# Aesthetic experience enhances first-person spatial representation

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**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, and 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 h after the museum visit. Liking also modulated memory for the room where a work of art 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-centered 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 a work of art. This linkage may have implications for museum design.**

aesthetics | spatial representation | first person | affect | memory

The binding between what and where information is a central organizing 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 a work of art 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 have shown an improvement of memory for spatial locations of emotional stimuli (14–16), while others have shown 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

## Significance

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 a work of art. Our results may have implications for museum design.

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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 posttraumatic stress disorder (34). Here, we hypothesized that the first-person perspective involved in aesthetic experience could play a role in space–affect interactions by favoring 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 has 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 nonfunctional, 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. 1*A*). A professional curatorial team (the Museum of Contemporary Digital Art, mocda.org) mounted an exhibition of 48 works of art 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 toward 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. 1 *A* and *B*) and then performed three main tasks (Fig. 1*C*): 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 a work of art was seen (Fig. 1*B*) and remembering the room in which it was seen (39–41). Recalling whether a work of art 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 a work of art 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.

## Results

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

Participants ($n$ = 124, see *SI Appendix*, Fig. S2 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. 1*D*; recognition task, SD = 2.67), with high confidence levels (six-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 the artworks were hung (Fig. 1*D*; 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 (*SI Appendix*, Fig. S1) [logistic mixed effects model on wall accuracy; wall, left/front/right: $\chi^2(2) = 116.47$, $P < 0.001$; room, 1 through 8: $\chi^2(7) = 30.44$, $P < 0.001$; museum layout: $\chi^2(3) = 2.72$, $P = 0.44$]. 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; *Materials and Methods, Tasks and Procedure*). A total of 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 (*SI Appendix*, Table S1). The distribution of liking ratings (Likert scale: −5 to +5) from the included participants ($n$ = 124) is shown in Fig. 1*D*. 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 recognized as being present in the museum (hits, recognition task) had the highest liking ratings (*SI Appendix*, Table S2). 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 a work of art was seen.

For more details about general performance, see *SI Appendix*, Table S2.

**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

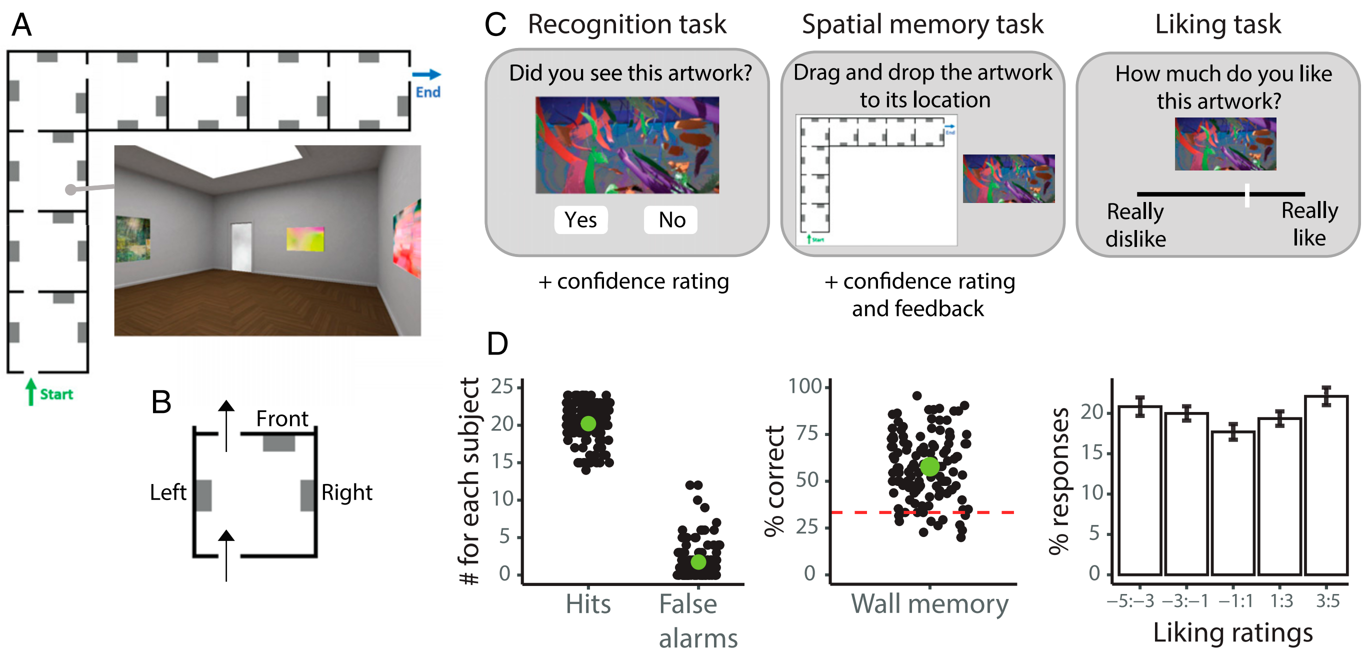


**Fig. 1.** Museum setting, paradigm, and general performance. (*A*) Example of a museum map and view of the environment. The virtual environment was composed of eight successive exhibition rooms with three artworks, one on the left, one on the front, and one on the right wall relative to the entrance door. See also *SI Appendix*, Fig. S1, showing the four maps used in this experiment. The three works of art shown in this view are: left, "#FOREST," by Mathieu Merlet-Briand (2019); front, "Digital Aquarelle 10," by Aaron Scheer (2019); and 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 artwork 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 were successively and randomly presented. Participants reported for each whether they had seen the artwork in the museum or not, and their confidence level (six-level scale). Spatial memory task: Participants were shown all the artworks they reported seeing and dragged and dropped each to its location in the museum map. They also reported their confidence (six-level scale) and were given feedback on their response. Liking task: Participants rated 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 were considered.



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, $\chi^2(1) = 7.71$, $P = 0.0055$], such that memory for the wall where artworks were hung increased with liking. This effect replicated a previous pilot study (*SI Appendix, Pilot Study*; $n = 96$; liking: b = 0.22, SE = 0.090, $\chi^2(1) = 6.05$, $P = 0.014$]. This effect showed that aesthetic experience of a work of art 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, $\chi^2(1) = 0.018$, $P = 0.89$], 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, $\chi^2(1) = 7.81$, $P = 0.0052$; intensity: b = 0.033, SE = 0.093, $\chi^2(1) = 0.13$, $P = 0.72$]. Our use of relative ratings imposes the assumption that each participant's 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

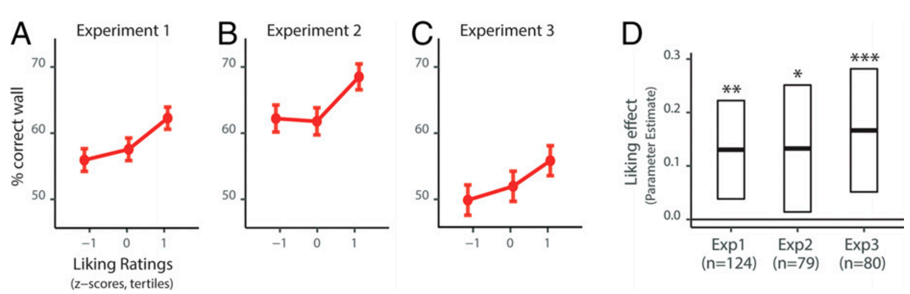


**Fig. 2.** Liking increases the ability to recollect the wall where artworks were hung. (*A–C*) Percentage of correct wall responses, for all responses collapsed across participants, in three quantiles along the liking scale (z scored for each participant). The *x* coordinate of each tertile corresponds to the average liking rating. Chance level: 33%. Error bars represent SEM. Experiment 1: main experiment; experiment 2: focus on abstractness; experiment 3: 24-h 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 noninterest: wall and room number; random effects: participant and artwork number). There was no significant difference between the parameter estimates from the three experiments. ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

recognize the museum layout (straight vs. 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, $\chi^2(1) = 7.71$, $P = 0.0055$; map recognition, correct/incorrect: b = 0.028, SE = 0.16, $\chi^2(1) = 0.032$, $P = 0.86$]. 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 also be 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, $\chi^2(1) = 13.57$, $P < 0.001$], 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 accuracy, wall number, and room number as predictors; liking: b = 0.11, SE = 0.047, $\chi^2(1) = 5.69$, $P = 0.017$, see *SI Appendix*, Table S3 for the full results of this model]. This indicates that the liking effect on memory for walls is independent from memory for rooms.

**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, $\chi^2(1) = 33.32$, $P < 0.001$; time: b = 0.44, SE = 0.061, $\chi^2(1) = 51.84$, $P < 0.001$]. 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, $\chi^2(1) = 5.22$, $P = 0.022$; distance: b = −0.056, SE = 0.051, $\chi^2(1) = 1.21$, $P = 0.27$; time: b = 0.068, SE = 0.048, $\chi^2(1) = 2.00$, $P = 0.16$]. 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 accuracy, and the interaction as predictors; liking: b = −0.12, SE = 0.031, $\chi^2(1) = 14.71$, $P < 0.001$; wall correct/incorrect: b = −0.15, SE = 0.038, $\chi^2(1) = 14.96$, $P < 0.001$; interaction: b = 0.077, SE = 0.039, $\chi^2(1) = 3.90$, $P = 0.048$]. 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 accuracy, the interaction, viewing time, viewing distance, wall left/front/right and room number; liking: b = −0.13, SE = 0.031, $\chi^2(1) = 17.32$, $P < 0.001$; wall correct/incorrect: b = −0.15, SE = 0.039, $\chi^2(1) = 13.92$, $P < 0.001$; interaction: b = 0.078, SE = 0.039, $\chi^2(1) = 4.06$, $P = 0.044$]. Among these factors, only room number had an independent effect on reaction times [room number: $\chi^2(7) = 45.74$, $P < 0.001$; 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. 1*C*). 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 (*SI Appendix, Museum Instructions*). Instead, participants (included: $n = 79$, see *SI Appendix*, Fig. S2 for demographic information) were instructed to focus on the abstractness of artworks during the museum visit. We excluded 44 participants who failed to report afterward the instruction they were given for the museum visit (*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. *SI Appendix*, Fig. S3 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, $\chi^2(1) = 21.31$, $P < 0.001$]. 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, $\chi^2(1) = 5.62$, $P = 0.018$; viewing time: b = 0.084, SE = 0.071, $\chi^2(1) = 1.42$, $P = 0.23$]. The reverse was observed for abstractness [mixed effects model on abstractness; viewing distance: b = 0.0088, SE = 0.065, $\chi^2(1) = 0.018$, $P = 0.89$; viewing time: b = 0.14, SE = 0.061, $\chi^2(1) = 5.36$, $P = 0.021$]. 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, $\chi^2(1) = 2.85$, $P = 0.091$]. Crucially, liking still modulated memory for walls when taking into account abstractness [Fig. 2*B*; mixed effects model on wall accuracy; liking: b = 0.122, SE = 0.0608, $\chi^2(1) = 4.00$, $P = 0.046$; abstractness: b = −0.091, SE = 0.063, $\chi^2(1) = 2.05$, $P = 0.15$]. 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 artifact 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, $\chi^2(1) = 1.03$, $P = 0.31$], which further suggests the effect of liking is not a global and unspecific mnestic 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 *SI Appendix*, Fig. S2 for demographic information and *SI Appendix*, Fig. S3 for the general performance of participants). As in experiment 2, the museum layout was straight.

Participants ($n$ = 80) correctly recognized 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, $\chi^2(1) = 36.77$, $P < 0.001$; viewing distance: b = −0.27, SE = 0.079, $\chi^2(1) = 11.76$, $P < 0.001$].

We found that despite the one-day delay, the effect of liking on memory for walls was again observed (Fig. 2*C*; logistic mixed effects model on wall accuracy; liking: b = 0.17, SE = 0.059, $\chi^2(1) = 8.03$, $P = 0.0046$]. 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, $\chi^2(1) = 6.74$, $P = 0.0094$; time between sessions: b = −0.045, SE = 0.019, $\chi^2(1) = 5.42$, $P = 0.020$; viewing time: b = 0.042, SE = 0.061, $\chi^2(1) = 0.46$, $P = 0.50$; viewing distance: b = −0.0042, SE = 0.065, $\chi^2(1) = 0.0041$, $P = 0.95$].

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, $\chi^2(1) = 4.49$, $P = 0.034$], and this effect did not account for memory for walls [logistic mixed effects model on wall accuracy, with liking, room accuracy, wall number, and room number as predictors; liking: b = 0.16, SE = 0.059, $\chi^2(1) = 7.06$, $P = 0.0079$].

**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 three 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 three experiments; liking: b = 0.14, SE = 0.032, $\chi^2(1) = 20.36$, $P < 0.001$; dataset: $|b|>0.15$, SE < 0.91, $\chi^2(2) = 23.60$, $P < 0.001$; liking*dataset: $|b|>0.015$, SE < 0.059, $\chi^2(2) = 0.73$, $P = 0.69$]. This suggests that our main effect of interest was comparable in size for all three experiments (Fig. 2*D*). In addition, none of the questions assessing art expertise, memory, and navigation abilities (*SI Appendix*, Figs. S4 and S5) 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 nonmutually 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 vs. positive liking: b = 0.20, SE = 0.074, $\chi^2(1) = 7.68$, $P = 0.0056$]. 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 vs. negative liking: b = 0.12, SE = 0.073, $\chi^2(1) = 2.72$, $P = 0.099$]. 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, $\chi^2(1) = 18.69$, $P < 0.001$; dataset: b = 0.32, SE = 0.090, $\chi^2(1) = 12.67$, $P < 0.001$; liking*dataset: b = 0.0075, SE = 0.055, $\chi^2(1) = 0.018$, $P = 0.89$]. 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, $\chi^2(1) = 4.71$, $P = 0.030$], while room memory for neutral and liked artworks did not differ significantly [neutral vs. positive liking: b = 0.14, SE = 0.095, $\chi^2(1) = 2.20$, $P = 0.14$]. 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 also 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 a work of art 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, *SI Appendix*, *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 behavioral 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.

Here we 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 three-dimensional (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 h 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 artworks 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 ref. 46, for an example of word presentation, ref. 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 posttraumatic 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 (*SI Appendix*, Fig. S4). Nonexperts are thought to refer primarily to personal feelings in establishing how much they like a work of art (51), resulting in an overlap between liking and valence (52). In addition, the artworks were abstract and presented with no labels, titles, or introductory text. This could limit the extent of interpretation, while favoring 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 works of art 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 work of art, rather than deperspectivized 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 toward 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 a work of art 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 visuospatial 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, optimizing 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 in at least one study on Prolific before, and not have participated in one of these experiments before. Participants were excluded from analysis based on criteria assessing technical issues, task performance, and attention, with the intention of having a conservative selection of participants (*SI Appendix*, Table S1). 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, *SI Appendix*, *Pilot Study*). A total of 124 participants were included in the main analyses of experiment 1 (64 females; age: mean = 24.48, SD = 5.55, minimum [min] = 18, maximum [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). *SI Appendix*, Fig. S2 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 University College London (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/h + bonus of the spatial memory task).

**Artwork Selection.** A total of 48 artworks from 25 contemporary digital artists were selected by M.C. and S.T., curators of 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 to their artworks being 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 *SI Appendix*, Fig. S1), 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. Twenty-four 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). 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 three 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 four 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 (*SI Appendix*, *Table S1*).

***Museum visit.*** Participants were shown the instructions for the museum visit (for the complete instructions see *SI Appendix*, *Museum Instructions*). Briefly, experiments 1 and 3 instructed participants to spend at least 30 s 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 10 s in each museum room (this shorter time was to avoid participants engaging in a 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 in their response (six-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 *SI Appendix*, Fig. S1) 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 seven 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; 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 colors of the artworks; 6, to pay attention to the different sizes of the artworks; 7, no specific instruction given for the museum visit). Afterward, participants were shown the 24 artworks of the museum and asked to indicate the one they found most abstract and their favorite.

***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 in their responses (six-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 virtual analogue scale (VAS) scale (101 levels, left label: "really dislike"; right label: "really like"). Artworks appeared in randomized order. Afterward, participants were shown the 24 artworks presented in the museum and 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) (*SI Appendix*, Figs. S4 and S5).

**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 30 s in each museum room were invited for session 2, the day after session 1. Participants performed session 2 on average 26.36 h 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 SDs 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. 1*B*). We fitted logistic mixed effects models to look at different aspects that could predict wall memory. Liking ratings were z scored across artworks (hits) for each participant, to account for interindividual variability in the use of the liking scale. All logistic mixed effects models on wall memory included wall (left, front, right) and rooms 1 through 8 as regressors of noninterest, to account for the fact wall memory depends on the wall and room (*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 $\chi^2$ 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.

**Data, Materials, and Software Availability.** Anonymized behavioral data, documentation, and analysis scripts have been deposited in Open Science Framework (OSF) (osf.io/zsm7v) (64).

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1. H. Eichenbaum, On the integration of space, time, and memory. *Neuron* **95**, 1007–1018 (2017).
2. R. A. Epstein, E. Z. Patai, J. B. Julian, H. J. Spiers, The cognitive map in humans: Spatial navigation and beyond. *Nat. Neurosci.* **20**, 1504–1513 (2017).
3. J. R. Manns, H. Eichenbaum, A cognitive map for object memory in the hippocampus. *Learn. Mem.* **16**, 616–624 (2009).
4. A. Postma, R. P. C. Kessels, M. van Asselen, How the brain remembers and forgets where things are: The neurocognition of object-location memory. *Neurosci. Biobehav. Rev.* **32**, 1339–1345 (2008).
5. H. Leder, G. Gerger, D. Brieber, "Aesthetic appreciation: Convergence from experimental aesthetics and physiology" in J.P. Huston and others (eds), *Art, Aesthetics and the Brain*, (Oxford 2015; online edn, Oxford Academic, 20 Aug 2015), pp. 57–78.
6. O. Vartanian, V. Goel, Neuroanatomical correlates of aesthetic preference for paintings. *Neuroreport* **15**, 893–897 (2004).
7. A. Chatterjee, O. Vartanian, Neuroaesthetics. *Trends Cogn. Sci.* **18**, 370–375 (2014).
8. H. Kawabata, S. Zeki, Neural correlates of beauty. *J. Neurophysiol.* **91**, 1699–1705 (2004).
9. S. Brown, X. Gao, L. Tisdelle, S. B. Eickhoff, M. Liotti, Naturalizing aesthetics: Brain areas for aesthetic appraisal across sensory modalities. *Neuroimage* **58**, 250–258 (2011).
10. S. Hamann, Cognitive and neural mechanisms of emotional memory. *Trends Cogn. Sci.* **5**, 394–400 (2001).
11. A. C. Holland, E. A. Kensinger, Emotion and autobiographical memory. *Phys. Life Rev.* **7**, 88–131 (2010).
12. E. A. Kensinger, J. H. Ford, Retrieval of emotional events from memory. *Annu. Rev. Psychol.* **71**, 251–272 (2020).
13. R. Brown, J. Kulik, Flashbulb memories. *Cognition* **5**, 73–99 (1977).
14. A. D'Argembeau, M. Van der Linden, Influence of affective meaning on memory for contextual information. *Emotion* **4**, 173–188 (2004).
15. M. Mather, K. Nesmith, Arousal-enhanced location memory for pictures. *J. Mem. Lang.* **58**, 449–464 (2008).
16. D. G. MacKay, M. V. Ahmetzanov, Emotion, memory, and attention in the taboo Stroop paradigm: An experimental analogue of flashbulb memories. *Psychol. Sci.* **16**, 25–32 (2005).
17. J. A. Bisby, N. Burgess, Negative affect impairs associative memory but not item memory. *Learn. Mem.* **21**, 21–27 (2013).
18. S. R. Touryan, D. E. Marian, A. P. Shimamura, Effect of negative emotional pictures on associative memory for peripheral information. *Memory* **15**, 154–166 (2007).
19. U. Rimmele, L. Davachi, R. Petrov, S. Dougal, E. A. Phelps, Emotion enhances the subjective feeling of remembering, despite lower accuracy for contextual details. *Emotion* **11**, 553–562 (2011).
20. J. A. Bisby, A. J. Horner, D. Bush, N. Burgess, Negative emotional content disrupts the coherence of episodic memories. *J. Exp. Psychol. Gen.* **147**, 243–256 (2018).
21. C. Z. Balaban, H. Karimpur, F. Röser, K. Hamburger, Turn left where you felt unhappy: How affect influences landmark-based wayfinding. *Cogn. Process.* **18**, 135–144 (2017).
22. M. Costanzi *et al.*, The effect of emotional valence and arousal on visuo-spatial working memory: Incidental emotional learning and memory for object-location. *Front. Psychol.* **10**, 2587 (2019).
23. C. R. Madan, A. G. Knight, E. A. Kensinger, K. R. Mickley Steinmetz, Affect enhances object-background associations: Evidence from behaviour and mathematical modelling. *Cogn. Emotion* **34**, 960–969 (2020).
24. K. Schmidt, P. Patnaik, E. A. Kensinger, Emotion's influence on memory for spatial and temporal context. *Cogn. Emotion* **25**, 229–243 (2011).
25. H. Leder, B. Belke, A. Oeberst, D. Augustin, A model of aesthetic appreciation and aesthetic judgments. *Br. J. Psychol.* **95**, 489–508 (2004).
26. P. L. St. Jacques, A new perspective on visual perspective in memory. *Curr. Dir. Psychol. Sci.* **28**, 450–455 (2019).
27. G. Nigro, U. Neisser, Point of view in personal memories. *Cognit. Psychol.* **15**, 467–482 (1983).
28. D. Berntsen, D. C. Rubin, Emotion and vantage point in autobiographical memory. *Cogn. Emotion* **20**, 1193–1215 (2006).
29. A. D'Argembeau, C. Comblain, M. Van der Linden, Phenomenal characteristics of autobiographical memories for positive, negative, and neutral events. *Appl. Cogn. Psychol.* **17**, 281–294 (2003).
30. H. K. McIsaac, E. Eich, Vantage point in episodic memory. *Psychon. Bull. Rev.* **9**, 146–150 (2002).
31. T. Sekiguchi, S. Nonaka, The long-term effect of perspective change on the emotional intensity of autobiographical memories. *Cogn. Emotion* **28**, 375–383 (2014).
32. P. L. St Jacques, K. K. Szpunar, D. L. Schacter, Shifting visual perspective during retrieval shapes autobiographical memories. *Neuroimage* **148**, 103–114 (2017).
33. S. Porter, A. R. Birt, Is traumatic memory special? A comparison of traumatic memory characteristics with memory for other emotional life experiences. *Appl. Cogn. Psychol.* **15**, S101–S117 (2001).
34. C. R. Brewin, J. D. Gregory, M. Lipton, N. Burgess, Intrusive images in psychological disorders: Characteristics, neural mechanisms, and treatment implications. *Psychol. Rev.* **117**, 210–232 (2010).
35. H. Leder, M. Nadal, Ten years of a model of aesthetic appreciation and aesthetic judgments: The aesthetic episode - Developments and challenges in empirical aesthetics. *Br. J. Psychol.* **105**, 443–464 (2014).
36. W. Tschacher *et al.*, Physiological correlates of aesthetic perception of artworks in a museum. *Psychol. Aesthet. Creat. Arts* **6**, 96–103 (2012).
37. D. Brieber, M. Nadal, H. Leder, In the white cube: Museum context enhances the valuation and memory of art. *Acta Psychol. (Amst.)* **154**, 36–42 (2015).
38. M. Pelowski, M. Forster, P. P. L. Tinio, M. Scholl, H. Leder, Beyond the lab: An examination of key factors influencing interaction with "real" and museum-based art. *Psychol. Aesthet. Creat. Arts* **11**, 245–264 (2017).
39. S. A. Marchette, L. K. Vass, J. Ryan, R. A. Epstein, Anchoring the neural compass: Coding of local spatial reference frames in human medial parietal lobe. *Nat. Neurosci.* **17**, 1598–1606 (2014).
40. S. A. Marchette, J. Ryan, R. A. Epstein, Schematic representations of local environmental space guide goal-directed navigation. *Cognition* **158**, 68–80 (2017).

41. M. G. Buckley, L. A. M. Myles, A. Easton, A. McGregor, The spatial layout of doorways and environmental boundaries shape the content of event memories. *Cognition* **225**, 105091 (2022).
42. K. J. Jeffery, Cognitive representations of spatial location. *Brain Neurosci. Adv.* **2** (2018).
43. D. Brieber, M. Nadal, H. Leder, R. Rosenberg, Art in time and space: Context modulates the relation between art experience and viewing time. *PLoS One* **9**, e99019 (2014).
44. P. J. Lang, M. K. Greenwald, M. M. Bradley, A. O. Hamm, Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology* **30**, 261–273 (1993).
45. J. F. Miller *et al.*, Neural activity in human hippocampal formation reveals the spatial context of retrieved memories. *Science* **342**, 1111–1114 (2013).
46. A. S. Petrucci, D. J. Palombo, A matter of time: How does emotion influence temporal aspects of remembering? *Cogn. Emotion* **35**, 1499–1515 (2021).
47. R. J. Maddock, S. T. Frein, Reduced memory for the spatial and temporal context of unpleasant words. *Cogn. Emotion* **23**, 96–117 (2009).
48. J. A. Bisby, N. Burgess, Differential effects of negative emotion on memory for items and associations, and their relationship to intrusive imagery. *Curr. Opin. Behav. Sci.* **17**, 124–132 (2017).
49. M. A. P. Moita, S. Rosis, Y. Zhou, J. E. LeDoux, H. T. Blair, Hippocampal place cells acquire location-specific responses to the conditioned stimulus during auditory fear conditioning. *Neuron* **37**, 485–497 (2003).
50. W. N. Butler, K. Hardcastle, L. M. Giocomo, Remembered reward locations restructure entorhinal spatial maps. *Science* **363**, 1447–1452 (2019).
51. D. Augustin, H. Leder, Art expertise: A study of concepts and conceptual spaces. *Psychol. Sci. Q.* **48**, 135–156 (2006).
52. H. Leder, G. Gerger, D. Brieber, N. Schwarz, What makes an art expert? Emotion and evaluation in art appreciation. *Cogn. Emotion* **28**, 1137–1147 (2014).
53. I. C. McManus, P. Weatherby, The golden section and the aesthetics of form and composition: A cognitive model. *Empir. Stud. Arts* **15**, 209–232 (1997).
54. D. E. Berlyne, Novelty, complexity, and hedonic value. *Percept. Psychophys.* **8**, 279–286 (1970).
55. E. A. Vessel, G. G. Starr, N. Rubin, Art reaches within: Aesthetic experience, the self and the default mode network. *Front. Neurosci.* **7**, 258 (2013).
56. M. Lebreton, S. Jorge, V. Michel, B. Thirion, M. Pessiglione, An automatic valuation system in the human brain: Evidence from functional neuroimaging. *Neuron* **64**, 431–439 (2009).
57. B. G. Witmer, J. H. Bailey, B. W. Knerr, K. C. Parsons, Virtual spaces and real world places: Transfer of route knowledge. *Int. J. Hum. Comput. Stud.* **45**, 413–428 (1996).
58. A. D. Ekstrom, H. J. Spiers, V. D. Bohbot, R. S. Rosenbaum, *Human Spatial Navigation* (Princeton University Press, 2018).
59. D. J. Huffman, A. D. Ekstrom, A modality-independent network underlies the retrieval of large-scale spatial environments in the human brain. *Neuron* **104**, 611–622.e7 (2019).
60. S. S. Chance, F. Gaunet, A. C. Beall, J. M. Loomis, Locomotion mode affects the updating of objects encountered during travel: The contribution of vestibular and proprioceptive inputs to path integration. *Presence (Camb. Mass.)* **7**, 168–178 (1998).
61. I. A. Clark, E. A. Maguire, Do questionnaires reflect their purported cognitive functions? *Cognition* **195**, 104114 (2020).
62. D. Bates, *et al.*, Lme4: Linear mixed-effects models using "Eigen" and S4. R package version 1.1-7.2014 (2015).
63. J. Fox, S. Weisberg, *An R Companion to Applied Regression* (SAGE Publications, 2018).
64. M. Babo-Rebelo *et al.*, Aesthetic experience enhances first-person spatial representation. OSF. https://osf.io/zsm7v/?view_only=7186e2c119504954859add7924ed084a. Deposited 12 January 2022.