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RESEARCH REPORT

Interactive Digital Engagement With Visual Artworks and Cultural Artefacts Enhances User Aesthetic Experiences in the Laboratory and Museum

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ABSTRACT
Digital technologies reshape the way we interact with our environment, including with artworks. Advanced computational imaging solutions allow having extremely high-resolution digital reproductions of artworks outside museums, presumably increasing artwork engagement. We tested whether exploring such reproductions via an interactive interface heightened aesthetic appreciation and enhanced recognition. With this interface, observers can move, turn, zoom, and relight the digital reproductions (http://artmyn.com/; https://osf.io/3srfw/). In Study 1, 82 participants explored paintings in the laboratory. In Study 2, 63 participants explored precious cultural artefacts in the museum. In both studies, participants' aesthetic appreciation (interest, pleasure, intensity, subjective learning) was higher towards artworks they had explored interactively as compared to non-interactively or as physical objects, highlighting the advantage of the tested technology. However, we found no evidence that interactive exploration improved artwork recognition. More studies are needed to learn when and why digital interaction is beneficial above and beyond subjective aesthetic evaluations.

1. Introduction

High-resolution computer technologies, combined with increasingly powerful online streaming possibilities, reshape the way we interact with our environment. We can finally explore foreign places and objects in unprecedentedly high detail. Just think of precious historical artefacts and art pieces, tugged away or hidden behind protective glass in museums, often to be admired from afar. But this is changing, being excellent news for art lovers. Museums are adapting to the digital engagement of visitors, by, for example, putting their collections online or implementing augmented reality (e.g., Bianchini, 2021). At present, research has only started to investigate the impact of digital engagements, and its optimal use remains a puzzle (e.g., Rodriguez-Boerwinkle et al., 2022; Trupp et al., 2022). If you were a museum curator, you may argue that digital engagements might boost a desire to visit the museum to see the artworks in real life. Or you might think that such an experience might create the impression that one has seen the artworks already, reducing the likelihood to physically come to the museum. One way or another, digital interfaces are finding their ways to museums.

Experiencing cultural environments in reality or digitally is unlikely to be the same. Museums are places where people deliberately go to experience and learn about culture (Smith, 2014). Just being in this context makes artworks more interesting, more liked, and more memorable (Brieber et al., 2014, 2015). When visiting a museum, a highly interested observer not simply screens a painting from the front, but might walk around it, looking at changes in the coloring, shadows, and texture that comes with the application of the painting coats and pigments (Carbon, 2020). Moreover, in museums, visitors interact with genuine ("real") physical artworks, while digitally, people interact with reproductions ("copies" or "digital twins") of the artworks. The quality of reproductions varies, and so do their interactive possibilities.

Most digital reproductions of artworks consist in taking a two-dimensional (2D) photograph, which removes perceptual richness and textural depth. Obviously, digital experiences can be enhanced in various ways, for instance, by increasing color saturation (Reymond et al., 2020), boosting resolution of reproductions (Bertamini & Blakemore, 2019), or creating immersive interactive artwork experiences (Marín-Morales et al., 2019). An example of an interactive experience is augmented reality, which combines the real and the virtual worlds

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through a device (often a smartphone). In an empirical study, participants spent more time on an individual painting as well as reported more flow and felt having learned more about it when using augmented reality as compared to participants using standard audio guides in a museum (Chang et al., 2014).

For the current studies, we worked with the start-up company ARTMYN (http://artmyn.com/; https://osf.io/3srfw/), which uses advanced computational imaging solutions allowing for high-resolution scanning of artworks and cultural artefacts, some reaching a billion pixels depending on the original size. The resulting three dimensional (3D) digital scans can be explored according to the observers' liking through an interactive digital interface. Observers can zoom deep into the artworks and cultural artefacts to see the relief of paint brush strokes and appreciate materiality. They can manipulate the pieces by moving and turning them to bring them into any desired viewpoint; or they can relight them by virtually changing the position of illumination, as a curator would do with the real artefact. Such manipulations are likely important for the full appreciation of an artwork, especially when dealing with priceless artworks and artefacts, often hidden behind glass for touch and light protection.

The goal of the studies presented here was to investigate whether such sophisticated exploration possibilities enhanced aesthetic appreciation and recognition of the material at hand. In two studies, we allowed participants to explore visual artworks and cultural artefacts with the digital interface and collected self-report aesthetic appreciation measures and recognition memory. We performed two studies, once under laboratory-controlled conditions and once in the field, namely directly in a museum setting. To measure aesthetic appreciation, we asked four questions regarding experienced aesthetic pleasure, interest in the artwork, intensity of exploration, and feelings of having learned. These measures tapped into the different components of aesthetic evaluation, both cognitive (interest, learning) as well as affective (pleasure, intensity; see Leder et al., 2004; Leder & Nadal, 2014, for the theoretical model). To measure recognition memory, we presented participants with the pictures of the material they had explored (or not) and asked whether they recognized them and to which degree of certainty. Additionally, we collected information on participants' art background and their general appreciation of the interface.

The first study enabled us to control the presentation of the artworks in the laboratory and eliminate any random effects arising from pre-existing differences in the appreciation scores of the artworks. That is, some artworks might have been more aesthetically pleasing than others irrespective of the interactive possibility. Participants explored the artworks either as physical objects or via the digital interface, or a combination of both. The digital interface was set to one of two possible modes—interactive or non-interactive. The interactive mode had all the interactive features, such as manipulation of the artwork and zooming, activated. The non-interactive mode displayed a high-resolution 2D image of the artwork. We collected participants' responses to the aesthetic appreciation and recognition questions at two time points: immediately (short-term assessment) and about a month later (long-term assessment).

In the second study, we installed the digital interface in a museum, where participants could explore cultural artefacts and their digital reproductions directly in the exhibition space (some interactively and others non-interactively). They also saw the real artefacts during their museum visit. In addition to bringing the digital interface into the real world, the second study differed from the first one as we tested the digital interface with a different kind of objects (i.e., paintings vs. cultural artefacts) and with different users (i.e., university students vs. museum visitors). We collected the same measures (i.e., aesthetic appreciation measures, recognition, art background, and general appreciation of the interface) in both studies to establish whether the results were reproducible in different experimental settings and participant samples. We expected the interactive digital exploration to boost participants' aesthetic experiences and recognition as compared to the non-interactive exploration since the interactive experience with the artworks and artefacts should be more complete and engaging (similar to Chang et al., 2014).

2. Method

2.1. Participants

Study 1 was conducted in a controlled laboratory environment at the University of Lausanne, Switzerland, in autumn 2016. Eighty-two first year psychology students (10 men) took part in the study (time 1), with a mean age of 22.30 years (SD_{age} = 6.52, range = 18–48 years). We invited all participants to return about a month later for the follow-up questions of the study (time 2). Four participants dropped out, leaving us with 78 participants (10 men, M_{age} = 22.10, SD_{age} = 6.40). Participants were not color-blind as confirmed with the Ishihara color vision deficiency test (Ishihara, 1993) and reported otherwise normal or corrected-to-normal vision. Participants were remunerated with course credit.

Study 2 was conducted at the *Fondation Martin Bodmer* museum in Cologny (Geneva), Switzerland, in spring 2016. The museum is home to historical artefacts and treasures, covering the age of about 5000 years. The experimenters were present in one of the museum spaces, close to the reception. There, they invited museum visitors to take part in our study at their convenience. We collected data from 63 adult visitors (29 men), with a mean age of 43.80 years (SD_{age} = 14.09; range = 19–72 years, 12 visitors did not provide age information). We additionally collected data from 15 children (6 boys, M_{age} = 12.5 years, SD_{age} = 2.1 years) during their school visits, which we did not analyze further (full data available at https://osf.io/3srfw). The latter visitors were much younger and arrived in groups with their teacher. All participants had normal or corrected-to-normal vision. Participants did not receive remuneration for the experiment.

Based on the power calculations, we needed at least 64 participants in Study 1 and 45 participants in Study 2 to

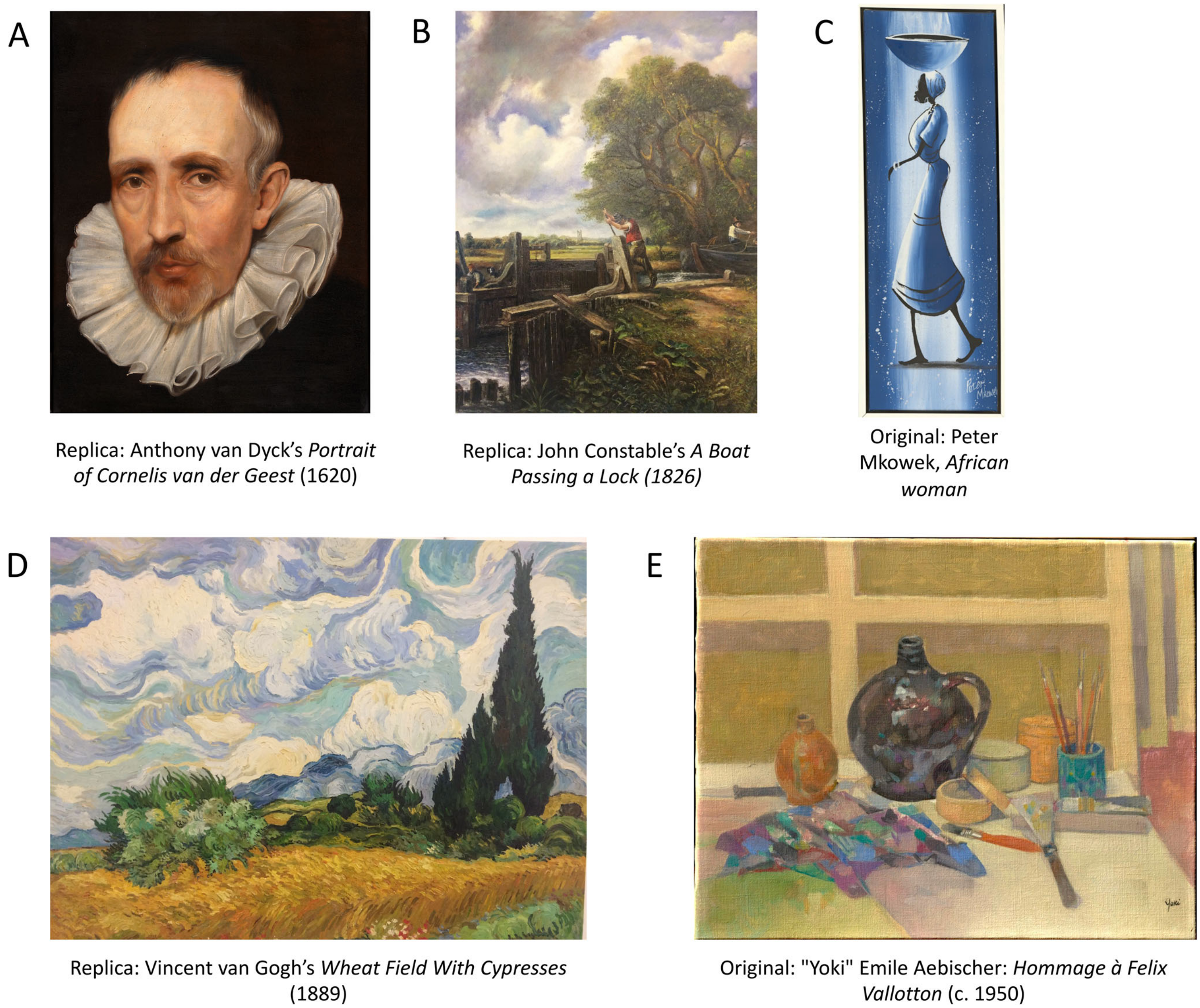

Figure 1. The five paintings presented interactively, non-interactively, and as physical objects in Study 1 in the laboratory.

achieve a power of 0.80, assuming a medium effect size, in the MANOVA tests on aesthetic variables (*WebPower* R package, Zhang & Mai, 2018). We recruited students taking part in the introductory course on Methods in Experimental Psychology for Study 1 and all museum visitors for Study 2, willing to take part in the experiment during the recruitment period. We exceeded the required minimum sample size in both studies. Both studies were conducted in French and in accordance with the principles of the Declaration of Helsinki (World Medical Association, 2013). The studies did not receive an explicit ethics approval since it was not required for behavioral experiments in the local canton.

2.2. Material

2.2.1. Paintings (Study 1)

In Study 1, we used five paintings that we presented as physical objects as well as their digital scans (see *Digital Interface: Interactive and Non-Interactive Digital Scans* and Figure 1). The five paintings were: (i) a replica of Anthony van Dyck's *Portrait of Cornelis van der Geest* (1620) (ii) a replica of Vincent van Gogh's *Wheat Field With Cypresses* (1889); (iii) a replica of John Constable's *A Boat Passing a Lock* (1826); (iv) an original still life by "Yoki" Emile Aebischer: *Hommage à Felix Vallotton* (c. 1950); and (v) an original painting of an African woman by Peter Mkowek. The physical paintings were painted on canvas and of a similar size to the originals.

Each painting was prepared for the following conditions: (i) an interactive digital 3D scan (i.e., interactive), (ii) a non-interactive digital 2D image (i.e., non-interactive), (iii) real physical painting (i.e., physical), (iv) an interactive digital scan and real physical painting (i.e., interactive & physical), and (v) non-interactive digital scan and real physical painting (i.e., non-interactive & physical).

Each participant was run through the five conditions, consequently seeing four of the paintings digitally (two interactive, two non-interactive) and three paintings physically, which also meant that each participant saw three of the paintings once and two paintings in a dual presentation mode. We randomized between participants which paintings were shown in which condition.

2.2.2. Cultural artefacts (Study 2)

In Study 2, we worked with six artefacts (i.e., cultural objects, Figure 2) that were part of a larger selection of objects that had already been digitally scanned (https://artmyn.com/explore/search?pattern=&category&movement&sort=title&collection=D3MZ7b) and were currently on display in the exhibition space at the *Fondation Martin Bodmer* (https://fondationbodmer.ch/en/). Half of the artefacts were presented as interactive digital scans (Cuneiform tablet, Mandorle, Roman coin) and the other half as non-interactive digital scans (Gutenberg's Bible, the New Testament, Roman diploma).

2.2.3. Digital interface: Interactive and non-interactive digital scans

We presented high-quality digital scans of paintings (Study 1) and artefacts (Study 2) on a digital table which was connected to a high-resolution screen (see an interactive example here: https://artmyn.com/explore/viewer/150 and a video showing the interaction here: https://osf.io/kptdq). These scans were obtained using the following technique (Baboulaz et al., 2018). The artworks or artefacts of interest were placed on the bed of the imaging device that captures thousands of high resolution images in various light conditions. This set of images is then processed using advanced computational machine-learning algorithms that extract the relevant maps such as depth, color, and apparent reflectance of the artwork or artefact. The resulting data is optimized for online visualisation to allow for a free and real-time manipulation of the artwork on a web browser (see an introductory video here: https://osf.io/e4qfs).

Participants used a Microsoft Surface touch tablet to interact with the scans from a full-screen web browser. The display of the tablet was also mirrored to a LG OLED 4 K 55'' screen located 2.5 meters in front of them. Participants could therefore observe the scans either directly on the tablet or on the screen. For the interactive scans, participants could manipulate the images by rotating or tilting them, zooming in and out, changing the location or angle of the light, or using a spotlight feature to focus on a particular section of the artefact. For the non-interactive scans, we only showed fixed images of the same scans (i.e., the starting position of the interactive condition). All participants received a short tutorial video before starting their exploration of the interactive images. Thus, we ensured that everyone knew what they could explore when using the digital interface.

2.2.4. Recognition memory and art appreciation

In Study 1, we used a photograph of each painting intermixed with photographs of control paintings. In Study 2, we used two photographs of each artefact—once as it appeared in the museum and once as it appeared digitally on the tablet.

For each painting or artefact, we asked four recognition and four aesthetic appreciation questions (see Table 1). First, we asked participants if they remembered seeing the piece as a physical object in the lab (Study 1) or in the museum (Study 2), testing recognition memory. Then, we asked them if they remembered seeing the piece as a digital object on the tablet. In addition to a simple yes/no response, participants also rated the certainty of their answers (i.e., recognition certainty).

Participants who responded *yes* to at least one of the two recognition questions received the aesthetic appreciation questions. If they responded *no* to both recognition questions, they moved to the next question. We chose these aesthetic appreciation questions based on the existing theoretical model (Leder et al., 2004; Leder & Nadal, 2014) to capture affective (i.e., pleasure, intensity) and cognitive (i.e., interest, learning) components of aesthetic evaluation. As these questions measure distinct aspects of an aesthetic evaluation, we analyzed them individually instead of computing a composite score. Other longer (e.g., Schindler et al., 2017) and shorter (e.g., Brieber et al., 2014) measures of aesthetic evaluation also exist.

2.3. Procedure

2.3.1. Study 1

The experiment was set up in an experimental room with physical paintings hanging on standing panels. The digital interface was located in the corner of the room. For the latter, we used a high-definition screen with a tablet attached to it. For each participant, we used sheets of cardboard to hide the physical paintings when they were only presented digitally.

After arriving to the laboratory, participants received written study information, before being asked to sign an informed consent form (see Figure 3). They then performed the Ishihara color vision deficiency test. Half of the participants went on to explore the paintings on the digital interface and then saw the physical paintings while the other half first saw the physical paintings and then did the digital exploration. Participants were free to take the time they wished for the digital and physical explorations. While participants were exploring the paintings digitally, the physical paintings had been hidden. While participants were exploring the paintings physically, the digital interface had been turned off. Thus, at any given time, participants saw the paintings on one medium only.

The digital exploration started with a tutorial video, always of the same painting, which was not used in the actual study. Participants were introduced to possible features of the digital interface and then given a chance to interact with it and get feedback from the experimenters. Once participants reported being comfortable with the interface, the experiment started. Each participant saw four paintings in random order. When faced with an interactive painting, participants used the tablet to explore the paintings and were encouraged to also watch it on the bigger screen, attached to the tablet. When faced with a non-interactive painting, participants were encouraged to enjoy the painting on the screen without being able to manipulate it. The physical exploration started with experimenters guiding participants to the paintings, in randomized order. Participants

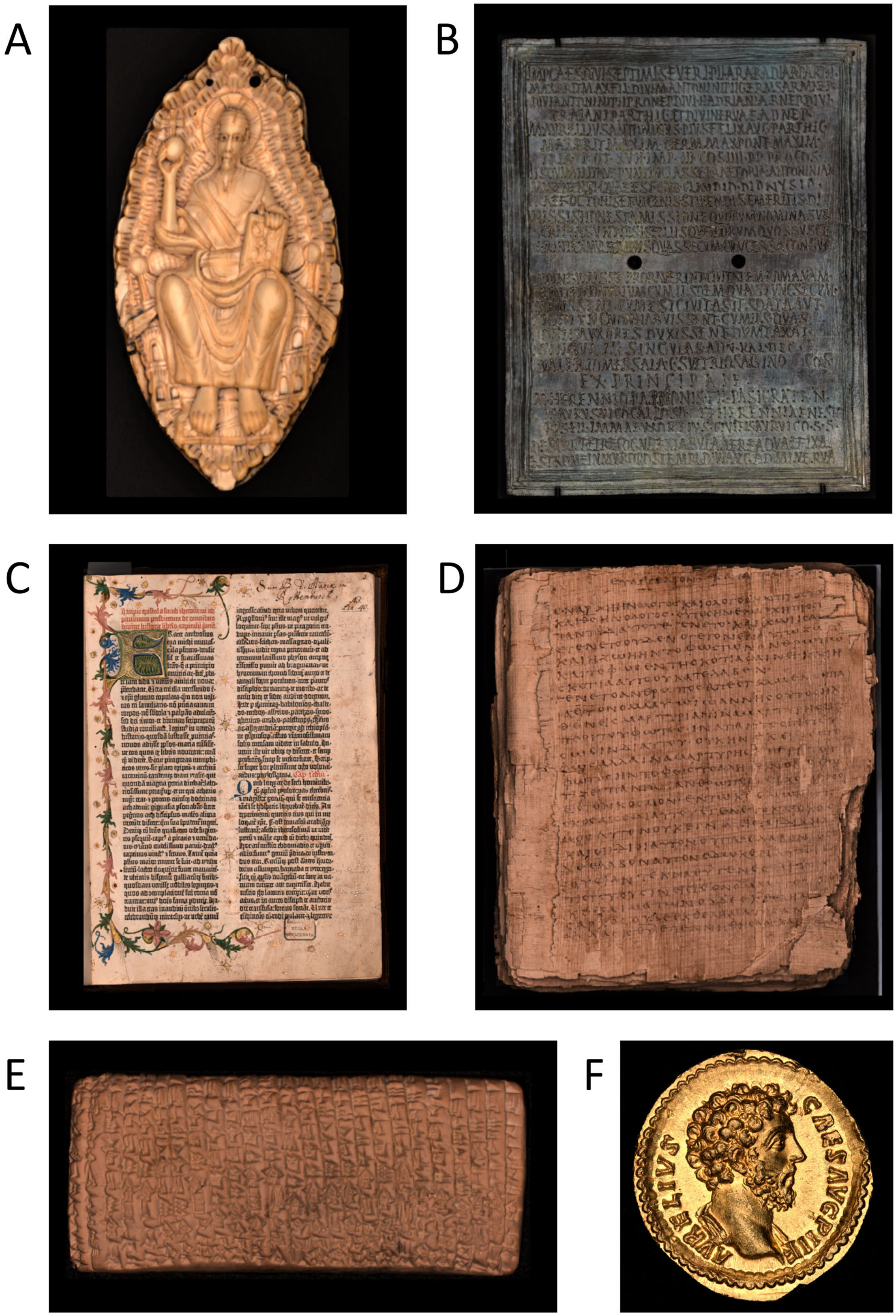

Figure 2. The six cultural artefacts presented interactively and non-interactively in Study 2.
(A) Mandorle (interactive)—an ivory figurine from Spain representing Christ in Majesty; (B) Roman diploma (non-interactive)—a stone diploma for a veteran of the Roman imperial fleet (Marcus Herennius Pasicrated), given by the emperor Caracalla to acknowledge his 26 years of duty; (C) Gutenberg's Bible (non-interactive)—The "Gutenberg" or "42-line" Bible, which was the first complete book to be printed in a movable type. Participants digitally interacted with the page 293 but two open pages in the museum were regularly changed to preserve the artefact; (D) New Testament (non-interactive)—two papyrus pages containing the Gospel of Saint John. The Bodmer manuscript is one of the oldest substantial copies in the world; (E) Cuneiform tablet (interactive)—a stone tablet containing documents of commercial trading, administrative archives, and cosmetics recipes from Sumerian times; (F) Roman coin (interactive)—a golden coin representing Auguste, the founder of the Roman Empire and the first Roman emperor, who ruled between 27 BC and 14 AD. These artefacts were available on display at the *Fondation Martin Bodmer* museum in Switzerland, and can be accessed digitally here: https://artmyn.com/explore/search?collection=D3MZ7b

Table 1. Questionnaires used in Studies 1 and 2.

Question group	Variable	The question	Response options
Demographics	Age	What is your date of birth?	Date
	Gender	What is your gender?	Masculine/ feminine
Cultural interest and art training	General importance of culture	Is this type of cultural heritage important to you?	1 (not at all)—5 (very much)
	Art training	To what degree do you have training in the arts domain?	1 (not at all)—5 (very much)
	Art interest	To what extent are you interested in art?	1 (not at all)—5 (very much)
Digital interface appreciation	Attraction to the digital interface	To what extent were you spontaneously attracted by the application on the tablet?	1 (not at all)—5 (very much)
	Appreciation of the digital interaction	To what extent did you appreciate the interaction with the tablet to explore the works of art?	1 (not at all)—5 (very much)
	Motivation to use the digital interface at home	Would you like to explore these works of art at home as you have just done?	1 (not at all)—5 (very much)
	Motivation to recommend the interface	Would you recommend the tablet to your friends?	1 (not at all)—5 (very much)
Recognition memory	Physical/museum recognition	Have you seen this painting hanging on the wall during the experiment? / Have you seen this artefact in the museum?	Yes/No
	Certainty of physical/ museum recognition	To what extent are you sure about it?	1 (not at all)—5 (very much)
	Digital recognition	Have you seen this work of art on the tablet?	Yes/No
	Certainty of digital recognition	To what extent are you sure about it?	1 (not at all)—5 (very much)
Aesthetic appreciation	Aesthetic pleasure	To what extent did you find this work of art aesthetically pleasing?	1 (not at all)—5 (very much)
	Interest in the artwork	To what extent were you interested by this work of art?	1 (not at all)—5 (very much)
	Intensity of exploration	With which intensity did you explore this work of art?	1 (not at all)—5 (very much)
	Feelings of having learned	Do you think you learned a lot about this work of art?	1 (not at all)—5 (very much)

Note. Recognition memory and aesthetic appreciation questions were measured separately for each painting (Study 1) and each cultural artefact (Study 2). The original questionnaires were conducted in French, which can be accessed here (supplemental Table S1): https://osf.io/3srfw/

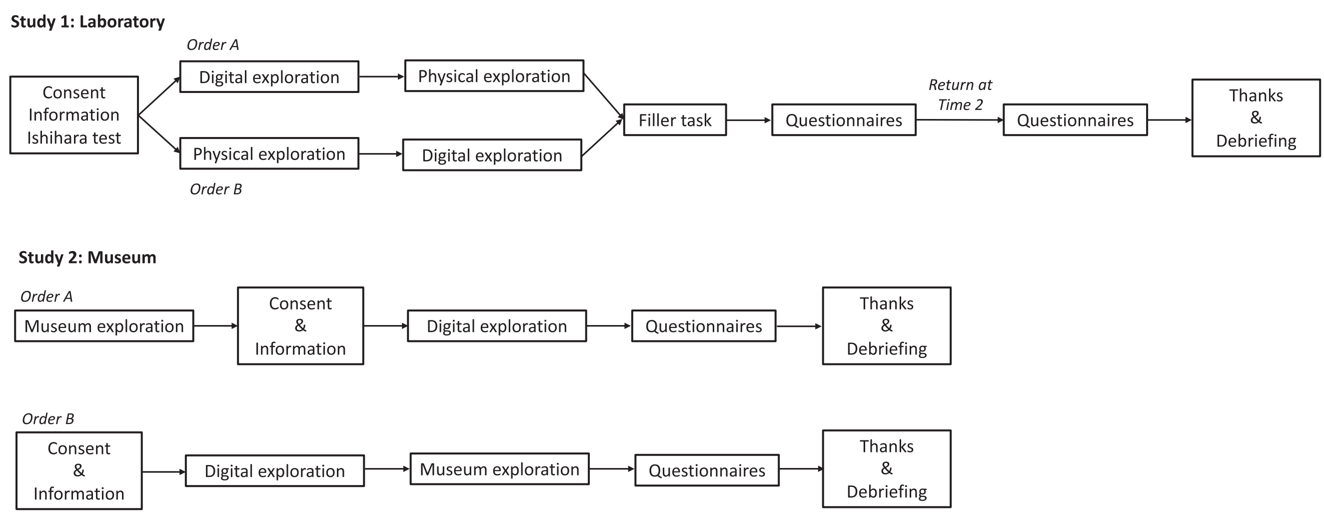

Figure 3. Procedure of Study 1, conducted in the laboratory, and Study 2, conducted in the museum.

were encouraged to simply look at the paintings as if they would in a museum setting.

After both explorations, participants went to a different room and completed a filler task—the International Color-Emotion Association Survey (Jonauskaite, Abu-Akel, et al., 2020; Mohr et al., 2018), which took about 10–15 min to complete. The latter data are part of larger datasets that were used in independent publications (Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020). The goal of the filler task was to create a break between the artwork exploration and the evaluation of memory and appreciation.

After the filler task, participants responded to the questionnaires, implemented on the LimeSurvey platform (see Table 1). In addition to being presented with the pictures of the paintings they had just explored, participants saw control paintings to make recognition less obvious. As control paintings, we chose two similarly looking paintings for each painting of interest, resulting in 10 additional paintings in total. After the questionnaires, participants were thanked and invited to return to the second part of the experiment at time 2. The experiment took about 1 h to complete, with the questionnaire part lasting on average 11 min.

Participants returned to the laboratory about a month later (time 2, $M = 28.3$ days, $SD = 8.24$ days, range = 8–46 days). They completed questions on recognition and aesthetic appreciation in relation to the paintings they had seen at time 1, as well as to 10 new control paintings. This time, participants did not interact with the paintings. The second part of the experiment took about 10–15 min to complete, after which participants were thanked and fully debriefed.

2.3.2. Study 2

We had two months for data collection. We invited all museum visitors to take part in our study (see Figure 3). About two thirds of the participants who agreed to participate ($n = 45$) first saw the artefacts in the museum and then explored the artefacts' digital scans (order A). The remaining third of the participants ($n = 18$) first explored the digital scans and then visited the museum (order B). It was not possible to tell the visitors when to visit the exhibition or when to do the experiment. Many visitors learned about the experimental set-up only at the end of their visit. Participants received comprehensive study information prior to giving written informed consent. Experimenters were available for questions throughout the study.

After having been in contact with the interactive or non-interactive scans on the digital interface, participants responded to the questionnaire, which we had implemented on the LimeSurvey platform (see Table 1). At the end of the study, participants were invited to give additional comments or ask questions. They then were thanked and debriefed. The questionnaire part took about 12 min to complete.

2.4. Statistical analyses

We had two groups of participants—students in Study 1 and museum visitors in Study 2. Thus, we first compared the two groups of participants on their socio-demographic data, reported in the participant section, and on other measures—(i) the cultural interest and art training, and (ii) the digital interface appreciation scores. For the latter two types of measures, we used the between-subjects MANOVA tests (see Table 1 for the exact questions and variables). Since we measured digital interface appreciation twice in Study 1, for the comparison between the two studies, we only considered scores on time 1. Participants in Study 2 were self-selected museum visitors, likely more interested in culture and art, than participants in Study 1, who were first year psychology students. Differences in the results of the two studies might be rooted in the differences between the participants.

Furthermore, to measure any potential change in the appreciation scores of the digital interface over time, we compared the responses between time 1 and time 2 of Study 1 using within-subjects MANOVA tests.

2.4.1. Recognition memory

We analyzed data from each study separately. To analyze the differences between conditions for the recognition memory, we created a new variable called *degree of certainty when recognized correctly* (or in short, *recognition certainty scores*). First, we weighed participants' recognition responses (yes/no) by their degree of certainty. We multiplied the degree of certainty for "No" responses by -1. This transformation resulted in variables ranging from -5 (very sure did not see this painting/artefact) to 5 (very sure I saw this painting/artefact). Such transformation was sufficient for Study 2 because we assumed that participants saw all the artefacts both on the digital interface and in the museum, and so the correct answer should always be "Yes." For Study 1, we implemented an additional step. We took into account whether participants actually saw the painting in the condition that we enquired about or not. For instance, if participants were shown a particular painting in the interactive condition, we then also asked whether they saw this painting hanging on the wall. The correct response would be "No." In such cases, we reversed the recognition certainty scores, multiplying them by -1. The final variable ranged from -5 (very sure did not see this painting but the painting was shown/very sure I saw the painting but the painting was not shown) to 5 (very sure I saw this painting and the painting was shown/very sure I did not see this painting and the painting was not shown).

We analyzed recognition certainty scores with repeated measures ANOVA tests, separately for Study 1 and Study 2. In Study 1, our independent within-subjects variables were condition (five artwork conditions: interactive, non-interactive, physical, interactive with physical, and non-interactive with physical), location (digital interface or physically hanging on the wall), and time (time 1, time 2). In the full model, we included participants who took part at both time points but used all the data for any further, more specific comparisons. In Study 2, our independent within-subject variables were condition (two conditions, interactive or non-interactive) and location (digital interface or museum). The dependent variable in both studies was the recognition certainty score, derived as explained above.

2.4.2. Aesthetic appreciation

We analyzed aesthetic appreciation scores with repeated-measures MANOVA tests, separately for Study 1 and Study 2. Our independent within-subject variables were condition, location, and time (only in Study 1). Our dependent variables were responses for the questions relating to aesthetic pleasure, interest in the artwork, intensity of exploration, and feelings of having learned (see Table 1 for the exact questions and variables). We followed up significant results with ANOVA tests and paired *t*-tests. We conducted these tests on data from participants who remembered seeing all the artworks. Participants who did not remember the artworks, did not rate them on the aesthetic appreciation variables. This resulted in missing data for these participants and these artworks. Therefore, the sample size for the full model is smaller than for the individual comparisons. We report the exact sample size for each test in the results section.

In all cases, when running multiple paired t-tests, we controlled for the family-wise error, arising from multiple comparisons, with the False Discovery Rate (FDR) correction (Benjamini & Hochberg, 1995). The alpha level was set to 0.050, and the statistical analyses were conducted using R (v 4.2.0) and SPSS 27 software. Readers can access the full data here: https://osf.io/3srfw

3. Results

3.1. Cultural interest and art training

The MANOVA test showed that participants in Study 1 differed from those in Study 2, Pillai's Trace = .977, $F(7, 137)$

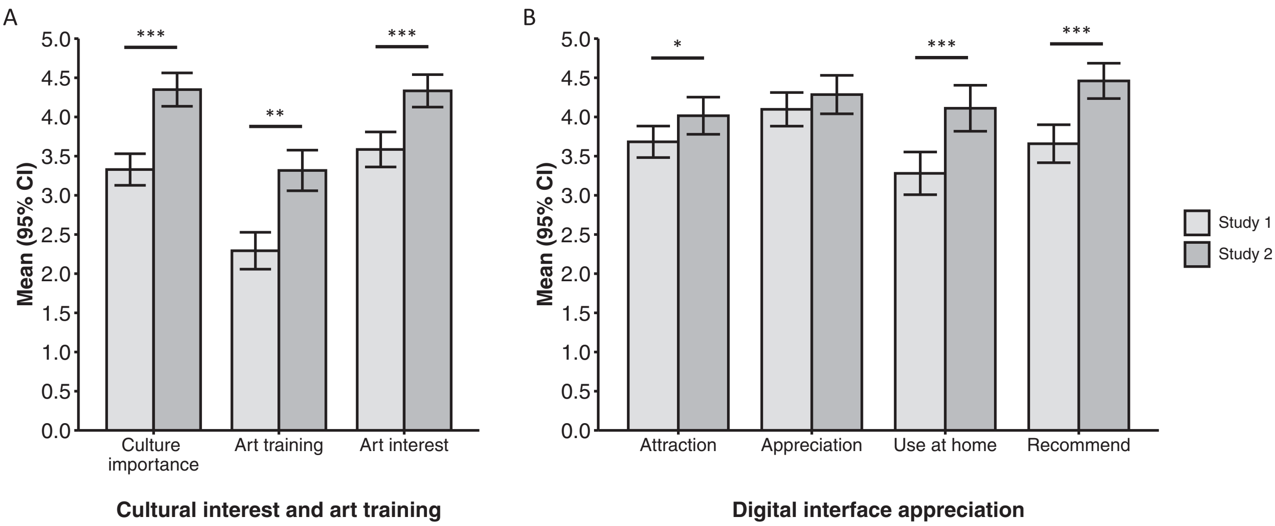

Figure 4. (A) Cultural interest and art training questions; (B) Digital interface appreciation questions—a comparison between Study 1 (time 1), conducted in the laboratory, and Study 2, conducted in the museum. For complete questions, see Table 1. Error bars mark 95% CI. Significance coded as such: $*p \leq 0.050$, $**p \leq 0.010$, $***p \leq 0.001$ (FDR adjusted).

Table 2. The number of participants (n) and percentage from total (%) who correctly recognized paintings (Study 1) and artefacts (Study 2) under different conditions.

	Study 1 (time 1)				Study 1 (time 2)				Study 2			
	Digital interface		Physical painting		Digital interface		Physical painting		Digital interface		Physical artefact	
	n	%	n	%	n	%	n	%	n	%	n	%
Interactive	75	91.46	64	78.05	64	81.01	62	78.48	61	96.83	48	76.19
Non-interactive	76	92.68	68	82.93	60	75.95	66	83.54	57	90.48	52	82.54
Physical	72	87.80	71	86.59	67	84.81	53	67.09	NA	NA	NA	NA
Interactive & physical	78	95.12	78	95.12	62	78.48	61	77.22	NA	NA	NA	NA
Non-interactive & physical	76	92.68	77	93.90	52	65.82	58	73.42	NA	NA	NA	NA

= 832, $p < 0.001$, partial η^2 = .977. Participants in Study 2 had higher art training, $F(1; 143)$ = 33.73, $p < 0.001$, partial η^2 = .191, higher general interest in culture, $F(1; 143)$ = 22.63, $p < 0.001$, partial η^2 = .137, and assigned higher importance to artworks, $F(1; 143)$ = 47.14, $p < 0.001$, partial η^2 = .248, than participants in Study 1 (Figure 4(A)). Museum visitors in Study 2 were also significantly older than participants in Study 1, $t(63.5)$ = 10.24, $p < 0.001$.

3.2. Digital interface appreciation

Based on the same MANOVA test, participants in Study 2 felt more attracted to the digital interface, $F(1; 143)$ = 4.60, $p = 0.034$, partial η^2 = .031, more motivated to use the interface at home, $F(1; 143)$ = 16.84, $p < 0.001$, partial η^2 = .105, and indicated being more likely to recommend it to their friends, $F(1; 143)$ = 22.12, $p < 0.001$, partial η^2 = .134, than participants in Study 1. Nonetheless, participants of both studies appreciated the exploration on the digital interface to the same extent, $F(1; 143)$ = 1.33, $p = 0.252$, partial η^2 = .009 (see Figure 4(B)).

In Study 1, when comparing responses on the digital interface appreciation questions between the first and the second assessments, the MANOVA test was not significant, Pillai's Trace = .062, $F(4, 75)$ = 1.23, p = .304, partial η^2 = .062. Thus, overall, participants evaluated the digital interface similarly immediately after the experiment and a month later. There were no differences on any of the individual digital interface appreciation measures either, $Fs(1, 78) \leq 2.69$, $ps \geq .105$, partial $\eta^2 \leq .033$ (see Table 1 for the measures)

3.3. Recognition memory

3.3.1. Study 1

Most participants recognized paintings correctly (see Table 2). The ANOVA model on participants' recognition certainty scores showed the main effect of time, $F(1, 78)$ = 56.88, $p < 0.001$, partial η^2 = .422, as participants reported higher certainty at time 1 than time 2. There was no main effect of condition, $F(4, 312)$ = 0.85, p = .492, partial η^2 = .011, or location, $F(1, 78)$ = 2.20, p = .142, partial η^2 = .027. The two-way interaction between condition and time was significant, $F(4, 312)$ = 3.78, $p = 0.005$, partial η^2 = .046, and so was the three-way interaction between condition, location, and time, $F(4, 312)$ = 3.91, $p = 0.004$, partial η^2 = .048. Figure 5(A) displays the only significant difference between the conditions at time 1. When asked whether they had seen the paintings physically, participants recognized paintings which they had explored both interactively and as physical paintings with a higher certainty than when responding to the paintings explored interactively (the correct response would have been "No"). The two-way interactions between condition and location, $F(4, 312)$ = 2.26, $p = 0.063$, partial η^2 = .028, and location and time, $F(1, 78)$ = 2.02, $p = 0.160$, partial η^2 = .025, were not significant.

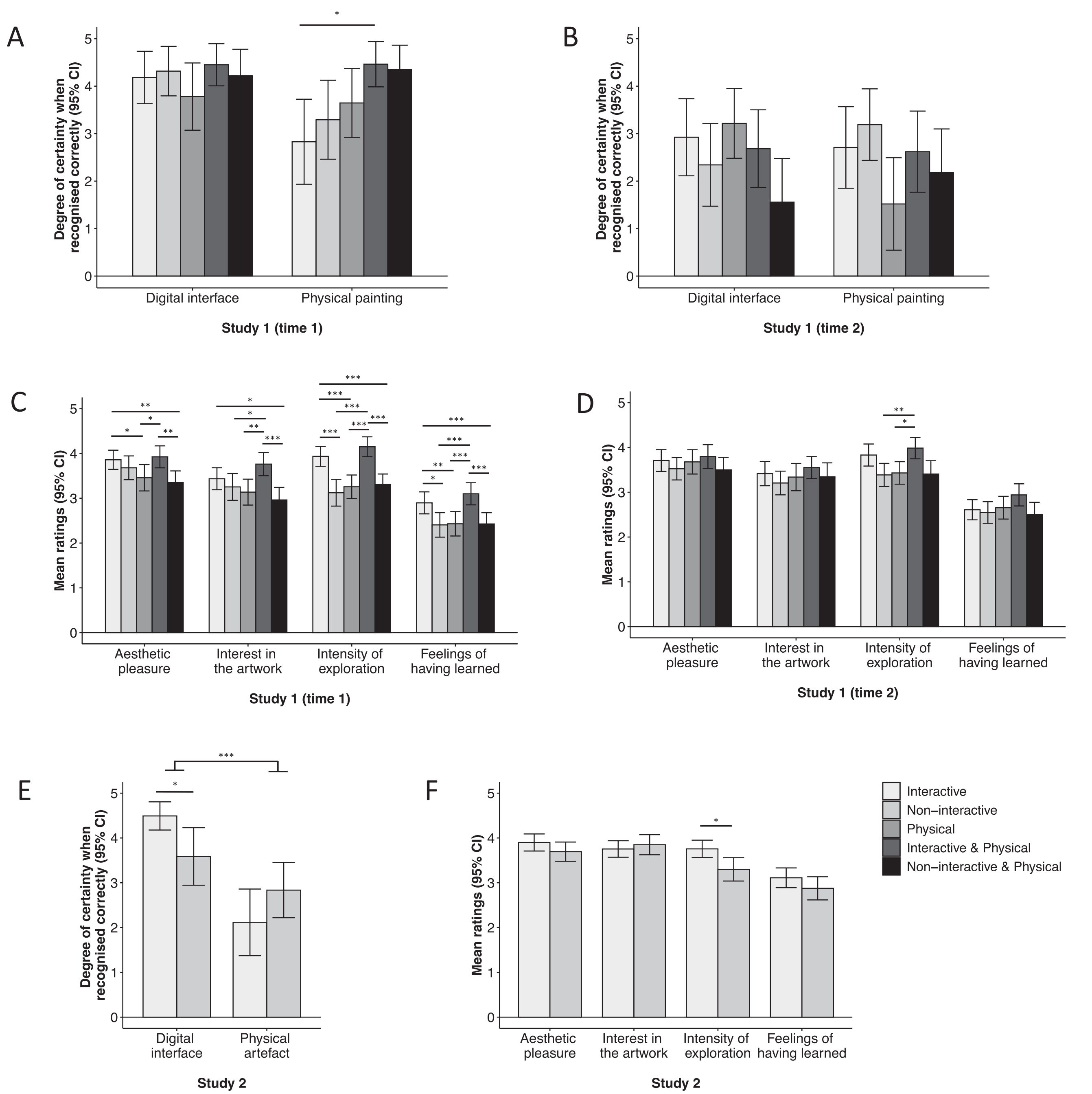

Figure 5. Cognitive and affective variables measured in Studies 1 and 2. (A) Recognition certainty at time 1, Study 1; (B) Recognition certainty at time 2, Study 1; (C) Aesthetic appreciation at time 1, Study 1; (D) Aesthetic appreciation at time 2, Study 1; (E) Recognition certainty in Study 2; (F) Aesthetic appreciation in Study 2. Error bars mark 95% CI. Significance coded as such: $^{*}p \leq 0.050$, $^{**}p \leq 0.010$, $^{***}p \leq 0.001$ (FDR adjusted).

3.3.2. Study 2

Most participants recognized artefacts correctly (see Table 2). The ANOVA model on participants' memory certainty scores showed the main effect of location (museum vs. digital interface), $F(1, 62) = 21.43$, $p < 0.001$, partial $\eta^2 = .257$. Participants remembered artefacts with a higher certainty when seen on the digital interface than in the museum (Figure 5(C)). The main effect of condition was not significant, $F(1, 62) = 0.10$, $p = .755$, partial $\eta^2 = .002$, but the interaction between location and condition was significant, $F(1, 62) = 12.37$, $p < 0.001$, partial $\eta^2 = .166$. Participants remembered better artefacts which they had explored interactively as compared to the non-interactive exploration, but this effect was only present for the digital interface mode (Figure 5(C)).

3.4. Aesthetic appreciation measures

3.4.1. Study 1

The MANOVA test showed a significant main effect of the artwork condition, Pillai's Trace = .338, $F(16, 304) = 1.75$, $p = 0.037$, partial $\eta^2 = .084$, $n = 20$, suggesting that participants' evaluation on aesthetic appreciation variables differed by condition. Immediately after the experiment (time 1), the

ANOVA tests showed a main effect of the artwork condition on aesthetic pleasure, $F(4,\ 240) = 4.72$, $p = 0.001$, partial $\eta^2 = .073$, $n = 61$, interest in the artwork, $F(4,\ 240) = 6.43$, $p < 0.001$, partial $\eta^2 = .097$, $n = 61$, intensity of exploration, $F(4,\ 220) = 15.25$, $p < 0.001$, partial $\eta^2 = .217$, $n = 56$, and feelings of having learned, $F(4,\ 224) = 10.71$, $p < 0.001$, partial $\eta^2 = .161$, $n = 57$. Looking at Figure 5(D), it becomes evident that interactive and interactive with physical conditions produced the highest degrees of aesthetic pleasure, interest in the artwork, intensity of exploration, and feelings of having learned. These two conditions did not differ between each other on any of the aesthetic appreciation variables.

At time 2, most of the significant differences had disappeared, $F(4,\ 116) \leq 1.97$, $p \geq .103$, partial $\eta^2 \leq .064$, apart from the intensity of exploration, $F(4,\ 112) = 3.33$, $p = 0.013$, partial $\eta^2 = .106$. Participants rated this intensity in the interactive with physical condition significantly more highly than in the non-interactive or physical alone conditions (see Figure 5(E)).

There was no main effect of time in the MANOVA, Pillai's Trace = .171, $F(4,\ 16) = 0.83$, $p = .528$, partial $\eta^2 = .171$, and no interaction between time and artwork condition, Pillai's Trace = .258, $F(16,\ 304) = 1.31$, $p = .189$, partial $\eta^2 = .064$. These results indicate that participants evaluated artworks similarly whether responding immediately after the experiment (time 1) or a month later (time 2).

3.4.2. Study 2

The MANOVA model comparing the interactive and the non-interactive artefact conditions on four aesthetic appreciation variables was overall significant, Pillai's Trace = .267, $F(4,\ 55) = 5.01$, $p = 0.002$, partial $\eta^2 = .267$. Univariate ANOVA tests indicated that, compared to the non-interactive exploration, the interactive one induced more intense exploration, $F(1,\ 58) = 9.26$, $p = 0.004$, partial $\eta^2 = .138$, but did not statistically increase aesthetic pleasure, $F(1,\ 58) = 2.79$, $p = .100$, partial $\eta^2 = .046$, experience of having learned, $F(1,\ 58) = 3.85$, $p = 0.054$, partial $\eta^2 = .062$, or participants' interest in the artefact, $F(1,\ 58) = 0.94$, $p = .336$, partial $\eta^2 = .016$ (see Figure 5(F)).

4. Discussion

Our experiences with visual artworks are changing thanks to varied advancements in digital visualizations, whether encountered directly in exhibition spaces or on our digital devices. As more and more products hit the market (e.g., Bianchini, 2021), any investor must consider which product would likely benefit the experience of artwork, by consequence being worth implementation. A museum curator would be more likely to adopt a product if at least two aspects are met, namely heightened aesthetic appreciation and enhanced cognitive processing, such as improved recognition of the artwork.

In two studies, we tested these aspects using a novel digital visualization technology (https://artmyn.com/, also see https://osf.io/e4qfs), providing an opportunity for interactive exploration of visual artworks and artefacts. In the first laboratory study, we tested university students and compared their recognition and aesthetic appreciation scores across five different painting conditions—when explored interactively vs. non-interactively vs. as a physical object, or as a combination of the digital and the physical interaction. We assessed the degree to which interactive digital exploration might be beneficial. We randomized the paintings appearing in each condition to eliminate potential differences between individual paintings. We also investigated long-term aesthetic and cognitive effects by testing participants again, approximately a month later.

In the second museum study, we recruited visitors of the museum who saw different cultural artefacts like priceless books, figurines, and coins. These participants were older, had more training in art, and showed higher interest in culture in general than participants of the laboratory study. This difference comes with no surprise as participants in Study 2 voluntarily chose to visit the museum while participants in Study 1 were psychology students, participating to gain methodological experience and course credit. Previously, it has been shown that art expertise increased aesthetic appreciation (Augustin & Leder, 2006; Leder et al., 2012; Pihko et al., 2011; van Paasschen et al., 2015), potentially explaining why participants in the museum study felt more attracted to the interactive tool, were more motivated to use it at home or recommend it to a friend than students participating in the laboratory study. Some of our participants in Study 2 might have worked in the field of art (e.g., artists, curators, designers, art historians). In this case, they might have particularly appreciated the tool as it would allow them to dive into the details of the artworks they are interested in. Nonetheless, participants in both studies equally appreciated the digital interface. Thus, the technology as such was well acclaimed by the users, irrespective of their level of art expertise.

If we return to the hypothetical museum curator, our results showed a clear advantage of the interactive exploration on aesthetic appreciation measures, but not on recognition. When participants in the laboratory explored paintings interactively or as a combination of an interactive and physical exploration, they reported a higher degree of aesthetic pleasure, a higher degree of interest in the artwork, a higher intensity of exploration, and stronger feelings of having learned during the exploration. A month later, when asked again about their aesthetic evaluations of the paintings, participants only reported a higher intensity of exploration of paintings seen in both modes, namely interactively as well as physically. These results highlighted the positive effects of the interactive technology.

In contrast to aesthetic appreciation measures, we found hardly any recognition advantage for the paintings explored interactively, whether asked immediately after the exploration or a month later. There was one exception to this result. When we asked participants if they remembered seeing the painting as a physical object immediately after the exploration, they were more certain about their responses in the condition when the painting was explored as a physical painting in combination with an interactive exploration, but only when compared to the condition in which participants explored the artwork only interactively. The result being very specific, we can imagine that participants confused the medium on which they saw the painting. Lack of an overall recognition advantage might signal that participants' cognitive processing remained relatively shallow, not allocating necessary attentional resources to the task of exploring artworks interactively (which would be needed for improved recognition; Krukar & Dalton, 2020). Alternatively, it might suggest that the task was too easy, and most participants correctly recognized all the paintings, irrespective of the condition (i.e., a ceiling effect). Yet, while recognition certainty decreased a month later, there was no obvious advantage for the interactively explored paintings, providing evidence against such a possibility. This observation, however, does not imply that this and similar technologies would not have beneficial effects on other cognitive abilities (Groome, 2021).

In the museum study, we could reproduce the aesthetic advantages, as our participants reported having explored the cultural artefacts more intensely when presented interactively versus non-interactively. Most participants also recognized the artefacts correctly, but they were more certain when responding to the artefacts they had explored interactively as compared to non-interactively, and when responding to the artefacts see digitally as compared to seen in the museum. However, the effects of the type of exploration and the features of the explored artefact were confounded since each artefact appeared in one condition only. Thus, while results of both studies mirrored each other, more weight should be given to the laboratory study, in which we could randomize paintings between conditions, eliminating potential effects driven by their idiosyncratic features.

Overall, the results of the two studies combined showed that aesthetically, participants enjoyed the interactive explorations of digital reproductions to a greater extent than non-interactive digital reproductions, and even more so than mere physical paintings. Thus, we supported independent reports showing that reproductions of higher quality were enjoyed more while enjoyment of genuine art did not necessarily differ from reproductions (Brieber et al., 2015; Grüner et al., 2019; Specker et al., 2021). Similarly, in other studies, participants appreciated interactive art installations in the museum to a greater degree than non-interactive installations (Savaş et al., 2021). Participants also experienced more flow when following an augmented reality guide than an audio guide (Chang et al., 2014). These previous studies, together with the current ones, reinforce the idea that interactive experiences with artworks have aesthetic, motivational benefits.

4.1. Limitations and future directions

One limitation of Study 1, conducted in the laboratory, was that more women than men participated in our experiment. Potentially, our results may be more relevant to women than men. Speaking against this possibility, we obtained comparable results in Study 2, in which we had a balanced gender composition. This comparability would also indicate that it was not problematic that participants in Study 2 were significantly older than in Study 1. Our reasoning does not exclude the possibility that future studies might find gender- or age-related differences.

Like in many studies involving novel technology, such as interactive features in exhibitions (Savaş et al., 2021) or virtual reality (Marín-Morales et al., 2019), one must consider alternative explanations for the observed effects. One of them is the novelty effect. Studies indicated that merely observing dynamically changing paintings rendered them more beautiful than the static ones (Isik & Vessel, 2019; Zhao et al., 2020). Perhaps, as people become more familiar with such interactive tools, novelty drops, and so might the boost in aesthetic appreciation. It might be worthwhile adding control conditions that are also novel but are not based on interaction to further investigate the novelty effect. For instance, the artwork experience could be enhanced through ambient experiences like music or odor (Herz & Cupchik, 1993; Limbert & Polzella, 1998).

Moreover, we wondered if this interactive technology could have broader benefits, such as affective enhancement or be a promising educational tool. In a related study, when given a chance to interact with digital reproductions in an online exhibition (e.g., Monet's Waterlilies), participants' negative mood, state anxiety, and loneliness decreased, and their subjective well-being increased (Trupp et al., 2022). Perhaps, the currently tested technology might positively impact one's affect states and well-being.

The current technology might have further advantages in educational settings, where user engagement, excitement, and immersive environment are crucial for learning and better educational outcomes (Dunleavy et al., 2009; Jin et al., 2022; Sun & Nembhard, 2022; Wekerle et al., 2022). A previous study suggested that positive outcomes of similar technologies might come from "learning through entertainment," as participants felt relaxed and had fun when interacting with art through immersive virtual reality (Kim & Lee, 2022). Furthermore, this technology might be particularly appealing to populations with visual impairments. As the artworks and cultural artefacts are scanned in very high resolution, it allows one to see even the tiniest details of small objects or explore fine-grained textures.

However, future studies might wish to consider other cognitive variables, potentially important for aesthetic experience and educational success. Such variables could include engagement with the artwork, its interpretation in terms of meaning and historical context, verbal recall when talking about it with others, or the ability to generalize its features and remember the artist (e.g., Chamberlain & Pepperell, 2021; Kass et al., 2015; Medved et al., 2004; Specker et al., 2017; Wang et al., 2016).

5. Conclusion

All in all, the current study reported on a promising interactive digital tool to explore artworks and cultural artefacts. We detected an aesthetic advantage of the interactive possibility over no interactive possibility and did so in both the laboratory and museum study testing participants of relatively low and high art training and awareness, respectively. We found no measurable impact on recognition memory, though, suggesting that our digital interactive exploration possibilities were limited to aesthetic experiences. More studies are needed to learn when and why digital interaction is beneficial above and beyond subjective aesthetic evaluations, which would inform on the utility and practical application of such technology. These technologies might be most welcome when cultural institutions are searching for solutions to give access to their collections remotely as well as in person. Cultural institutions, frequently supported by public money, could then provide access to their collections to everyone and everywhere. Many of us have just experienced how enriching such an access could have been during the extended restrictions on spatial movement during the COVID-19 pandemic.

The technology has multiple technical applications, such as enhanced readability of some cultural objects (e.g., cuneiform tablets), improved damage identification, and more accurate and easier authentication procedures. Digital interactions through this technology might also boost sales of promoted artworks in auctions or attract new visitors to the museums. In addition, enhanced engagement with the artworks and cultural artefacts might prove beneficial in educational and marketing settings, facilitating teaching and learning in the general population as well as populations with visual impairments. Speculating even further, this immersive technology could be combined with other contemporary technologies such as MetaVerse, the NFTs (Non-Fungible Tokens), and Pokemon Go, to spread engagement with art and cultural pieces to wider and younger audiences.

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Data availability statement

The data that support the findings of this study are openly available in OSF at http://doi.org/10.17605/OSF.IO/3SRFW

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