10 (2019): e0223881. <https://doi.org/10.1371/journal.pone.0223881>.
7. "Mirrora."AsahiGlassPlaza". <https://www.asahiglassplaza.net/products/mirrora/>.
8. Nakatsu, Ryohei, Tosa, Naoko, Niiyama, Satoshi, and Kusumi, Takashi. "Evaluation of the Effect of Art Content on Human Psychology Using Mirror Display with AR Function." In *Nicograph International* 2021, 54-61, June 2021.
9. Nakatsu, Ryohei, Tosa, Naoko, Pang, Yunian, Niiyama, Satoshi, Munaka, Tatsuya, Ueda, Yoshiyuki, Furuta, Masafumi, and Nomura, Michio. "Construction of Immersive Art Space Using Mirror Display and Its Preliminary Evaluation." In *Proceedings of International Display Workshop 2023 (IDW'23)*, 781-784, December 2023.

10. Nakatsu, Ryohei, Tosa, Naoko, Pang, Yunian, Niiyama, Satoshi, Uraoka, Yasuyuki, Kitagawa, Akane, Murata, Koichi, Munaka, Tatsuya, Ueda, Yoshiyuki, Furuta, Masafumi, and Nomura, Michio. "Construction of Immersive Art Space Using Mirror Display and Its Evaluation by Psychological Experiment." In Proceedings of EAT ArtsIT 2023, 2023.
11. Nakatsu, Ryohei, Tosa, Naoko, Pang, Yunian, Niiyama, Satoshi, Munaka, Tatsuya, Furuta, Masafumi, Ueda, Yoshiyuki, and Nomura, Michio. "Construction of Immersive Art Space Using Mirror Display and Its Preliminary Evaluation." In Proceedings of The 27th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2023), 434-439, September 2023.
12. Nakatsu, Ryohei, Tosa, Naoko, Takada, Hiroyuki, and Kusumi, Takashi. "Psychological Evaluation of Image and Video Display on Large LED Displays and Projections." Journal of the Society for Art and Science 20, no. 1 (2021): 45-54.
13. Pang, Yunian, Zhao, Liang, Nakatsu, Ryohei, and Tosa, Naoko. "A Study of Variable Control of Sound Vibration Form (SVF) for Media Art Creation." In Proceedings of the 2017 International Conference on Culture and Computing, 2017.
14. Pyun, Kyung Rok, John A. Rogers, and Seung Hwan Ko. "Materials and devices for immersive virtual reality." Nature Reviews Materials 7 (2022): 841–843. <https://doi.org/10.1038/s41578-022-00501-5>.
15. Smith, John L., et al. "Measuring Physiological Responses to Sensation in Typical Adults." Psychophysiology 55, no. 3 (2018): e13025.
16. Tosa, Naoko, and Nakatsu, Ryohei. "Creating Japanese Culture through the Fusion of Art and Technology." Journal of the Institute of Electronics, Information and Communication Engineers 99, no. 4 (2016): 295-302.
17. Tosa, Naoko, Yamada, Akihiro, Pang, Yunian, Toba, Shigetaka, Ito, Azusa, Suzuki, Takashi, and Nakatsu, Ryohei. "Creation of Fluid Art 'Sound of Ikebana' under Microgravity Using Parabolic Flight." Leonardo/ISAST, MIT Press, 2023. https://doi.org/10.1162/leon_a_02360.