Neurological Perceptions of Art through Augmented & Virtual Reality

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By CUSEUM

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STUDY GOAL

In 1935, Walter Benjamin published his groundbreaking essay, "The Work of Art in the Age of Mechanical Reproduction," in which he claims that the *aura* of a work of art is denigrated through its reproduction. "Even the most perfect reproduction of a work of art is lacking in one element," he writes, "its presence in time and space, its unique existence at the place where it happens to be". The current study seeks to end the debate around the nature of the experience with authentic, original works of art and its virtual equivalent by measuring non-conscious engagement in four discrete environments: Augmented reality, virtual reality, 2-dimensional photographic reproduction, and authentic original.

Participants

Nine participants were recruited for the current study after responding to a short survey which asked questions about the participants' demographic, psychiatric/neurological diagnoses, technology experience, and art background. The 9 chosen participants responded with entirely neuronormal answers in their surveys (e.g. strong visual acuity, no psychiatric diagnoses, no chronic alcohol or drug use). To avoid bias, all chosen participants had no background in art or art history, were not close to anybody with a background in any art areas, and had only experienced augmented and virtual reality 1-2 times prior to the study (Pounder 2018). Other general demographic identities (e.g. gender, race, age) varied across participants.

STUDY DESIGN

Experimental Phases

All study sessions took place at the Museum of Fine Arts in Boston, MA. Before each study session, participants provided signed consent. Next, participants were fitted with the Muse2 headset, which has two input electrodes located on the forehead, and one input electrode above each ear. Proper connectivity of all four EEG channels was ensured before proceeding with the experiment.

Each participant was guided through the five experimental phases in a randomized order. Each phase involved the viewing of a painting in a unique medium: Augmented reality, virtual reality, a 2-dimensional image on an iPad, and a real painting hung in the museum's gallery. A fifth "baseline" phase was also recorded, where participants were asked to look at a blank wall. Baseline was used during analysis to eliminate any inter-participant differences in brain activity that was unrelated to the experimental environments we were interested in.

Each of the five environment sessions lasted one minute and participants were asked to sit in a chair, relax their bodies and keep their head as still as possible for the entire duration of the session (Krigolson, Williams, Norton, Hassall, & Colino, 2017). In the virtual reality environment, participants were asked to place the Oculus VR headset over the Muse2 headset, and confirmed that they were comfortable before the session began. To ensure that all experimental environments were standard, and that participants remained seated for all environments, participants were asked to sit in a wheelchair during the real gallery environment session (Krigolson, Williams, Norton, Hassall, & Colino, 2017). In the augmented reality session, participants were asked to hold up an iPad, their elbows rested on the arms of their chair, and look at the iPad's display of a painting superimposed onto the real-life wall of the museum (Pounder, 2018).

Between each of the five experimental phases, participants were given a survey in which they were asked to describe as many details as they could remember about the painting they had just seen.

Although participants only viewed one painting per environment, each of the five environments had several options of paintings that the participant could have viewed. Participants were randomly assigned a painting for each environment, and every painting selected had thick brush strokes and fell into one of the following three categories: Impressionist landscape, impressionist portrait, and abstract; Prior research has shown that engagement differs between these art categories (Balas & Sinha, 2007). Researchers ensured that all three art categories were sampled throughout a single participant's sessions, so that no variables were added to the experiment that could affect a participant's experience beyond the tested environment (Sinha & Russell, 2011).

Data Acquisition

EEG signals are represented in Muse as the absolute band power for the five standard frequencies commonly used in EEG research (delta, theta, alpha, beta, and gamma). Due to the frequent disconnection of electrodes due to muscle noise and head movement, the EEG signals are filtered based on the "is_good" variable provided by the Muse. Any recorded data during a period of disconnection were omitted from analysis (Muse Research and Krigolson, Williams, Norton, Hassall, & Colino, 2017).

All sessions were recorded at the Museum of Fine Arts which, at times, was both crowded and loud. This was not considered to be a drawback to the study design because it created an authentic museum-going experience for participants, however video of each session was recorded and any times where excessive noise or external distractions occurred were eliminated from analysis.

DATA ANALYSIS

Muse2 acquires data at a sample rate of 256 Hz/sec which is automatically aggregated and averaged based on band frequency and sensor location, and records an output of 1 Hz/sec used for further analysis (Muse Research). Data was automatically separated into readings from the 4 electrodes (TP9, TP10, AF7, and AF8) and further separated into the five standard frequency bands (e.g. Alpha_TP9, Gamma_TP9, Beta_TP9, etc.). *Figure 1* provides an overview of the Muse2 electrode locations.

While data recordings began at the start of each environment session, video recordings of the sessions were also used to trim down the data sets to ensure that analysis was only being run on the 1-minute experimental sessions.

Next, a Fourier Analysis was conducted in order to transform the domain of the data sets from time into frequency in order to map the relative magnitude of the signal (Klingenberg, 2005). The Fourier Analysis was conducted on each frequency band of each electrode, for each of the five environmental sessions, across all nine participants.

The average magnitude of each participant's control environment session was subtracted from the magnitude of each electrode in each of the 4 experimental environment sessions, in order to isolate the effect of the environment from individual participant differences.

Finally, the highest peak in magnitude per electrode during each of the 4 environment sessions was calculated, and compared across participants in order to determine if there is a difference in environment-dependent engagement.

However, while the peak magnitude of activation is a great step forward in understanding non-conscious experience, in order to tell the entire story of aesthetic enjoyment and engagement with the four environments, analyses of the frequency bands per sensor location were also examined. Together with established scientific literature, further conclusions were drawn about the underlying non-conscious experience that takes place during these four distinct avenues of art viewing.

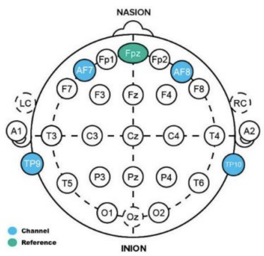

Figure 1. Muse2 Electrode Locations: AF7, AF8, TP9, TP10 highlighted in blue (Abujelala, Sharma, Abellanoza, & Makedon, 2016)

4x4 Matrix Vector Analysis

In a 4x4 matrix, paired t-tests under the four conditions (2D, AR, VR, Real) were used to detect any significant differences in brain activity. Specifically, we examined the similarity of alpha band, gamma band, and alpha and gamma activity together (see figure below).

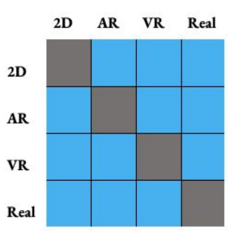

Figure 2. Each 4x4 matrix shows p-values of paired t-tests. The column and row orders are: 2D, AR, VR, Real, as shown in the figure below. The gray boxes correspond to non-meaningful entries that show up as 'NaN's (Not a Number) in the matrices.

Qualitative Data Analysis

Participants were requested to rate how well they remembered each painting following the observation period when the painting was no longer in view. A follow-up survey was also sent at least one week following the museum visit, again requesting participants to assess their own memory of each painting. These assessments allowed us to test which environments may be more conducive to memory consolidation, as well as provide support of our non-conscious EEG results with conscious reflection.

RESULTS

Fast Fourier Transform Analysis Results

Average peak magnitude per environment was calculated across participants, and then averaged across sensors (*Figure 2*). Peak magnitude of EEG activation was greatest in virtual reality, augmented reality, real museum gallery, and 2-D respectively.

Augmented Reality

	Sensors			
	TP9	TP10	AF7	AF8
Average Peak Magnitude Per Sensor:	0.8040757021	0.9304768647	0.9080465924	0.6940692766
Average Peak Magnitude Per Environment	**0.8341671089**			

Virtual Reality

	Sensors			
	TP9	TP10	AF7	AF8
Average Peak Magnitude Per Sensor:	0.9389450263	0.8559232977	0.9833170582	0.9574374743
Average Peak Magnitude Per Environment	**0.9339057141**			

2-D

	Sensors			
	TP9	TP10	AF7	AF8
Average Peak Magnitude Per Sensor:	0.7476141104	0.8664965589	0.8112781046	0.604592718
Average Peak Magnitude Per Environment	**0.757495373**			

Real Museum Gallery

	Sensors			
	TP9	TP10	AF7	AF8
Average Peak Magnitude Per Sensor:	0.740395211	0.7547833978	1.005561227	0.7554050473
Average Peak Magnitude Per Environment	**0.8140362206**			

Figure 2. Average Peak Magnitude Per Sensor and Environment

4x4 Matrix Vector Analysis Results

The results reveal that the recorded EEG responses across the conditions is not statistically distinguishable, except for the comparison between 2D vs VR, as well as AR vs VR, especially in the gamma band (significant differences, at $p<0.05$ level, shown in red). Data from sensor AF7 have been excluded from analysis as it was only detected in three of the five subjects. The analyses for alpha and gamma band responses were analyzed together as well as separately, and demonstrates that the brain appears to respond similarly to 2D, AR and VR presentations as to the real stimuli; Only the differences between VR and 2D/AR appear to be significant.

Table 1. *4x4 matrices of p-values for EEG sensors TP9, AF8, & TP10 respectively. Each set of matrices (1a-1c) are grouped according to alpha band activity, gamma band activity, and the alpha and gamma bands together.*

1a.)

Alpha and Gamma bands together:

Sensor TP9				*Sensor AF8*				*Sensor TP10*			
NaN	0.2502	0.0151*	0.7159	NaN	0.3436	0.0057*	0.1425	NaN	0.7486	0.1855	0.9734
0.2502	NaN	0.0205*	0.3877	0.3436	NaN	0.0115*	0.3513	0.7486	NaN	0.1303	0.8988
0.0151*	0.0205*	NaN	0.2239	0.0057*	0.0115*	NaN	0.1346	0.1855	0.1303	NaN	0.2681
0.7159	0.3877	0.2239	NaN	0.1425	0.3513	0.1346	NaN	0.9734	0.8988	0.2681	NaN

** indicates a significant difference, where p<0.05*

1b.)

Alpha band:

Sensor TP9				*Sensor AF8*				*Sensor TP10*			
NaN	0.5004	0.4572	0.5124	NaN	0.7792	0.0206*	0.5960	NaN	0.4600	0.7478	0.4473
0.5004	NaN	0.4046	0.8232	0.7792	NaN	0.0271*	0.6350	0.4600	NaN	0.8901	0.7728
0.4572	0.4046	NaN	0.2844	0.0206*	0.0271*	NaN	0.3839	0.7478	0.8901	NaN	0.6341
0.5124	0.8232	0.2844	NaN	0.5960	0.6350	0.3839	NaN	0.4473	0.7728	0.6341	NaN

** indicates a significant difference, where p<0.05*

1c.)

Gamma band:

Sensor TP9				*Sensor AF8*				*Sensor TP10*			
NaN	0.4117	0.0052*	0.4292	NaN	0.3963	0.0462*	0.1937	NaN	0.8619	0.0061*	0.2674
0.4117	NaN	0.0220*	0.1571	0.3963	NaN	0.0858*	0.4717	0.8619	NaN	0.0183*	0.5593
0.0052*	0.0220*	NaN	0.5190	0.0462*	0.0858*	NaN	0.2904	0.0061*	0.0183*	NaN	0.2903
0.4292	0.1571	0.5190	NaN	0.1937	0.4717	0.2904	NaN	0.2674	0.5593	0.2903	NaN

** indicates a significant difference, where p<0.05*

Qualitative Results

Qualitative results were interpreted using a 6 point scale of -3 to +3 (-3 to 0 describes the degree to which a participant's memory is unclear, and 0 to +3 describes the degree to which a participant's memory is clear) (*Table2)*.

Our qualitative analysis found that participants reported an equally clear short-term memory of paintings in the AR, VR, and real environments, while paintings viewed in 2D were less clear (*Table 3)*.

The results of the long-term memory assessment showed paintings in the 2D and VR environments were less clear than the real environment. Paintings in the AR environment were reported to be the most memorable in the long-term out of all four experimental environments, including the real environment.

Table 2. *Six point scale used by participants to assess their memory of each painting.*

Self-Assessment	Scale Value
Extremely Clear	3
Moderately Clear	2
Slightly Clear	1
Neither clear nor Unclear	0
Slightly Unclear	-1
Moderately Unclear	-2
Extremely Unclear	-3

Table 3. *Tables 3a and 3b show the sum of memory assessment ratings for each environment. Table 3a shows the results of the Short-term memory assessment, while table 3b shows the results of the long-term memory assessment.*

(3a)

SHORT-TERM MEMORY ASSESSMENT OF 5 PARTICIPANTS	
AVG(2D) Values	1.8
AVG(AR) Values	2.6
AVG(VR) Values	2.6
AVG(REAL) Values	2.6

(3b)

LONG-TERM MEMORY ASSESSMENT OF (SAME) 5 PARTICIPANTS	
AVG(2D) Values	0.6
AVG(AR) Values	1.6
AVG(VR) Values	0.6
AVG(REAL) Values	1.2

CONCLUSIONS & FURTHER RESEARCH

Alpha activity, characterized by its 8-12 Hz rhythm found in EEG, is detected in the brain during times of relaxation, calmness, sensory perception, passive memory recall, or peaceful state. Gamma activity, the fastest frequency band that is characterized by anything over 30 Hz for EEG, is characterized by hyperactivity or processing information across different areas of the brain (Herrmann, 2001). Together, alpha's indication of subdued relaxation in direct contrast to gamma's indication of high concentration, tell a well-rounded story of a participants experience in all four of the experimental environments.

The data show the greatest difference in gamma activity at all sensors in the AR vs 2D and AR vs VR environments, whereas the greatest difference in alpha brain activity was only found at the AF8 sensor location. However, gamma data also show that the brain processes information similarly to observing a real painting hung in a gallery than it does to paintings shown in any of the 3 digital environments. With a closer examination of brain activity among the digital environments, we found that information processing is higher in the VR and AR environments than the 2D environment as evidenced by the results of our FFT analysis, and supported by the participants' memory reporting. Overall, participants reported a clearer memory of the painting in AR after a week or more of time since visiting the museum, therefore the AR environment may elicit the best long-term memory recall. In summary, technology seems to be on par with an authentic museum experience in terms of information processing, particularly when viewing a painting in augmented reality.

Our current EEG findings would suggest that aesthetic experience is not denigrated by a digital interface representation and, in fact, digital reproductions in the case of augmented reality are shown to *improve* magnitude of brain activity compared to the viewing of original works of art. This finding is supported by conscious self-reports from the participants following their study sessions as mentioned in the paragraph above.

Further research to improve upon our present results could be done with the EEG analysis of participants who do not remain stationary during their sessions, but instead move through a museum environment to be compared to the stationary perception of digital reproductions using at-home technology. Movement would create a stronger facsimile of a true museum experience, and results would reflect more closely a person's authentic experience across all four environments. Additionally, the current study used paintings for each of the four experimental environments in order to remain consistent and so that no variables were added to the experiment that could affect a participant's experience beyond the tested environment. Future research that seeks to understand the perception of other forms of art (e.g. statue, photographs, or performance art) in their authentic form versus mechanical reproduction, would form a well-rounded answer to just how much importance lies in real artwork.

While the results found in this study would likely be met with outrage from Walter Benjamin in 1935, they demonstrate just how far technology has gone to improve digital experience in art and show promise that digital interfaces have the potential to amplify a museum-goer's experience.

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