**Looking, liking and locating:
aesthetic experiences shape spatial representations.**

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Abstract

Episodic autobiographical memories are characterized by a spatial context and an affective component. But how do affective and spatial aspects interact? Does affect modulate the way we encode the spatial context of events? We investigated how one element of affect, namely aesthetic liking, modulates memory for location, in three online experiments (n=124, 79, 80). Participants visited a professionally-curated virtual art exhibition. They then relocated previously-viewed artworks on the museum map, and reported how much they liked them. Across all experiments, liking an artwork was associated with increased ability to recall the *wall* on which it was hung. The effect was not explained by viewing time and appeared to modulate recognition speed. The liking-wall memory effect remained when participants attended to abstractness, rather than liking, and when testing occurred 24 hours after the museum visit. Liking also modulated memory for the room where an artwork was hung, but this effect primarily involved reduced room memory for *disliked* artworks. Further, the liking-wall memory effect remained after controlling for effects of room memory. Recalling the wall requires recalling one's facing direction, so our findings suggest that positive aesthetic experiences enhance first-person spatial representations. More generally, a first-person component of positive affect transfers to wider spatial representation and facilitates the encoding of locations in a subject-centred reference frame. Affect and spatial representations are therefore important, and linked, elements of sentience and subjectivity. Memories of aesthetic experiences are also spatial memories of how we encountered an artwork. This linkage may have implications for museum design.

Significance statement

Spatial context and affect are two hallmarks of episodic memory, but what is the interaction between the two? We investigated how one element of affect, aesthetic liking, modulates memory for location, in three online experiments involving visiting a virtual art gallery. We consistently show that participants recall the wall where an artwork was hung more successfully when they liked the artwork. Recalling the wall requires recalling one's facing direction, so our findings suggest positive aesthetic experiences enhance first-person spatial representations. Memories of positive aesthetic experiences therefore include information about how we encountered an artwork. Our results may have implications for museum design.

Introduction

The binding between *what* and *where* information is a central organising principle of memory, by which objects are associated with the location where they were encountered. However, in real life, encountering an object is often associated with an affective experience. While memory for object-location associations has been extensively studied in the spatial cognition literature (1–4), a general understanding of whether and how the affective and spatial pillars of memory interact remains elusive. We here looked at how affect can modulate memory for the spatial representation of an object. For this, we focused on the case of aesthetic experience of artworks, which involves at its roots the most basic components of affect (5), namely positive vs negative reactions, based on reward systems (6–9). Importantly, affective subjective experience of an artwork in a museum setting is bound to the location where it is displayed. Since aesthetic experience is characterized by first-person perspective and subjective response, we tested whether it could modulate first-person spatial representations.

Strong affective valence improves object recognition (10–12). However, how affect influences memory for spatial details is less clear. Flashbulb memories for strongly emotional events often include a clear representation of the location where the event happened (13). Many studies showed an improvement of memory for spatial locations of emotional stimuli (14–16), while others showed detrimental effects of negative emotion on memory for spatial context (17–19). These seemingly conflicting results might arise because some studies operationalize memory for space in terms of the spatial *location* of a to-be-remembered object, while others focus on a spatial *context* in which an object is embedded (20). Several other factors, including complexity, intensity, positive/negative valence and significance also influence the relations between affect and space (15, 21–24). Importantly, most of these studies targeted negative affect. In contrast, we looked at a whole range of negative *and* positive affective reactions, in a setting where the interaction between space and affect seems to play an important, constitutive role, namely an art gallery environment.

Subjective experience of an object, including its aesthetic evaluation, involves a first-person perspective (25). Viewpoint has been shown to modulate certain aspects of memory (26). Recollecting a memory from a first-person as compared to third-person perspective is associated with more sensory and emotional reliving (27, 28), both when

first-person perspective is adopted spontaneously (29) and when it is explicitly manipulated (30–32). Traumatic episodes are often reported under first-person perspective (33), perhaps explaining the intrusive memories of post-traumatic stress disorder (34). Here, we hypothesized that the first-person perspective involved in aesthetic experience could play a role in space-affect interactions by favouring first-person spatial representation.

Aesthetic experience related to artworks involves three key nodes: the art object itself, the perceiver and the context or setting in which the perceiver interacts with the object. Most research on aesthetic experience focused on visual features of artworks, and their effects on the perceiver, often with methods recalling classical psychophysics (35). Here, in contrast, we considered aesthetic experience as an active perception-oriented behavior, located in a rich, navigable spatial context. Museums implicitly impose spatial structure on aesthetic experience. The gallery space needs to be navigated, even if not attended to. This navigation is non-functional, in the sense that visitors have weak or minimal expectations about object-location associations (in contrast with functional environments like a house, where, for example, a refrigerator is expected to be in the kitchen). Therefore, the patterns of aesthetic experiences occurring when visiting a museum are relatively unpredictable, and take place specifically in the location where the artwork is seen (36). Spatial layout can work as a memory cue, improving the retrieval of seen artworks (37). The physical space and organization of the museum strongly influence overall aesthetic experience through factors such as lighting, space segmentation, visitor routing and curatorial organization or “hang” (38). However, little is known about the reverse relationship, i.e. how aesthetic experiences might modulate the representation of the space within which those experiences occur.

We investigated these questions across three online experiments using a realistic virtual museum (Fig. 1A). A professional curatorial team (the Museum of Contemporary Digital Art, mocda.org) mounted an exhibition of 48 artworks from 25 contemporary digital artists (see Methods for details), with the combined purposes of artistic dissemination for the general public, and the present scientific experiments. These experiments were performed during the Covid-19 crisis (January to April 2021), while most museums were closed, triggering a major shift across the art world towards virtual online spaces. Thus, our experiments benefitted from a unique and authentic context, including a link to genuine aesthetic experience.

Participants first visited the virtual museum (Fig. 1A,B) and then performed three main tasks (Fig. 1C): a *recognition* task in which they viewed artworks, and reported whether these had been seen in the museum or not; a *spatial memory* task requiring them to place artworks on a museum map in the place where they had seen them; and a *liking* task, in which they rated how much they liked each artwork.

We make an important distinction between remembering the *wall* on which an artwork was seen (Fig. 1B), and remembering the *room* in which it was seen (39–41). Recalling whether an artwork appeared on the left, front or right wall involves accessing first-person perspective facing information about body orientation and turning movements, relative to the local environment. In contrast, recalling the room where an artwork was shown requires recalling one's progression through rooms, involving a map-like or more chronological type of representation. Wall vs room memory does not map directly onto the usual dichotomy between first-person vs third-person representation, but may be closer to the contrast between facing direction and path signals that underpin spatial navigation (42). To investigate the relation between liking and first-person representations, we therefore focused here on wall memory, rather than room memory.

In three experiments, we consistently found that positive aesthetic experiences of an artwork enhanced memory for the wall where the work was located, suggesting a link between aesthetic experience and first-person spatial representations.

Fig. 1. Museum setting, paradigm and general performance. **A**, Example museum map and view of the environment. The virtual environment was composed of eight successive exhibition rooms with three artworks, one on the left, one on the front and one on the right wall relative to the entrance door. See also Supplementary Figure 1, showing the 4 maps used in this experiment. The three artworks shown in this view are: left, ‘#FOREST’, by Mathieu Merlet-Briand (2019); front, ‘Digital Aquarelle 10’, by Aaron Scheer (2019); right, ‘Clouds’, by Arnaud Laffond (2016). See all artworks at www.mocda.org/abstract-art-new-media. **B**, Schematic representation of the position of the artworks on the left, front and right walls. **C**, Tasks after the museum visit. Recognition task: the 24 artworks of the museum and 24 new artworks are successively and randomly presented. Participants report for each whether they had seen the artwork in the museum or not, and their confidence level (6-level scale). Spatial memory task: participants are shown all the artworks they reported seeing, and drag and drop each to its location in the museum map. They also report their confidence (6-level scale) and are given feedback on their response. Liking task: participants rate their liking of all 48 artworks. The artwork shown here is ‘Explicitly Activist’, by Darcy Gerbarg (2017). **D**, General performance. Left: number of hits and false alarms for each participant (black dots; average: green dot). Middle: percentage of correct wall responses for each participant (black dots; average: green dot; chance level: red dotted line). Right: percentage responses in each bin of the liking scale, averaged across participants. Only artworks presented in the museum are considered.

Results

General performance (Experiment 1)

Participants started by visiting the virtual museum (Fig. 1A). They were instructed to spend at least 30s in each room, to look at all the artworks and to consider how much they liked each of them.

Participants (n=124, see Supplementary Figure 2 for a demographical description of the sample) correctly recognized on average 20.22 artworks out of 24 they had previously seen during their visit (Fig. 1D; Recognition task, SD=2.67), with high confidence levels (6-level scale; mean=5.54, SD=0.43). They made few false alarms (mean=1.73, SD=2.42; confidence: mean=3.55, SD=1.02).

Participants were above chance at recalling the walls where artworks were hung (Fig. 1D; Spatial memory task, chance level=33%, mean accuracy=57.76%, SD=17.13). Memory for walls depended on the wall and on the room where artworks appeared, but was comparable across the four different museum layouts (see Supplementary Figure 1) (logistic mixed effects model on Wall accuracy; Wall, Left/Front/Right: $X^2(2)=116.47$, $p<0.001$; Room, 1 to 8: $X^2(7)=30.44$, $p<0.001$; Museum layout: $X^2(3)=2.72$, $p=0.44$). The left and right walls were associated with better memory than the facing wall. Further, memory for walls was strongest in the first room.

Doors between rooms appeared on the front wall, except for one room where the door was located on one of the lateral walls, resulting in an L-shaped museum layout. The simplicity and high predictability of this layout allowed us to test attention to space by asking participants a secondary question, namely whether the museum layout was straight or L-shaped (Map recognition task; see Materials and Methods, *Tasks and procedure*). 29.8% of participants mistakenly identified the museum layout as being straight.

Testing the relation between aesthetic reports and memory requires that ratings show sufficient variation. Some participants who consistently rated in a restricted positive or negative range were therefore excluded (see Supplementary Table 1). The distribution of liking ratings (Likert scale: -5 to +5) from the included participants

($n=124$) is shown in Figure 1D. The mean liking rating of artworks in the museum was 0.09 ($SD=0.85$ across participants), and the mean of individual SDs across artworks was 3.01. Artworks recognised as being present in the museum (hits, Recognition task) had the highest liking ratings (Supplementary Table 2). Interestingly, artworks incorrectly identified as being in the museum (false alarms) also had higher liking ratings than artworks identified as not being present in the museum (correct rejections and misses). This could suggest that liking is associated with a higher probability of reporting an artwork was seen.

For more details about the general performance, see Supplementary Table 2.

Liking increases memory for walls (Experiment 1)

Our main goal was to test whether aesthetic experience modulated memory for walls. For this, we fitted a logistic mixed effects model, where z-scored liking ratings predicted memory for walls (for more details see Materials and Methods, *Data analysis*). We found that memory for walls was significantly explained by liking (Fig. 2A; logistic mixed effects model on Wall accuracy; Liking: $b=0.13$, $SE=0.047$, $X^2(1)=7.71$, $p=0.0055$), such that memory for the wall where artworks were hung increased with liking. This effect replicated a previous pilot study (see Supplementary Material, *Pilot study*; $n=96$; Liking: $b=0.22$, $SE=0.090$, $X^2(1)=6.05$, $p=0.014$). This effect showed that aesthetic experience of an artwork modulated the recollection of the wall where it was hung.

We then tested whether this effect could be related to the *intensity* of the aesthetic experience, as opposed to its valence. For this, we considered the absolute values of the z-scored liking ratings, thus pooling across positive and negative experiences by suppressing signed valence. Intensity alone did not explain memory for walls (logistic mixed effects model on Wall accuracy with Intensity, as predictor; Intensity: $b=0.013$, $SE=0.092$, $X^2(1)=0.018$, $p=0.89$), and signed liking still explained memory for walls when accounting for unsigned intensity (logistic mixed effects model on Wall accuracy with Liking and Intensity as predictors; Liking: $b=0.13$, $SE=0.047$, $X^2(1)=7.81$, $p=0.0052$; Intensity: $b=0.033$, $SE=0.093$, $X^2(1)=0.13$, $p=0.72$). Our use of relative ratings imposes the assumption that each participants' experiences cover a similar range of subjective intensities. We therefore additionally repeated this analysis using the absolute, unsigned,

value of raw liking ratings, without z-scoring, which avoids this assumption, and we obtained the same results.

To test whether attention to space played a role in this effect, we also fitted a model that included participants' ability to recognize the museum layout (straight versus L-shaped). The effect of liking remained after taking into account museum layout recognition (logistic mixed effects model on Wall accuracy with Liking and Museum layout recognition as predictors; Liking: $b=0.13$, $SE=0.47$, $X^2(1)=7.71$, $p=0.0055$; Map recognition, correct/incorrect: $b=0.028$, $SE=0.16$, $X^2(1)=0.032$, $p=0.86$). This suggests that the association between liking and wall memory arose implicitly during viewing, and was unrelated to participants' attention to space during the gallery visit.

We also considered memory for the room where artworks were shown. Memory for rooms requires participants to retrieve the sequence in which artworks were viewed. Memory for rooms appeared to be also modulated by liking (logistic mixed effects model on Room accuracy, with Liking, Wall number and Room number as predictors; Liking: $b=0.18$, $SE=0.050$, $X^2(1)=13.57$, $p<0.001$), such that participants were more likely to report the correct room of artworks they liked. Importantly, liking still significantly accounted for wall memory, after taking into account memory for rooms (logistic mixed effects model on Wall accuracy, with Liking, Room memory, Wall number and Room number as predictors; Liking: $b=0.11$, $SE=0.047$, $X^2(1)=5.69$, $p=0.017$, see Supplementary Table 3 for the full results of this model). This indicates that the liking effect on memory for walls is independent from memory for rooms.

Fig. 2. Liking increases the ability to recollect the wall where artworks were hung. **A-C,** Percentage of correct wall responses, for all responses collapsed across participants, in 3 quantiles along the liking scale (z-scored for each participant). The x-coordinate of each tertile corresponds to the average liking rating. Chance-level: 33%. Error bars represent standard error of the mean. Experiment 1: main experiment; Experiment 2: focus on abstractness; Experiment 3: 24-hour delay testing. **D,** Liking effect for each of the three experiments. Each bar represents the parameter estimate of the liking effect, from the models predicting wall memory (predictor: Liking; predictors of non-interest: wall and room number; random effects: participant and artwork number). There was no significant difference between the parameter estimates from the three experiments. ***: $p < 0.001$, **: $p < 0.01$; *: $p < 0.05$.

The liking-wall memory association is not linked to viewing time or viewing distance (Experiment 1)

We tested whether the liking-wall memory association could be explained by viewing time (43) or viewing distance to artworks. Unsurprisingly, participants spent more time and got closer to artworks they liked (mixed effects model on raw aesthetic ratings, with mean viewing distance and mean viewing time as predictors, z-scored; Distance: $b = -0.37$, $SE = 0.064$, $X^2(1) = 33.32$, $p < 0.001$; Time: $b = 0.44$, $SE = 0.061$, $X^2(1) = 51.84$, $p < 0.001$). However, the link between liking and memory for walls remained after controlling for these factors (logistic mixed effects model on Wall accuracy; Liking: $b = 0.11$, $SE = 0.048$, $X^2(1) = 5.22$, $p = 0.022$; Distance: $b = -0.056$, $SE = 0.051$, $X^2(1) = 1.21$, $p = 0.27$; Time: $b = 0.068$, $SE = 0.048$, $X^2(1) = 2.00$, $p = 0.16$). These results suggest the liking-wall memory association does not simply reflect exposure and/or salience.

The liking-wall memory association modulates recognition speed (Experiment 1)

We tested whether recognition reaction times differed depending on liking and wall memory. We found that recognition reaction times were predicted by liking, by wall memory and by their interaction (mixed effects model on Recognition reaction times, with Liking, Wall correct/incorrect and the interaction, as predictors; Liking: $b=-0.12$, $SE=0.031$, $X^2(1)=14.71$, $p<0.001$; Wall correct/incorrect: $b=-0.15$, $SE=0.038$, $X^2(1)=14.96$, $p<0.001$; Interaction: $b=0.077$, $SE=0.039$, $X^2(1)=3.90$, $p=0.048$). More specifically, recognition time was lowest when participants both liked the artwork in question, *and* also remembered the wall on which it was hung. This result was not confounded by viewing time, viewing distance, wall or room number (mixed effects model on Recognition reaction times, with Liking, Wall correct/incorrect, the interaction, viewing time, viewing distance, wall left/front/right and room number; Liking: $b=-0.13$, $SE=0.031$, $X^2(1)=17.32$, $p<0.001$; Wall correct/incorrect: $b=-0.15$, $SE=0.039$, $X^2(1)=13.92$, $p<0.001$; Interaction: $b=0.078$, $SE=0.039$, $X^2(1)=4.06$, $p=0.044$). Among these factors, only room number had an independent effect on reaction times (Room number: $X^2(7)=45.74$, $p<0.001$; all other $p>0.33$), due to a recency effect whereby artworks from later rooms were recognized faster. This result suggests that recognition was more efficient for artworks that were liked and for which wall information was known. Importantly, participants' instructions at this stage of the experiment had not drawn attention to the spatial location of artworks, because the recognition task was performed *prior* to spatial memory testing (Fig. 1C). This effect thus suggests that the liking-wall memory association appears to *incidentally* modulate recognition speed.

The liking-wall memory association is specific to subjective experience (Experiment 2)

In Experiment 2, we tested the specificity of this effect to aesthetic experience. Aesthetic evaluation was not explicitly mentioned in the instructions (see Supplementary Materials – *Museum instructions*). Instead, participants (included: $n=79$, see Supplementary Figure 2 for demographic information) were instructed to focus on the abstractness of artworks during the museum visit. We excluded 44 participants who failed to report afterwards the instruction they were given for the museum visit (See Materials and Methods, *Control for museum instruction*), and who may therefore not have

attended to abstractness. Contrary to Experiment 1, the museum layout here was straight, with no turn. We also added a task involving rating the abstractness of each artwork. Supplementary Figure 3 shows the general performance of participants in Experiment 2.

Liking decreased for greater abstraction (mixed effects model on Liking; Abstractness: $b=-0.12$, $SE=0.027$, $X^2(1)=21.31$, $p<0.001$). Contrary to Experiment 1, liking was not associated with viewing time, but was again associated with viewing distance (mixed effects model on Liking; Viewing distance: $b=-0.18$, $SE=0.075$, $X^2(1)=5.62$, $p=0.018$; Viewing time: $b=0.084$, $SE=0.071$, $X^2(1)=1.42$, $p=0.23$). The reverse was observed for abstractness (mixed effects model on Abstractness; Viewing distance: $b=0.0088$, $SE=0.065$, $X^2(1)=0.018$, $p=0.89$; Viewing time: $b=0.14$, $SE=0.061$, $X^2(1)=5.36$, $p=0.021$). Participants spent more time looking at more abstract artworks, but the average viewing distance did not vary with abstractness. This suggests that their focus of attention was not primarily on liking, but rather on the abstractness of artworks, as instructed.

Abstractness alone had only a marginal effect on memory for walls (mixed effects model on Wall accuracy; Abstractness: $b=-0.11$, $SE=0.063$, $X^2(1)=2.85$, $p=0.091$). Crucially, liking still modulated memory for walls when taking into account abstractness (Fig. 2B; mixed effects model on Wall accuracy; Liking: $b=0.122$, $SE=0.0608$, $X^2(1)=4.00$, $p=0.046$; Abstractness: $b=-0.091$, $SE=0.063$, $X^2(1)=2.05$, $p=0.15$). This result shows that the link between liking and wall memory is still present when attention is not primarily focused on liking, but on other aspects. Moreover, making judgements other than liking judgements (i.e., abstractness judgements) did not produce a link between those control judgements and memory for walls. This result suggests that the link between liking and memory for walls is not merely an artefact of attention, and indeed arises independent of attention.

Finally, in this experiment liking did not modulate memory for rooms (logistic mixed effects model on Room accuracy, with Liking, Wall number and Room number as predictors; Liking: $b=0.062$, $SE=0.061$, $X^2(1)=1.03$, $p=0.31$), which further suggests the effect of liking is not a global and unspecific mnemonic effect.

The liking-wall memory association is long-lasting (Experiment 3)

We further tested the duration of the liking-wall memory association, by asking participants to perform the memory and rating tasks the day after they had visited the museum (see Supplementary Figure 2 for demographic information and Supplementary Figure 3 for the general performance of participants). As in Experiment 2, the museum layout was straight.

Participants ($n=80$) correctly recognised 17.86 out of 24 artworks on average (Recognition task, $SD=3.78$), with a false alarm rate of 2.65 ($SD=2.98$). As in Experiment 1, participants spent more time looking at artworks they liked, and got closer to them (mixed effects model on Liking; Viewing time: $b=0.46$, $SE=0.076$, $X^2(1)=36.77$, $p<0.001$; Viewing distance: $b=-0.27$, $SE=0.079$, $X^2(1)=11.76$, $p<0.001$).

We found that despite the one-day delay, the effect of liking on memory for walls was again observed (Fig. 2C; logistic mixed effects model on Wall accuracy; Liking: $b=0.17$, $SE=0.059$, $X^2(1)=8.03$, $p=0.0046$). The effect remained after taking into account viewing time, viewing distance and the significant effect of time between sessions (logistic mixed effect model on Wall accuracy; Liking: $b=0.16$, $SE=0.061$, $X^2(1)=6.74$, $p=0.0094$; Time between sessions: $b=-0.045$, $SE=0.019$, $X^2(1)=5.42$, $p=0.020$; Viewing time: $b=0.042$, $SE=0.061$, $X^2(1)=0.46$, $p=0.50$; Viewing distance: $b=-0.0042$, $SE=0.065$, $X^2(1)=0.0041$, $p=0.95$).

As in Experiment 1, liking also modulated memory for rooms (logistic mixed effects model on Room accuracy, with Liking, Wall number and Room number as predictors; Liking: $b=0.16$, $SE=0.074$, $X^2(1)=4.49$, $p=0.034$), and this effect did not account for memory for walls (logistic mixed effects model on Wall accuracy, with Liking, Room memory, Wall number and Room number as predictors; Liking: $b=0.16$, $SE=0.059$, $X^2(1)=7.06$, $p=0.0079$).

The liking-wall memory association did not differ between experiments and corresponds to a positive effect of liking

We tested for differences in the liking-wall memory association between experiments. Combining the datasets from the 3 experiments revealed a significant effect

of liking and of dataset on memory for walls, but no interaction between liking and dataset (logistic mixed effects model on Wall accuracy, pooled data from 3 experiments; Liking: $b=0.14$, $SE=0.032$, $X^2(1)=20.36$, $p<0.001$; Dataset: $|b|>0.15$, $SE<0.91$, $X^2(2)=23.60$, $p<0.001$; Liking*Dataset: $|b|>0.015$, $SE<0.059$, $X^2(2)=0.73$, $p=0.69$). This suggests that our main effect of interest was comparable in size for all three experiments (Fig. 2D). In addition, none of the questions assessing art expertise, memory and navigation abilities (Supplementary Figures 4 and 5) modulated the effect (logistic mixed effects models on Wall accuracy, pooled data, with experiment as random factor, one model for each item of the questionnaires; Interaction between Liking and Item: all $p>0.24$, uncorrected for multiple comparisons).

Two non-mutually exclusive hypotheses could explain the direction of the liking-wall memory association. It could either be explained by *enhanced* wall memory for liked artworks and/or by *impaired* wall memory for disliked artworks. To disentangle these possible explanations, we combined the data from all three experiments to increase power, and then subdivided the dataset into negative, neutral and positive liking ratings (tertiles on z-scored ratings; mean liking rating for negative tertile: -1.13; mean neutral: 0.04; mean positive: 1.1). Finally, we included experiment number as a random factor in this analysis. We found that liked artworks led to better wall memory than neutral artworks (logistic mixed effects model on Wall accuracy, including only artworks with Neutral and Positive liking ratings; Neutral versus Positive liking: $b=0.20$, $SE=0.074$, $X^2(1)=7.68$, $p=0.0056$). Wall memory did not differ significantly for disliked compared to neutral artworks (logistic mixed effects model on Wall accuracy, including only artworks with Neutral and Negative liking ratings; Neutral versus Negative liking: $b=0.12$, $SE=0.073$, $X^2(1)=2.72$, $p=0.099$). This result suggests that *positive* aesthetic experiences *enhance* wall memory, rather than negative aesthetic experiences impairing wall memory. Note that the average rating for negative liking had a larger magnitude than that for positive liking, and was further from neutral, thus ruling out alternative explanations based on magnitude differences between positive and negative valence.

Disliking an artwork impairs room memory

We performed the same analyses as above on the liking-room memory effect that was observed in Experiments 1 and 3. The effect did not significantly differ between Experiments 1 and 3 (logistic mixed effects model on Room accuracy, pooled data from Experiments 1 and 3; Liking: $b=0.18$, $SE=0.042$, $X^2(1)=18.69$, $p<0.001$; Dataset: $b=0.32$, $SE=0.090$, $X^2(1)=12.67$, $p<0.001$; Liking*Dataset: $b=0.0075$, $SE=0.055$, $X^2(1)=0.018$, $p=0.89$). Interestingly, we found that disliked artworks were associated with worse room memory than neutral artworks (logistic mixed effects model on Room accuracy, on artworks with Neutral and Negative liking ratings; Neutral vs Negative liking: $b=0.22$, $SE=0.099$, $X^2(1)=4.71$, $p=0.030$), while room memory for neutral and liked artworks did not differ significantly (Neutral vs Positive liking: $b=0.14$, $SE=0.095$, $X^2(1)=2.20$, $p=0.14$). The liking-room memory effect thus seems to be explained by a memory impairment that arises when an artwork is disliked, rather than the memory enhancement for liked artworks, that we had observed for wall memory. These contrasting patterns suggest that the effect of liking differs for wall and room memory, and suggest that the effects of positive liking on wall memory do not simply reflect general or unspecific memory enhancements.

Discussion

We investigated how aesthetic experience of an artwork could affect its spatial representation in memory. We found that positive aesthetic experiences were associated with better memory for the wall where the artworks were hung in the virtual museum. This effect was replicated across three online experiments (n total=283) and additional in-person pilot study ($n=96$, see Supplementary Materials, *Pilot study*), comprising participants with a large range of age, geographic origin, and art expertise, and across two different collections of abstract artworks. In our experiments, participants navigated freely through a virtual space, and turned to view each artwork. Thus, to recall whether an artwork was seen on the left, front or right wall requires recalling one's facing orientation. Our results therefore suggest that positive aesthetic experiences enhance first-person spatial representations. Of course, disliked artworks also involve first-person

experiences. However, our results suggest that liked artworks are stored in memory together with the first-person, experiential and spatial, dimension.

Our analyses further showed that this effect reflected aesthetic value, rather than mere arousal. Specifically, we considered that strongly positive and strongly negative aesthetic experiences would elicit an arousing response (44), and therefore took the absolute value of liking ratings as a proxy for behavioural arousal. We found that this arousal-related measure could not explain the liking-wall memory association. Liking ratings were well distributed along the scale, and participants whose aesthetic judgements were highly stereotyped were excluded. We also controlled for viewing time and distance. Viewing time was related to the participants' primary goal in all experiments, namely that they should study the artworks in order to answer questions about them after their visit. However, differences in viewing time and distance could not explain the relation between liking and wall memory that we repeatedly observed.

We here aimed at creating real, life-like, events, which would generate rich and meaningful episodic memories. We designed these experiments around a visit of a virtual museum, and made it as naturalistic and relevant as possible, by creating a realistic 3D environment and professionally curating the content of the art exhibition. The liking-wall memory association was found not only shortly after the museum visit (Experiments 1 and 2), but also 24 hours later (Experiment 3), suggesting this association is consolidated in long-term memory. Since the liking-wall memory association was found even when spatial location and aesthetic evaluation were irrelevant to the instructed task (Experiment 2), this appears to be an automatic feature of artwork memory. Furthermore, the liking-wall memory association appeared to influence the speed with which artworks were recognized. More specifically, artworks for which the hanging wall was correctly remembered were recognized faster than those whose wall location was misremembered, and especially when they were associated with positive aesthetic experiences. Importantly, the recognition task was performed *before* participants were asked or told anything about spatial locations. This shows how spatial information becomes incidentally and automatically associated with artwork memory. This is consistent with previous work showing that spatial content of memories is automatically recalled and reinstated (45). Superior recognition could indicate more efficient encoding of artworks. Overall, the association between positive affect and first-person spatial representations

appears to be long-lasting, independent of the attentional focus and an intrinsic feature of episodic memories.

Research on spatial representation draws a fundamental distinction between egocentric representations, that directly reflect first-person experiences occurring when navigating an environment, and allocentric representations ('maps') that can be abstracted from those first-person experiences. In this experiment, memory for walls was a proxy for memory for facing orientation (39), i.e. for a first-person representation of local spatial locations. Memory for rooms could potentially involve a map-based form of representation, but it could also involve recalling the temporal sequence of the exhibition. Memory for rooms was modulated by liking in Experiments 1 and 3, but not in Experiment 2. Memory for rooms was reduced when an artwork was disliked, but was not significantly enhanced when an artwork was positively liked. The effect of liking on room memory is compatible with previous work showing that negative affect impairs memory for temporal order (for a review see (46), e.g. of word presentation (47)), as well as memory for spatial context (17-19). Interestingly, this pattern contrasts with the effects of wall-memory, which revealed enhanced memory for liked artworks, but no significant impairment for disliked artworks. Further investigation is needed to understand the contrasting effects of liking on wall-memory and room-memory, and to better characterize the nature of the room-memory effects observed here. However, the pattern of differences observed is not readily explained by global and unspecific effects of liking on memory.

Several studies have shown that egocentric spatial representations dominate in memories of extreme negative affect, notably in cases of post-traumatic stress disorder and consequent intrusive memories (48). We did not find any evidence for an enhanced use of first-person representations for negative aesthetic experiences. We cannot exclude though that pictures with stronger negative valence than the abstract patterns used here might have a similar effect. However, for the range of artworks and associated affective reactions in our study, positive and not negative affect was associated with first-person spatial representations. Being able to remember the location of objects, in particular those that are affectively significant, is fundamental for survival, since it allows animals to avoid threats (49) and retrieve rewards (50). The fact that aesthetic experiences also interact with this so-called "what-where binding" principle suggests that the human aesthetic

capacity, while not directly critical for survival, might have built on these primitive mechanisms.

The relation between liking and affect is controversial, as positive aesthetic experiences can arise from negatively-valenced artworks and vice-versa. Our participants were not selected for expertise in art, and were not frequent museum visitors (Supplementary Figure 4). Non-experts are thought to refer primarily to personal feelings in establishing how much they like an artwork (51), resulting in an overlap between liking and valence (52). In addition, artworks were abstract and were presented with no labels, titles or introductory text. This could limit the extent of interpretation, while favouring immediate affective reactions. Finally, neuroimaging studies of aesthetic experience show its links to reward neural circuitry (6–8), further suggesting a basic relation between liking and valence, i.e. between aesthetic experience and affect.

Aesthetic experience is considered to include both a perceptual and an interpretative level (25). Perceptual aesthetics proposes that low-level stimulus patterns, such as golden section (53) or simplicity/complexity (54), induce particular aesthetic experiences. Interpretative aesthetics in turn proposes that artworks become associated with self-relevant information, such as specific memories, and that processing these associations contributes to the distinctive richness of many aesthetic experiences (25, 55). Importantly, these accounts are strongly focused on the *content* of the art object, on its intrinsic visual properties and on its impact on structural self-related cognitive information. They do not consider the instantaneous and immediate sentient subject of experience. Our research suggests that memories of aesthetic experiences are not restricted to the strictly perceptual and interpretative levels. They are also a memory of how we encountered the artwork, as a perceiving subject. The first-person perspective of aesthetic experience has marked spatial consequences, since it strengthens the representation of how we came to interact with the art object. In support of this self-referenced aspect of aesthetic experience, we also found that more object-oriented modes of evaluation, such as abstractness judgement, did not show a relation with spatial representations (Experiment 2). Furthermore, the liking-wall memory association was still present even when subjects did not primarily focus on their aesthetic experiences. This is consistent with previous work showing the automaticity of subjective value evaluations (56). Of course, aesthetic evaluation is likely to impact memory for other

intrinsic properties of artworks, such as palette, scale or balance. Here though, we explored a new and different set of properties of aesthetic experience, that we could call “secondary properties”, since they are not properties of the artwork itself, but rather properties of the way we encounter the object. These properties highlight the relation between the viewer and the object. In sum, our studies suggest that aesthetic liking strongly affects the storage in memory of the spatial perspective during the interaction between viewing and art object. We retain in memory first-person aesthetic experiences, complete with the spatial perspective of the encounter between subject and artwork, rather than de-perspectivized records of aesthetic objects. “Beauty is in the eye of the beholder” is a commonplace statement in perceptual aesthetics: it is usually taken to reflect subjectivity and individual differences in an *interpretative* level of aesthetic response. Our research suggests that subjectivity of aesthetic response has a perceptual and perspectival element as well, since the first-person perspective towards an aesthetic object forms a central feature of aesthetic memory.

Finally, our work may have important applied relevance for museums, art galleries, and similar settings. It shows that the memory of seeing an artwork is a spatially-situated experience which includes the wider spatial context of the museum. We found no influence of age, gender or art expertise, showing that the link between aesthetic experience and spatial orientation memory is quite general. The question remains as to the applicability of these results to a real museum setting. Virtual reality environments appear to be good models of real-life environments (57), potentially because visuo-spatial cues are also available in virtual settings, and they constitute the core source of orienting signals for humans (58). While map-based representations seem to not benefit from body movements (59), participant-based representations may be improved in conditions where subjects can actually move (60). In addition, liking is usually also higher in museum as compared to laboratory settings (37, 43). One can then speculate that transferring our study scenario from virtual museum to a physical environment could boost both wall memory *and* liking, thus maintaining – if not enhancing – the liking-wall memory effect (and similarly for the liking-room memory effect). Therefore, our results could potentially be used for a cognitive form of cultural engineering, optimising the ‘hang’ of artworks within a museum environment to provide positive and enduring aesthetic experiences.

Materials and Methods

Participants

Participants were recruited using Prolific (www.prolific.co, 2020). Participants were invited for this study if they met the following criteria: participants should speak English fluently, have no ongoing mental health/illness condition, have an approval rate of at least 85% on Prolific, have participated to at least one study on Prolific before, not have participated in one of these experiments before. Participants were excluded from analysis based on criteria assessing technical issues, task performance and attention, intended to have a conservative selection of participants (See Supplementary Table 1). We defined the exclusion criteria before testing and continued acquiring data until we reached a similar number of included participants as in our pilot study ($n=96$, see Supplementary Material, *Pilot study*). 124 participants were included in the main analyses of Experiment 1 (64 females; age: mean=24.48, SD=5.55, min=18, max=46), 79 in Experiment 2 (38 females, age: mean=23.94, SD=4.66, min=18, max=39) and 80 in Experiment 3 (21 females, age: mean=23.32, SD=3.33, min=18, max=33). Supplementary Figure 2 further illustrates the variability in age and demographical origin of the three samples. Analyses of each experiment were performed once the whole dataset of the experiment had been collected.

All procedures were approved by the local UCL ethics committee. Participants gave informed consent by ticking and validating all items of the consent form and were paid for their participation (£7.5/hour + bonus of the spatial memory task).

Artwork selection

48 artworks from 25 contemporary digital artists were selected by MC and ST, curators of the Museum of Contemporary Digital Art (MoCDA). The selection was based on the following criteria: only abstract pieces, square or rectangular shape, not too similar from each other (especially if from the same artist). All artists agreed for their artworks to be included in this experiment. This collection was also shown as an art exhibition on MoCDA's website (www.mocda.org/abstract-art-new-media).

The virtual environment

The virtual environment consisted of a museum, composed successively of an entrance room, eight exhibition rooms and an exit room. Rooms were separated by a doorway on the front wall (except for room 4 or 5 in Experiment 1, where the doorway was located on a lateral wall, see Supplementary Figure 1), occluded by a foggy material. Returning to rooms already visited was not possible. Each exhibition room presented three paintings, one on the left wall, one on the front wall and one on the right wall relative to the entrance. 24 artworks were randomly selected for each participant and were presented in random rooms and walls.

The virtual environment was implemented with Unity (version 2020.1.5f1, Unity Technologies, CA, USA). Participants navigated using the W, A, S and D or with the arrow keys of the keyboard and the mouse to rotate the view (left-right). A first-person perspective and a head bobbing effect during navigation were used to improve immersiveness, and the rendered field-of-view was 60° vertically and 82° horizontally.

Tasks and procedure

Training on navigation commands. After reading the instructions about navigation commands, participants performed 3 short blocks of training. In each block, they navigated the entrance room of the museum, which contained many obstacles (chairs, tables, plants), in order to collect 4 diamonds located in distant positions in the room. An illustration of the navigation commands stayed on the screen throughout. This task also allowed us to detect participants having difficulties with navigation keys (Supplementary Materials – *Exclusion criteria*).

Museum visit. Participants were shown the instructions for the museum visit (for the complete instructions see Supplementary Material- *Museum instructions*). Briefly, Experiments 1 and 3 instructed participants to spend at least 30s in each museum room, look at all the artworks and evaluate how much they liked each of them. Experiment 2 instructed participants to attend to the abstractness of artworks, and spend at least 10s in each museum room (this shorter time was to avoid that participants engaged in more aesthetic oriented focus, after having concluded on the abstractness of artworks).

Recognition task. Participants were successively presented with all 48 artworks (24 seen, 24 new) in randomized order. For each artwork, they were asked whether they had seen it in the museum or not (the position of “Yes” and “No” buttons was randomized

between participants) and how confident they were on their response (6-level scale, only Experiment 1).

Map recognition task (Experiment 1 only). Participants were shown the map of the museum they visited (containing one direction change, see Supplementary Figure 1) and the map of an alternative museum (straight direction throughout). Participants selected the map they thought corresponded to the museum they visited.

Control for museum instruction (Experiment 2 only). Participants were asked to report which among 7 options was the instruction they were given before starting the museum visit (Options: 1-to decide which artwork was most liked; 2-to decide which artwork was the most abstract one; 3-to try and memorize the artworks shown in the museum; 4-to remember the location of the artworks; 5-to pay attention to the colours of the artworks; 6-to pay attention to the different sizes of the artworks; 7-I did not see any specific instruction for the museum visit). Afterwards, participants were shown the 24 artworks of the museum and asked to indicate the one they found most abstract and their favourite.

Spatial memory task. Participants replaced each artwork they reported seeing (from Recognition task) on the museum map, in the location where they remembered seeing it. Artworks were shown in randomized order and appeared on the left or right of the museum map randomly. After validating their choice, participants reported their confidence on their response (6-level scale). Each replaced artwork disappeared after response validation, so the same location could be used for more than one artwork. Participants were encouraged to retrieve the location by a system of points which gave them an extra bonus payment. They received 1 point for correctly reporting the location of the artwork (both room and wall correct) and 0.5 points for correctly reporting either the room or the wall.

Abstractness task (Experiment 2 only). Participants reported the level of abstractness of each of the 48 artworks, on a continuous scale (101 levels) from “Completely realistic” (left label) to “Completely abstract” (right label).

Liking task. Participants reported how much they liked each of the 48 artworks using a VAS scale (101 levels, left label: “Really dislike”; right label: “Really like”). Artworks appeared in randomized order. Afterwards, participants were shown the 24 artworks presented in the museum and were asked to freely write about their aesthetic experience about them.

Final questionnaire. Participants were asked questions about their familiarity with museums and art, and about their navigation and memory skills (61) (Supplementary Figures 4 and 5).

Delayed testing in Experiment 3

In Experiment 3, participants visited the museum on day 1 (Session 1). The experiment was available during the morning and early afternoon, according to the time zone of each participant's current location. Participants who followed the instruction of spending at least 30s in each museum room were invited for Session 2, the day after Session 1. Participants performed Session 2 on average 26.36 hours after Session 1 (SD=3.81, min=20.13, max=44.64).

Viewing distance and time measures

Viewing distance was computed as the distance between the camera in the environment and the center of the artwork. Viewing time corresponded to the time spent with the center of the artwork in the field of view. Viewing distances and times were then z-scored for each participant.

Reaction times (Recognition and Spatial memory task)

Reaction times for the Recognition task were computed for hits, as the time between artwork presentation and "Yes" response. Since this was an online study, we could not control the conditions under which participants performed the task, so we removed outlier reaction times. For each participant, reaction times that were larger than the average reaction time for the participant plus 3 standard deviations were excluded from analysis. Reaction times were then z-scored for each participant.

Reaction times on the Spatial memory task were computed as the time difference between artwork presentation and validation of the response. The same procedure as for the Recognition task, for excluding outlier reaction times and z-scoring, was used.

Data analysis

We scored wall memory performance for each recognized artwork present in the museum (i.e. hit), according to the correct/incorrect choice of wall (left, front or right, Fig. 1B). We fitted logistic mixed effects models to look at different aspects that could predict

wall memory. Liking ratings were z-scored across paintings (hits) for each participant, to account for inter-individual variability in the use of the liking scale. All logistic mixed effects models on wall memory included Wall (left, front, right) and Room (1 to 8) as regressors of non-interest, to account for the fact wall memory depends on the wall and room (see Results, General Performance). The intercept in all models was allowed to vary between participants and artworks, unless specified otherwise.

These analyses were conducted in R, using the “glmer” and “lmer” functions from the lme4 package(62) to compute logistic and linear mixed effects models respectively, and the “Anova” function from the car package(63) to derive corresponding statistics (Type II Wald chi-square tests). We report logistic regression weights as our unstandardized effect size estimates, as they correspond to the expected change in log-odds for a one-unit increase in the corresponding predictor value.

The data and analysis code are available at
https://osf.io/zsm7v/?view_only=7186e2c119504954859add7924ed084a.

Author contributions

MBR and PH designed the study. MC and ST curated the exhibition. MBR and AN created the virtual environment and the experiment. MBR and PH analysed the data. ET gave support for the pilot study and for data analysis. MBR and PH wrote the paper. KJ facilitated and managed the interdisciplinary collaboration. All authors approved the final manuscript.

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Supplementary Material

Pilot study

134 participants volunteered to take part in the pilot study, in three different contexts: the laboratory (n=10), a neuroscience festival at the Tate Modern museum in London (n=87), and a science festival at University College London (n=37). 34 participants were excluded at the time of testing, due to difficulties with navigation, major distractions during task performance or interference from audience. Four participants were excluded at the memory screening stage, recognizing less than 33% of paintings previously seen. 96 participants were included in the main analyses (46 males, 45 females, 5 preferred not to answer; age: mean=35.4, SD=14.7, min=9, max=72). We did not set a minimal sample size for this study, as the experiment was designed to be tested with all visitors of these public events who wanted to participate. All analyses were performed once the whole dataset had been collected. All procedures were approved by the relevant ethics committees for the data collection setting (UCL or Tate Exchange).

The virtual environment resembled the one of the main experiments, except that the museum contained only 4 rooms, with one overall direction change (lateral door) and one front wall containing two doors. This resulted in 6 different museum layouts. 15 abstract paintings were selected from the asset “Art Gallery Showroom” by 3dfactorio (<https://assetstore.unity.com/packages/3d/environments/art-gallery-showroom-141559#description>, paintings free for use extracted from Unsplash.com), among which 12 were presented in the museum (randomized). All paintings were the same size.

Two participants could visit the museum simultaneously, one being the leader and the other the follower. The leader controlled navigation, while the follower simply watched the museum visit on a second screen, facing the leader. Both participants then performed the recognition task (no confidence judgment), the spatial memory task (no confidence judgment, no feedback) and the liking task (only seen paintings). The experiment was organized under a painting-by-painting design, not task-by-task as the online experiments. Participants could talk during the museum visit, but not while completing the tasks.

As for the online experiments, we computed a logistic mixed effects model on wall memory, with liking, wall and room as predictors, subject number and artwork as random factors. The result is presented in the main text (Results, *Liking increases memory for*

walls). We performed an additional model, where we added the role (leader/follower), and the testing context (laboratory, Tate, science festival) as controls (predictors of non-interest). We found that liking still significantly explained memory for walls (Liking: $b=0.22$, $SE=0.091$, $X^2(1)=6.12$, $p=0.013$).

Virtual environments – maps

Supplementary Figure 1: Museum maps. **A**, The 4 maps used in Experiment 1. Each grey rectangle represents the position of an artwork. Each participant visited one of these museums. **B**, The 2 maps used in Experiments 2 and 3.

Museum instructions

Experiments 1&3	<i>You will now visit a virtual museum of contemporary art. Your task is to move around the museum, look at every artwork in detail, and work out how much you like each one – just as you would do in a real museum. Take your time and look at all the artworks. You need to spend at least 30 seconds in each room of the museum – if not, you may not receive full payment for this task! You will use the same keys as before to move. You can get really close to the artworks if you want. In this museum you can't go back to an already visited room. Enjoy!</i>
Experiment 2	<i>You will now visit a museum of contemporary art. These artworks are abstract pieces. Some are purely abstract, while others are more realistic. Your task will be to focus on how abstract you think each artwork is, and to pick out at the end what you felt was the single most abstract artwork in the museum. There are no right or wrong answers, we are interested in your own judgments about what abstraction means. You will need to look at every artwork and spend at least 10 seconds in each room of the museum – if not, you may not receive full payment for this task! You will use the same keys as before to move. You can get really close to the artworks if you want. In this museum you can't go back to an already visited room.</i>

Exclusion criteria

		Exp. 1	Exp. 2	Exp. 3 (sess. 2)
Total number of tested participants		197	172	129
Excluded participants	Subjects reporting technical issues	6	3	3
	Subjects not spending enough time in each museum room (Exp 1: <30s; Exp 2: <10s; Exp 3: subjects were not invited to session 2)	22	3	-
	Subjects not spending enough time reading the instructions for the museum visit (<7s)	5	15	2
	Difficulties with navigation keys (duration of at least 2 training blocks was above 1.5 SD of the group)	7	9	6
	Low number of hits (Exp 1 and 2: <15, Exp 3: <10)	13	7	5
	Missed at least one attention check (Attention checks: 2 questions in final questionnaire asking to select a specific answer)	0	2	1
	Subjects not reporting the correct museum instruction (Exp. 2 only)	-	44	-
	Limited distribution of liking ratings (>2/3 of liking ratings were positive, or >2/3 of liking ratings were negative)	20	12	32
Total number of included participants		124	79	80

Supplementary Table 1: Exclusion criteria.

Demographics

Experiment 1

Experiment 2

Experiment 3

Supplementary Figure 2: Demographical description of the samples tested in each experiment. The pie chart represents the percentage of male and female participants. The histogram represents the age distribution of the samples. The world map shows the country of residence of participants.

General description

		Exp. 1	Exp. 2	Exp. 3
Recognition task	Hits (mean±SD, max=24)	20.22±2.67	21.11±2.49	17.86±3.78
	Hit confidence	5.54±0.43	/	/
	False alarms (mean±SD, max=24)	1.73±2.42	1.48±1.82	2.65±2.98
	False alarm confidence	3.55±1.02	/	/
	Reaction time (hits, mean±SD, in seconds)	2.13±1.25	1.53±0.45	1.89±0.64
Map task	Wall performance (% mean±SD, chance level = 33%)	57.76±17.13	63.81±17.15	51.46±15.06
	Confidence Wall correct (mean±SD, max=6)	3.28±1.15	3.24±1.02	2.81±1.05
	Confidence Wall incorrect	2.79±1.08	2.55±0.88	2.49±0.89
	Reaction time (Wall corr., mean±SD, in s)	7.86±3.53	6.9±2.74	7.37±3.69
Liking task	Liking, artworks in museum (raw ratings, mean±SD)	0.09±0.85	-0.07±0.81	-0.12±0.73
	Liking, artworks outside museum (raw ratings, mean±SD)	-0.83±1.05	-0.76±1.09	-0.90±0.85
	Liking, for hits (raw ratings, mean±SD)	0.28±0.97	0.03±0.84	0.25±0.91
	Liking, for false alarms (raw ratings, mean±SD)	-0.15±2.11	-0.54±1.88	-0.55±1.74
	Liking, for misses (raw ratings, mean±SD)	-0.92±1.77	-0.87±1.99	-1.15±1.41
	Liking, for correct rejections (raw ratings, mean±SD)	-0.84±1.06	-0.78±1.09	-0.97±0.9
	Liking variability, artworks in museum (mean individual SD ± SD)	3.04±0.61	2.96±0.62	2.80±0.63

Supplementary Table 2: General performance across tasks and experiments

Liking and memory for rooms

Model: Wall accuracy ~ Liking + Room memory + Wall number + Room number + (1 Subject) + (1 Artwork)	
Liking (z-scored)	b=0.11, SE=0.047 $X^2(1)=5.69$, $p=0.017$
Room memory (correct, incorrect)	b=0.53, SE=0.11 $X^2(1)=24.08$, $p<0.001$
Wall number (1-3)	Abs(b)<1.16, SE<0.12 $X^2(2)=117.32$, $p<0.001$
Room number (1-8)	Abs(b)<0.51, SE<0.19 $X^2(7)=30.19$, $p<0.001$

Supplementary Table 3: complete results of the model testing the effect of liking on wall memory while taking into account room memory.

Supplementary Figure 3: General performance for the three experiments. Performance on the recognition and spatial memory tasks, and responses on the liking and abstractness tasks are represented, as in Fig. 1D.

Supplementary Figure 4: Participants' responses on questions about art expertise.

Experiment 1

Experiment 2

Experiment 3

Please rate your ability to remember your personal past.

When recalling the past, to what extent do you think in images?

If you think in images when recalling the past, to what extent do you evoke spatially coherent scenes in your mind's eye compared to imagining single objects?

Please rate your navigational ability.

Supplementary Figure 5: Participants' responses on questions about memory and navigation abilities (61).