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CRITICAL REVIEW OF MUSEUM ARCHITECTURE FROM A NEURO-ARCHITECTURE PERSPECTIVE

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Abstract

Introduction: This study focused on the behavior of people in museums. Museum visitors are known to explore the works of art through various presentation methods. People's behavior during the museum exhibit was analyzed. The **purpose of the study** was to obtain physiological responses to indoor and outdoor tours in terms of neuro-architecture. Therefore, the focus was on evaluating the cognitive responses people have to spaces during museum tours. Based on this evaluation, it aimed to make spatial arrangements more human-centered. **Methods**: The study was conducted in a virtual reality environment. A virtual museum was designed for the study, and experiments took place in this museum. Unlike other studies, this study used Electroencephalogram (EEG), Eye Tracking (ET), Heart Rate Variability (HRV), and Skin Conductance Response (SCR) techniques. The focus was on two presentation methods commonly used in museums: audio description (AD) and information board (IB). As a **result**, most striking findings came from the examination of the AD+IB presentation technique. EEG records and the data from other physiological measurement devices indicated that the AD+IB presentation technique induced stress in the visitors. That is, the participants could not focus enough on the works of art. Audio description alone was found very effective in museum visits. However, if it was used simultaneously with information board (IB), the effect of the artworks on the visitors was reduced to a minimum.

Keywords: interior design; neuro-architecture; museum architecture; cognitive design.

Introduction

Human perception often tries to recognize or identify objects when viewing them in everyday life. This perception is engaged when viewing and observing artworks in galleries and museums. It sometimes offers the opportunity to recognize the work of art and evoke proper cognitive responses. Cupchik et al. (2009) described this experiential perception as a particular psychological process, characterized by a focus on objects (works of art) and suppression of everyday concerns. If this particular psychological process is managed in the right way, it is possible to perceive the presented works correctly. Although the studies explain the cognitive processes involved in the perception and evaluation of works of art, the aesthetic experiences they provide and the related stimuli are still controversial. Some studies claim that such criteria as stimuli, colors, symmetry, and mathematical proportions in works of art play an essential role in promoting people's aesthetic experiences (Jacobsen and Höfel, 2003). Museums are entities presenting millennia-long history. Planning museum areas, especially museum architecture, covers protection, restoration, security, and display. The primary purpose here is for visitors to view the exhibits comfortably. Many researchers focused on visitors' behavior (Del Chiappa et al., 2014; Huber at al., 2019; Nurse Rainbolt et al., 2012; Ross et al., 2012; Skov et al., 2018; Trunfio et al., 2022) and highlighted the importance of museum architecture in shaping these behaviors.

On the other hand, Livio (2008) stated that titles, text, and other art structures could influence aesthetic assessments of visitors. This experience is intense in museums and art galleries. Therefore, there are many specific factors, from the presentation style of the works to the lighting method, the choice of architectural colors, the design of the space in museums and art galleries, to focus on the works of art. According to Becker (2008), the way objects or collections are presented and positioned can evoke various emotions in people. Thus, arranging or displaying the exhibited elements is crucial for creating spatial environments for people and enhancing cognitive recall mechanisms associated with space. Hence, researchers who emphasized the importance of designing museums and exhibition spaces correctly (MacLeod et al., 2015; Olesen et al., 2020; Wineman and Peponis, 2010) stated that this is not enough. They indicate that even the locations of objects are essential for museum design and human experience (Alberti, 2005; Antonelli et al., 2003).

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Museums have to offer the necessary comfort values and establish a communication-interaction between the visitors and works of art when presenting their identity. In this respect, visiting a museum can be an exciting, aesthetically impressive, and multifaceted experience that involves learning and having fun (Pine and Gilmore, 1998). In addition to museums' functionality today, different methods have been developed for the correct presentation of the exhibited works. First, an information board is located next to the object exhibited. This method, called the Information Board (IB), involves placing boards at specific points. These information boards are placed at an angle and in size that users can see.

An audio description system gives detailed information/contents about the work exhibited if requested. Audio Description (AD) is a verbal description method that aims to make visual elements of objects exhibited in museums and/or galleries accessible by a voice guide. Within the context of both the research and practice, the AD is in a relatively early development stage compared to the information board. There were studies evaluating how Audio Description (AD) meets visitors' demands and assessing the effect of auditory narrative on visitors' understanding (Braun, 2008; Hutchinson and Eardley, 2019; Walczak and Fryer, 2017).

Neuro-architecture, especially in recent years, has been offering new analysis and examination methods by looking at architectural research from different perspectives. Combining neurosciences with architecture, neuro-architecture enhances the field of architecture, particularly in human-centered design aspects (Higuera Trujillo et al., 2016), from wayfinding to spatial analysis (Prandi et al., 2023), from urban design (Erkan, 2024b) to spatial sensations (Erkan, 2024a).

This study was designed to measure the neuro-cognitive effects created by the presentation methods on museum visitors, rather than making cognitive assessments of the works of art themselves. Thus, the study questions the cognitive effects of the two essential elements (information boards and the audio description system) that appear in today's museums and are used to present the works of art.

Methods

This study used a method involving neuro-architecture tools.

Participants

The study was conducted with 304 volunteers (mean age = 25.6, SD = 1.9, 144 males). Having healthy vision, good cardiac health, healthy psychological condition, and not receiving any stimulant medication were prerequisites for inclusion in the study. All participants were right-hand dominant.

Experimental Environment

The study was completed in about 11 months. The experimental environment was prepared and isolated from the outside for the study. The environment of appropriate temperature and humidity was provided for the study to allow a comfortable setting for the participants.

Apparatus

The experiment employed the following technical means: one electroencephalography (EEG) monitor, one virtual reality headset (VR), one eye-tracking device (ET), one galvanic skin conductance response device (SCR), one Wii controller (WII), and one heart rate variety (HRV) device. The participants were introduced to the devices and provided with the needed information before the experiment began. Participants who were not eligible for any of these devices were excluded from the experiment.

Experimental Procedure

All stages of the experiment were explained to the participants individually before starting the experiment. At this stage, participants who did not want to be involved in the experiment were excluded from the study. A museum was designed in a virtual reality environment for the experiment. The entire experiment was developed to analyze the current presentation methods that people encounter during museum visits. Two different areas were designed for the experimental stages:

The first space consisted of an "exhibition designed entirely in open space". The architectural space, called the outdoor exhibition area, contained architectural landscape elements and urban furniture. There were sculptures, archaeological remains, paintings, and objects in different artistic styles exhibited outdoors. Participants passed through this outdoor exhibition to the second stage of the experiment.

The second stage was an indoor exhibition space. This indoor space was designed with an open architectural style and presented artistic objects of different disciplines (paintings, sculptures, etc.). The action plan of the participants in the experimental environment is shown in Fig. 1.

The primary reason the experiment was designed to move from outdoors to indoors is that it closely mirrors real life. That is, people who want to visit the museum approach the building in a specific direction. In other words, when people approach the buildings (especially the buildings with an architectural identity, such as a museum), they exhibit specific emotional responses. Therefore, recording these responses was of importance for the study.

Both environments were designed with Cinema 4D and transferred to a virtual reality environment with the help of C++. Objects of different artistic styles (from sculptures to paintings, handwork, etc.) in both of the designed spaces (indoors and outdoors) cater to many different art disciplines (Appendix 1). All the participants visited the outdoor and indoor exhibition areas one by one. The participants were required to

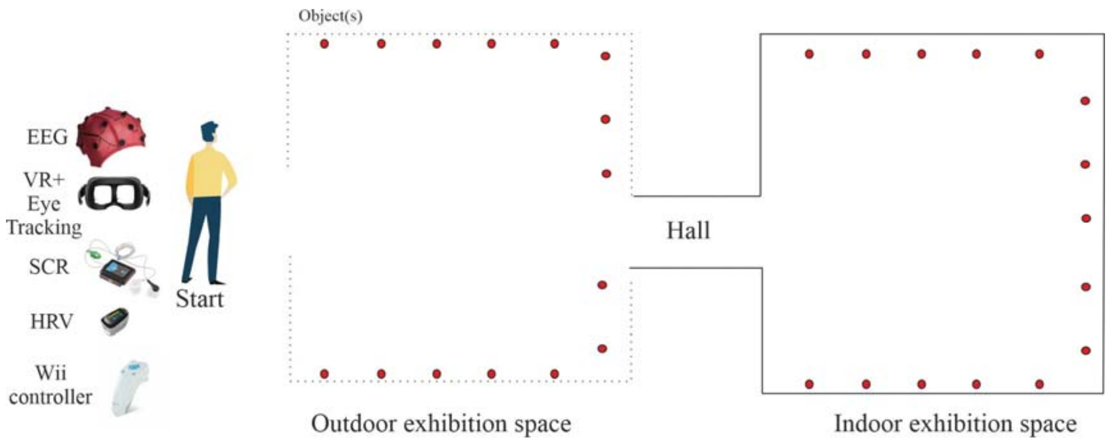

Fig. 1. Experimental architecture plan

see all the works. The participants were required to wait a maximum of 180 seconds when they arrive in front of the exhibited works of art. At the end of this period, the system automatically redirected them to the other object, and no participant exceeded this period. Fig. 2 shows an example of the indoor space and the display area in front of the exhibited object, as seen by the virtual reality goggles.

As shown in Fig. 2, a specific approach was set to each exhibited work. Visitors faced three different options in front of the exhibited works of art (paintings, sculptures, reliefs, etc.).

The first option was the information board (IB) in front of the displayed element. This board contained 300 words of information about the work of art. The participants were asked to read the IB texts on the works.

The second option provided just the audio description (AD) system, without an information board, when participants approached an object. Information about the exhibited work was narrated through the headset to the viewer. This voice guide narrated 300 words of information to the visitors.

The third option (IB+AD) was a combination of information board and audio description (IB+AD) in front of the exhibited work. While the participants were reading the information board, they were also informed via a headset. Besides the 300-word information board, different 300 words were provided by the voice guide. In other words, the information board and the voice guide system had different information. Fig. 3 shows a simple diagram of the visitors' navigation.

There was a total of 30 objects, with 15 of these objects exhibited outdoors, and 15 indoors. Each participant tested different presentation methods indoors and outdoors five times each. In other words, it was possible to test AD for 10 objects, IB for 10, and the AD+IB for another 10 objects indoors and outdoors. The participants traveled in a virtual reality environment using the Wii remote. With it, they were able to turn right, left, and move back and forth. The participants were also asked to rate the work displayed

Fig. 2. The larger picture – the indoor space visited by participants, and the smaller one depicts the virtual reality environment when they reach the artworks

on the screen from 1 to 10 (10 being the best) after examining all three stages. After the participants rated the objects, the experiment continued.

In the final stage of the experiment, participants were asked about the works they saw/remembered in the virtual reality environment after completing their indoor and outdoor museum tours. This process was performed with the "WHILE NAVIGATING" software developed for this study. The interface of the software developed is shown in Appendix 2. With the help of the software developed, 60 different works of art were shown to the participants at 5-second intervals. In other words, this stage also included 30 different exhibition elements that were not shown in the previous stages. This stage determined the objects the participants were able to recall.

Analysis

Statistical Analysis

To explore the relationships among skin conductance data, heart rate data, EEG data, and architectural liking scores, we employed a general linear model (ANOVA) for repeated measurements using R software. We established a significance

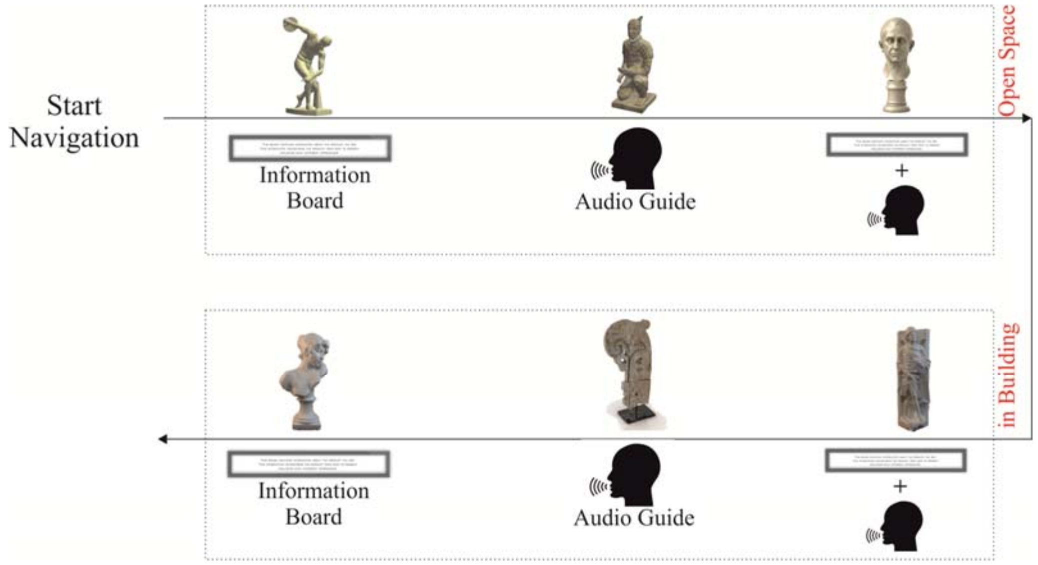

Fig. 3. Example of participants' navigation route

threshold of $p < 0.05$. To further investigate potential double significance across different conditions, we conducted t-tests on these variables, also with a significance level of $p < 0.05$. Additionally, we utilized bootstrap methods in EEGLAB for a comprehensive analysis of the EEG data, maintaining a significance level at $p < 0.05$. This multi-faceted approach enhances our understanding of the data and findings.

EEG Data

A 14-channel EEG device was used for this study. Data processing was carried out using the toolbox software developed for this study with MATLAB. This software uses Fast Fourier Transform (FFT) to analyze the spectral power of EEG rhythms, following the methods of Polat and Güneş (2007) and Murugappan et al. (2014). Eye blinks were corrected as described by Gratton et al. (1983), and the quality of all electrodes was assessed to minimize the impact of poor channels on the analysis.

Five different cases were taken into account when analyzing the EEG data:

• first case, brain images of the visitors recorded during the museum visits only in the information board (IB) setting;

• second case, brain images of the visitors recorded during the museum visits only in the audio description (AD) setting;

• third case, brain images of the participants recorded during the museum visits in both IB and AD (IB+AD) setting;

• fourth case, brain images of the participants recorded while rating the works of art;

• fifth case, the participants' responses during the "recall test" at the end of the experiment.

Skin Conductance Response (SCR)

SCR reflects excitement-related physiological reactions, and physiological or psychological stimuli. Fear, joy, or stress are the conditions that affect skin conductance (Dawson et al., 2011). Skin conductance is used to indicate ongoing emotional processes and emotional arousal. It is a reliable measurement technique. Skin conductance data were collected from the participants using SCR wristbands. The participants were fitted with wristbands prior to any equipment; the data were recorded continuously until completion of the entire experiment. The SCR signals were recorded from the left fingers.

Heart Rate Variability (HRV)

HRV analyses are regarded as an indicator of autonomic nervous system activity, which is responsible for the body's involuntary movements (Acharya et al., 2006). Heart rate variability (HRV) provides an insight into the cardiovascular autonomic function using RR intervals (interval variance).

A polar HR sensor was used in the study. The HR sensor was set on a strap attached to the participants' chests. HRV is used for determining power spectral density, sympathetic and parasympathetic autonomic nervous system activities. In the power spectrum, the low-frequency component (LF) ranges from 0.04 to 0.15 Hz, influenced by both sympathetic and parasympathetic activities. Meanwhile, the high-frequency component (HF), which is between 0.15 and 0.4 Hz, is primarily affected by parasympathetic activity. LF/HF ratio is regarded as an indicator of sympathovagal balance (Massaro and Pecchia, 2019). In studies conducted to measure and evaluate stress, the most commonly used parameters are the mean heart rate (HR), LF, HF, and LF/HF (Taelman et al., 2009).

Eye Tracking

The basic idea behind the eye-tracking technique is to make inferences about cognitive processes based on eye movements (Jacob and Karn, 2003). The eye-tracking device used in the study was placed inside the virtual reality goggles. Thus, the participants' eye-tracking responses to the spaces were recorded while they navigated the museum in a virtual reality environment. In the eye-tracking study, a heat map and fixation count were examined. The heat maps show the points that participants are looking at and the duration of their gazes. It is a color-coded measurement data formed by combining points of view, fixation points, and dynamic (moving) points. It is a method to see the points of the objects that draw attention. Heat maps visualize the focus areas, from green to red, indicating less focus to more intense focus, respectively. Red areas show a high focus count and an increased level of interest, while yellow and green areas show a lower focus count, hence weaker visual interest.

The Fixation Count analysis shows how many times people focus on these areas in total. In the analysis, the view screen is divided into segments as desired. The focus count data of the participants were processed into these segments, together with the colorings determined by the focus intensity.

Liking Score

The participants were asked to give a score between 1 and 10 to each work of art on the screen after examining the objects in all three stages. This rating was mandatory, and the experiment could not continue unless the participant rated the object. Each participant rated both the indoor and outdoor works. The analysis of the liking scores was inspired by Erkan (2021). Statistical values were calculated for the scores given by each participant. The participants gave liking scores for both indoor and outdoor spaces.

Recall Test

A special software was developed for this study. This software tried to determine which works were recalled by the participants in the space they visited. The recall test was the final stage of the experiment. At this stage, the participants were asked, with the help of the software interface shown in Appendix 2, if they had seen the objects on the screen.

Results and Discussion

The study explored the cognitive and physiological impacts of various presentation techniques in museums by utilizing different physiological measurement devices and examining how these effects are reflected in museums. The study used such physiological measurement instruments as SCR and HRV. A cognitive analysis was performed using EEG. The eye-tracking device identified the participants' points of focus. The author developed a software for a recall test, "Remember-Again", to reveal recall statuses of the participants. In addition, architectural liking scores of the participants regarding the works were analyzed.

The study focused on the prefrontal cortex and orbitofrontal cortex, as they are specifically related to the understanding, decision-making, and selection processes in humans. During the IB stage, visitors tried to comprehend the objects by focusing solely on the text they had read. During the IB stage, the prefrontal cortex was the most active region of the participants' brains. If it is examined in more detail by taking the Talairach Stereotactic System into account with the approach by Koessler et al. (2009), intense interaction with the "dorsolateral prefrontal cortex" is observed. The prefrontal cortex has been associated with various cognitive processes, from identification to perception and viewing (Siddiqui et al., 2008). However, when an individual experiences a stressful situation, changes in the prefrontal cortex can occur, which can lead to lower decision-making abilities and error handling (Arnsten, 2009) and a decline in working memory (Qin et al., 2009). In this study, alpha activity in the frontal lobe was examined in detail. A decrease in alpha activity in the dorsolateral prefrontal cortex was detected, especially during the IB+AB stage, and this decrease is believed to be stress-induced. The decreasing tendency in alpha activity in EEG analysis may also result from a decline in people's perception or reasoning about the objects. This result is due to the stress caused by reading and listening simultaneously.

However, theta activity in the frontal region was studied in three different stages. As with alpha activity, frontal theta activity was significantly reduced during the AD+IB stage. Our findings confirm the theory by Mizuki et al. (1992) that frontal theta synchronization is associated with decreased anxiety; as supported by EEG records, the third stage is more stressful than two other stages (Fig. 4).

Changes in SCR and HRV data were also observed when there was a decrease in EEG alpha wave while the subjects were under acute stress (Fig. 5).

SCR records showed that the participants' SCR values increased during the AD+IB stage and decreased during the IB stage. The HRV data of the same participant was obtained. Both HRV and SCR analyses demonstrated that the 3rd (IB+AD) stage was the most stressful. Physical and mental burden significantly affects the cardiovascular response. Stressors cause decreased oscillations in heart rate variability (HRV) that reflect parasympathetic nervous system activity. Accordingly, the LF/HF ratio increases. In individuals experiencing stress, cardiovascular responses may persist even during the periods of rest. Studies report that short-acting stressors suppress the parasympathetic nervous system and increase sympathetic nervous system activity (Acharya et al., 2006). Low LF/HF ratio was evaluated as an indicator of increased vagal activation. The mean and standard deviations of HRV and related parameters obtained from all participants are shown in Table 1.

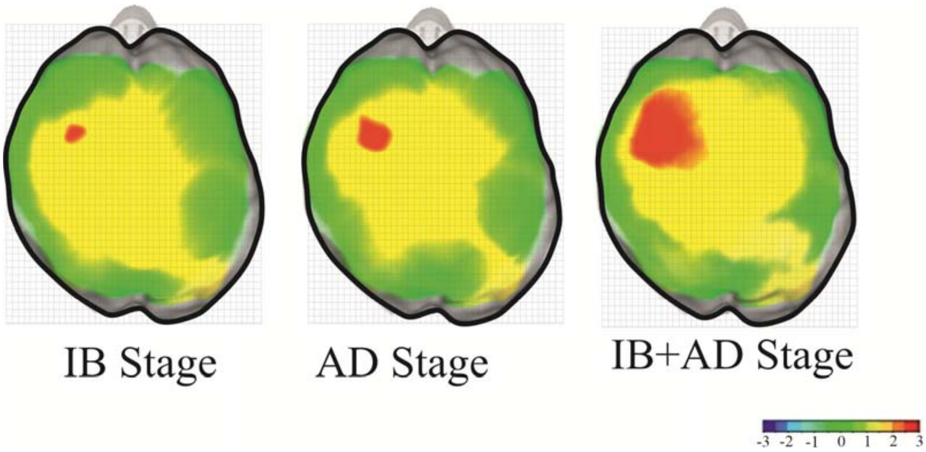

Fig. 4. Brain map showing the state of alpha and theta activity in the prefrontal cortex in the first three stages

Statistical HF values were found to decrease in all participants in the careful analysis of the experimental stages. The decreased parasympathetic activity was associated with people exposed to fatigue, stress, and anxiety (Kemp et al., 2017; Shaffer and Ginsberg, 2017).

Table 1 also showed that an increase in participants' LF/HF ratio was statistically significant during the same experimental stages. Therefore, when both HF and LF/HF ratios are examined, it can be stated that participants face the most intense stress during the AD+IB stage. Statistical values of

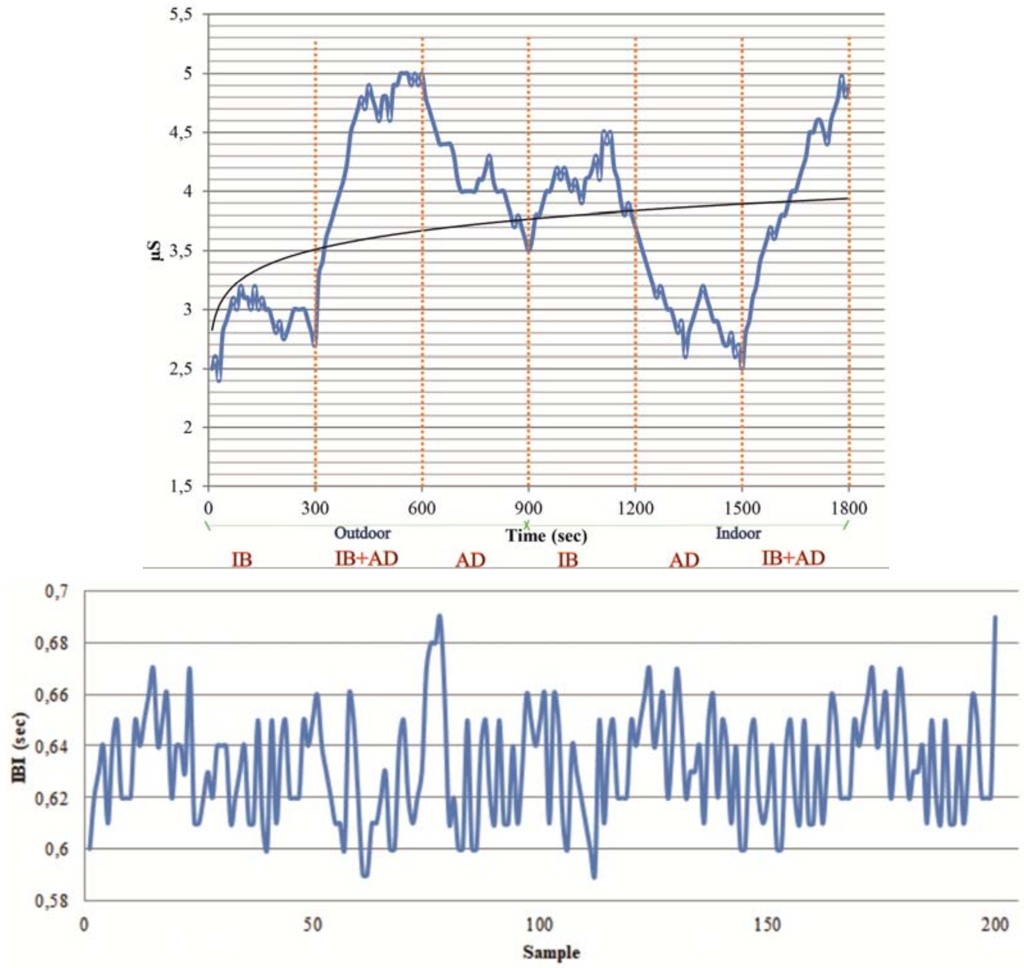

Fig. 5. SCR and HRV graph recorded when a participant was navigating both the indoor and outdoor spaces with different presentation methods

Table 1. **Comparison of the HRV feature results for different presentation types**

Presentation/HRV	IB		AD		IB+AD	
	Avg	SD	Avg	SD	Avg	SD
Inter-Beat Interval (IBI) (Avg)	700.45	134.45	700.14	124.47	700.15	121.14
HR (Avg)	84.14	16.45	84.11	14.11	83.77	12.47
Low frequency (LF), ms²	304.48	277.47	412.14	341.44	421.74	377.89
High frequency (HF), ms²	221.45	265.84	219.11	231.40	205.14	212.01
LF/HF	1.89	1.21	1.92	1.45	1.98	1.67

skin conductance were collected in all stages of the experiment. Average skin conductance attributes obtained by SCR devices for all participants are presented in Table 2. In this comprehensive study, an increase was observed in all statistical findings related to skin conductance.

Changes in SCR were found to reflect the stress levels of individuals. Analysis of the SCR data showed that SCR increased among users as their cognitive load increased. When different presentation techniques were analyzed, all statistical findings were observed in the data on skin conductance. SCR was at its highest in the AD+IB stage. Thus, SCR data can be correlated with the stresses the participants experienced in the AD+IB stage.

Table 2. **Comparison of SCR feature results for different presentation types**

Skin Conductance Attribute Types	IB		AD		IB+AD	
	Avg	SD	Avg	SD	Avg	SD
Min	2.12	0.95	2.21	0.98	2.31	1.02
Avg	2.42	0.96	2.84	0.97	2.96	1.01
Max	2.78	1.16	2.96	0.99	3.24	1.12
SD	0.12	0.04	0.14	0.06	0.21	0.08
Median	2.41	1.05	2.74	1.05	2.88	1.04
Skewness	–0.44	1.14	–0.21	0.78	–0.10	0.98
Kurtosis	3.44	1.42	3.88	1.49	3.99	1.24

In addition to SCR and HRV analyses, eye-tracking data showing the focus of the participants were collected. Fig. 6 shows a participant's eye-tracking analysis in the same artist's works in different presentation techniques.

As shown in Fig. 6, in the AD setting, the participant scrutinized the work of art in detail and even concentrated on many areas, as confirmed by total fixation count (fixation count in the AD setting Avg:439.46 SD:36.92, fixation count in the IB+AG setting Avg:354.43 SD:26.63). In the study, participants focused on specific areas in the IB+AD environment, as reflected in heat map analysis, and the cause for this might have been the participants' distraction.

Also, the eye-tracking heat map of almost all visitors (96.65 %) showed that the smallest areas were in the AD+IB stage. In other words, at the AD+IB stage, the areas that people look at and even examine carefully are smaller than those in other settings. Besides, each object was examined separately in the fixation count analysis. The fixation counts of a total of 30 objects grouped by presentation methods are shown in Fig. 7.

The fixation count analysis can be efficient for studies that deal with the focus on the desired area rather than the focus duration. It was found that the total focus count on the works was greater in the AD setting compared to others.

Finally, the liking status of the participants was evaluated. Given that they were obliged to rate the works from 1 to 10, it was possible to determine the

Fig. 6. Heat map in paintings that a participant examined in different presentation techniques

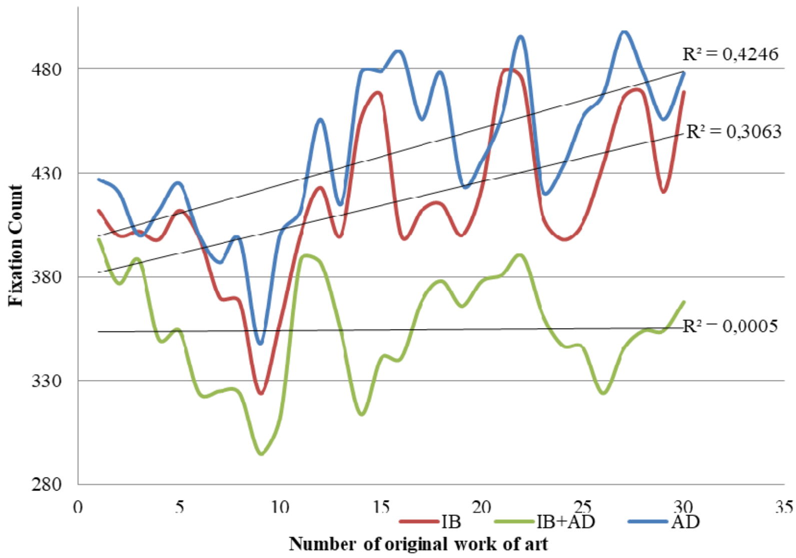

Fig. 7. Examination of the participants' fixation count analysis for each presentation technique

participants' architectural liking about the indoor and outdoor spaces. The results of repeated analyses for IB, AD, and IB+AD environments, which are independent variables in the study, are shown in Table 3.

The total liking scores for the indoor and outdoor were analyzed, and the binary differences between the three settings were statistically significant. Participants were asked which objects they remembered during their museum visits. The primary purpose here was to measure which space and which presentation setting was suitable for recalling the objects. The participants examined a total of 30 different works of art (15 were outdoors) during their museum trips. However, the participants were shown 60 works during the recall test. The goal here was to find the recall percentages of 30 different objects in total. In the recall test performed indoors and outdoors, the average for the indoor space (12.68, SD: 1.78) was higher than that for the outdoor space (11.59, SD: 1.67). Each participant's recall percentages, for both indoors and outdoors, are shown in Fig. 8.

Table 3. **Results of repeated analyses for IB, AD, and IB+AD settings**

Pairwise Comparisons

Indoor

(X)	(Y)	Mean Difference (X-Y)	Std. Error	Sig.[b]	95 % Confidence Interval for Difference[b] (Bonferroni)	
					Lower Bound	Upper Bound
IB	AD	0.964*	0.071	0.000	0.792	1.135
	IB+AD	2.306*	0.063	0.000	2.154	2.458
AD	IB	–0.964*	0.071	0.000	–1.135	–0.792
	IB+AD	1.342*	0.074	0.000	1.163	1.521
IB+AD	IB	–2.306*	0.063	0.000	–2.458	–2.154
	AD	–1.342*	0.074	0.000	–1.521	–1.163

* The mean difference is significant at the 0.05 level

Outdoor

(X)	(Y)	Mean Difference (X-Y)	Std. Error	Sig.[b]	95 % Confidence Interval for Difference[b] (Bonferroni)	
					Lower Bound	Upper Bound
IB	AD	1.643*	0.094	0.000	1.418	1.869
	IB+AD	2.949*	0.084	0.000	2.746	3.152
AD	IB	–1.643*	0.094	0.000	–1.869	–1.418
	IB+AD	1.306*	0.081	0.000	1.112	1.500
IB+AD	IB	–2.949*	0.084	0.000	–3.152	–2.746
	AD	–1.306*	0.081	0.000	–1.500	–1.112

* The mean difference is significant at the 0.05 level

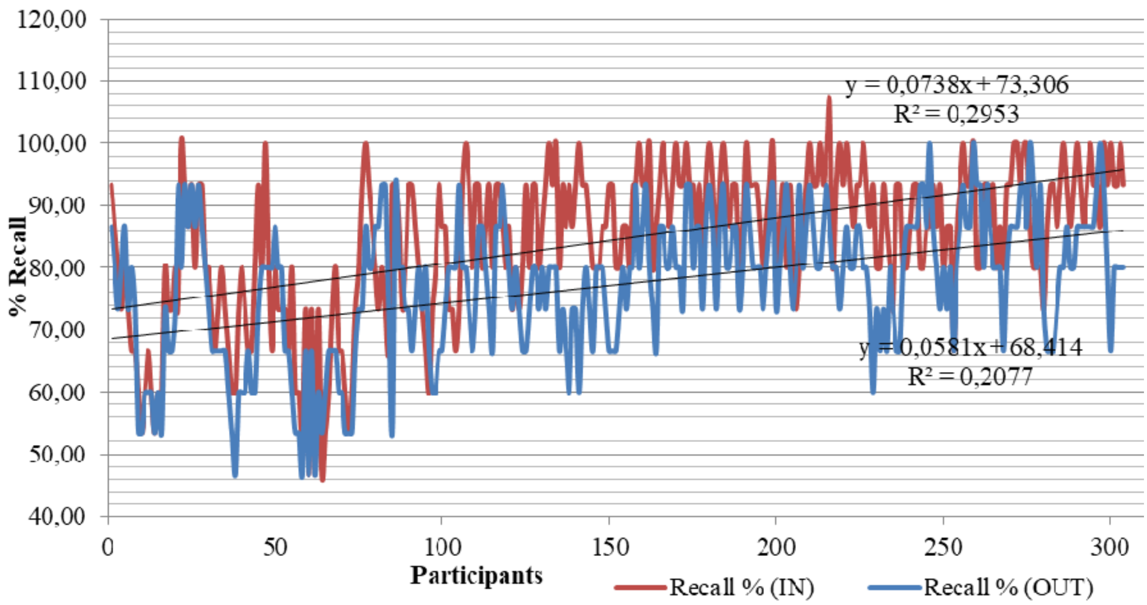

Fig. 8. Indoor and outdoor recall percentages of the participants

The participants usually had a better recollection of the indoor objects (t-value = 7.75003, $p < 0.00001$.). Another important finding was that participants in both the AD+IB setting and outdoors had the least recall percentage.

Conclusion

The study investigated presentation methods of exhibited objects in a virtual reality environment using different measurement techniques. Detailed analyses resulted in the following conclusions.

One of the most striking findings of the study was the examination of the AD+IB presentation technique. EEG records and the data from other physiological measurement devices indicated stress during this presentation technique; that is, the participants could not focus enough on the works of art. There follows a chain reaction. As a result of the stress experienced during this presentation technique, the visitor, who cannot concentrate on the work, cannot examine it adequately and gives it a lower score. Remarkably, the recall rate is at its lowest with this presentation technique.

While the IB setting is traditionally considered helpful in understanding art, eye-tracking analysis shows the AD setting is more beneficial.

In addition, we analyzed two different environments (indoors and outdoors) for three different presentation techniques. In these three settings, the average liking scores were found to be different. Moreover, the statistical analysis showed that this difference was statistically significant.

The recall rate of exhibited objects in the indoor space was much higher than that in outdoors. This recall rate may be due to the stimulating factors of the outdoors. Therefore, it is recommended to minimize outdoor stimulating factors and pay attention to this critical point when designing outdoor display units.

The study showed that the IB presentation method alone was not enough for people to understand the works of art. The AD method has significant importance for perceiving art, according to many physiological tests. In addition, it is clear that examining art in an IB+AD setting is not beneficial for visitors and hinders understanding in the museum.

Given that one of the primary goals of museum architecture is to offer genuine access to the museum experience, museums must acknowledge the visual information of visitors and consider the social, cognitive, and emotional aspects of their visits. From this perspective, it is believed that audio description systems (AD) will help museums of the future to evolve beyond the visual museum concept.

The study is expected to aid virtual tours and online presentations of artworks. During the pandemic, museums relied heavily on virtual presence to highlight their collections. This study could help the developers of virtual museum tours regarding the use of emerging technologies and user interfaces to improve presentation techniques. This paper also emphasizes the value of universal access to collections for those who cannot physically visit a museum due to medical risks or distance, which may help address the underrepresentation of certain groups in existing visitor populations. The study can also improve experts' experience prior to visits by assisting practitioners and museum managers in understanding visitors' desires and getting ready for an in-person meeting.

The paper can also be reframed to understand the importance of virtual examination of artworks in future studies. This paper helps practitioners understand the growing interest in virtual representation that deepens interaction with works of art outside the museum. Different physiological and cognitive approaches can be experimented with, considering the better utilization of virtual infrastructures.

The study considered only indoor and outdoor space interactions as architectural influences. It can be improved in further studies to incorporate color, light, and even space geometry studies. This way, the effects of different stimuli on people's cognitive states can also be studied for the spaces in question. Besides, not all outdoor stimuli were taken into account in the study. In this regard, outdoor sounds are one of the most critical limitations of the study. Indeed, it is clear that outdoor sounds significantly stimulate and impact people's cognitive states.

Moreover, the interiors were predominantly designed in black and white colors in the study. Color is one of the limitations of this study; it is clear that many color and pattern factors influence cognitive perception. Therefore, further studies can experiment with different colors and architectural styles.

This study analyzed visitor behavior at a museum space using both physical and cognitive methods. In light of the visitors' behavioral and cognitive feedback, inferences about the different presentation techniques in museums were made. Since the study was conducted across multiple disciplines, it is multifaceted and provides both emotional/behavioral and sociological/psychological insights. The study was conducted in a museum space. Since it was an experimental setup in a simulation, using a wide range of analysis methods, the study could affect many behavioral mechanisms.

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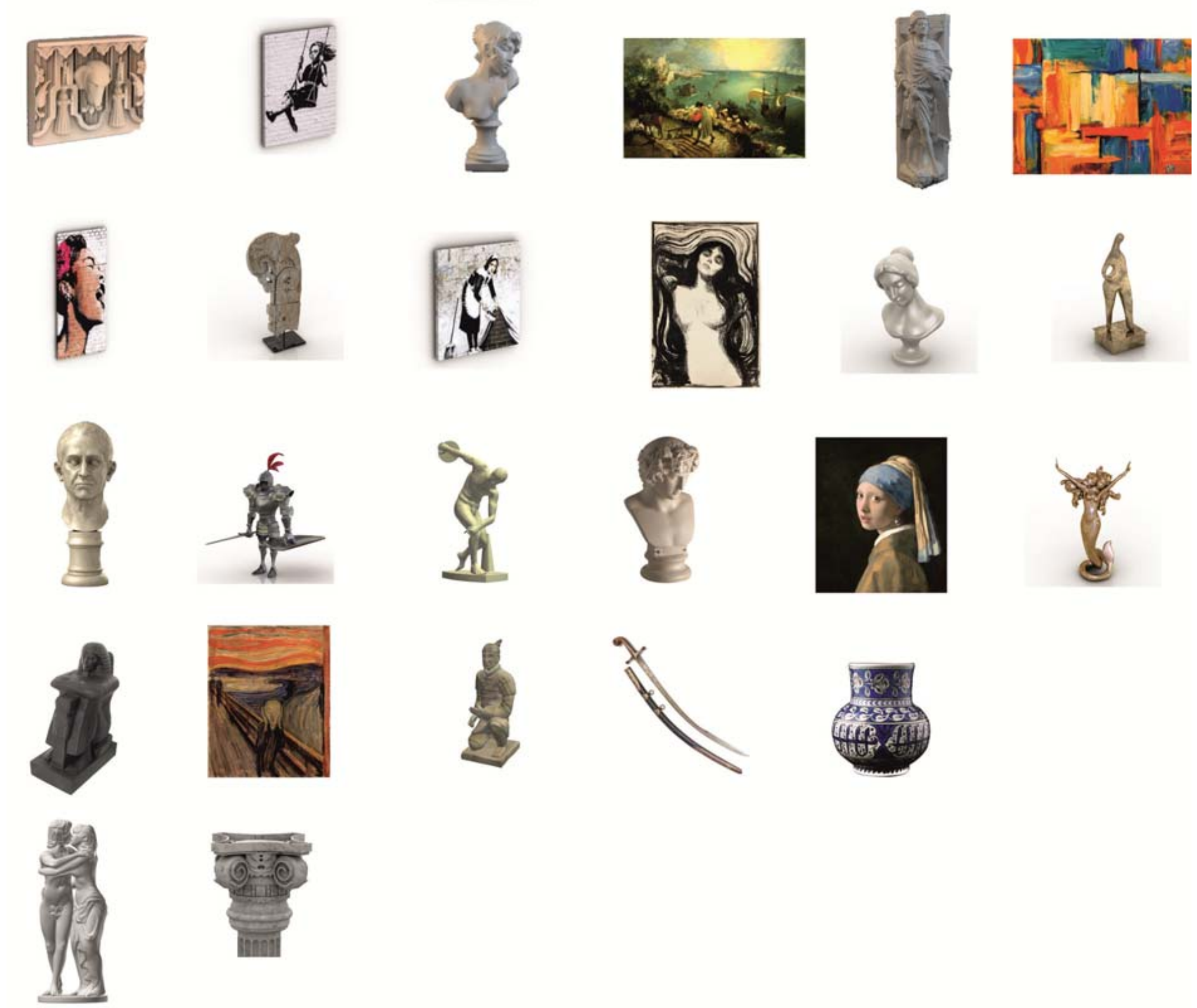
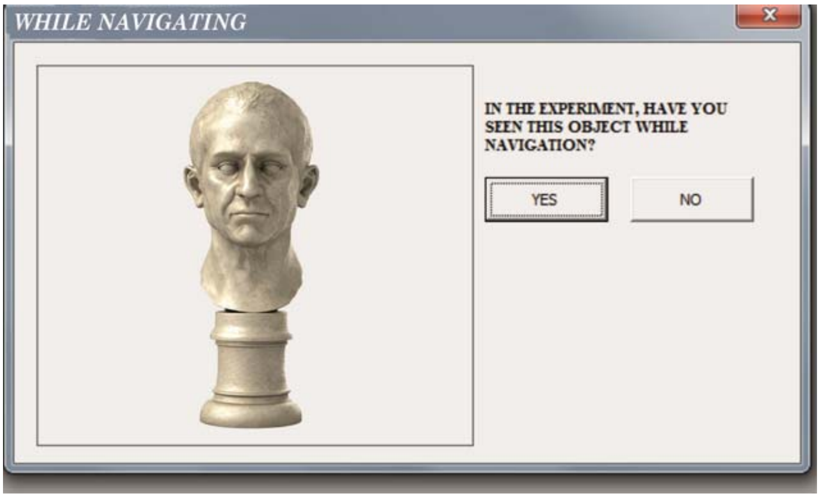
Appendices

Appendix 1. **Objects Used in Virtual Reality Environments**



Appendix 2. **Software Interface**



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КРИТИЧЕСКИЙ ОБЗОР МУЗЕЙНОЙ АРХИТЕКТУРЫ С ТОЧКИ ЗРЕНИЯ НЕЙРОАРХИТЕКТУРЫ

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Аннотация
Введение. Данное исследование посвящено поведению людей в музеях. Известно, что люди, посещающие музей, изучают произведения искусства, представленные различными методами. В статье представлено когнитивное обсуждение поведения людей во время осмотра произведений искусства в музее. **Цель исследования**: проанализировать физиологические реакции посетителей на экскурсии снаружи и внутри музея с точки зрения нейроархитектуры. Таким образом, мы сосредоточились на оценке когнитивных реакций на архитектурные пространства во время экскурсий по музею. На основе этой оценки мы попытались сделать пространственные решения более «человекоцентричными». **Методы:** исследование было проведено в среде виртуальной реальности; для исследования был разработан виртуальный музей, в котором и проводились эксперименты. В отличие от других исследований, в нашем использовались такие методы, как электроэнцефалограмма (ЭЭГ), отслеживание движения глаз, вариабельность сердечного ритма и реакция кожной проводимости. Внимание было сосредоточено на двух методах представления информации, часто используемых в музеях: аудиоописании и информационной табличке. Одним из наиболее поразительных **результатов** исследования стало одновременное использование методов аудиоописания и инфотаблички. Согласно ЭЭГ и данным других приборов для измерения физиологических показателей, одновременное использование этих методов вызывало стресс у посетителей — участники не могли в достаточной степени сосредоточиться на произведениях искусства. Аудиоописание само по себе оказалось очень эффективным при посещении музея. Однако если оно использовалось одновременно с информационной табличкой, воздействие произведений искусства на посетителей сводилось к минимуму.

Ключевые слова: интерьерный дизайн; нейроархитектура; музейная архитектура; когнитивный дизайн.