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The influence of music liking on episodic memory for rich spatiotemporal contexts

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ABSTRACT
It is thought that the presence of music influences episodic memory encoding. However, no studies have isolated the influence of music liking – the hedonic value listeners attribute to a musical stimulus – from that of the core affect induced by the presence of that music. In an online survey, participants rated musical excerpts in terms of how much they liked them, as well as in terms of felt valence, felt arousal and familiarity. These ratings were then used to inform the stimuli presented in an online episodic memory task which, across different scenarios, involved dragging cued objects to cued locations and then recalling details of what was moved, where they were moved to and the order of movements made. Our results showed an influence of liking and music-reward sensitivity on memory for what was moved, as well as a detrimental effect of arousing musical stimuli on memory for un-cued scenario details. Taken together, our study showcases the importance of episodic memory paradigms that involve rich spatiotemporal contexts and provides insights into how different aspects of episodic memory may be influenced by the presence of music.

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Many listeners are able to describe vivid memories that are strongly associated with the experience of specific pieces of music. However, there is still much to comprehend about the influence that music's presence, in the context of everyday life events, has on later recall of said events. Music has the ability to induce strong emotions and elicit aesthetic pleasure – in idiosyncratic ways and to varying degrees – in listeners. Critically given the ubiquity of music in homes and public spaces, not to mention the extent to which listeners integrate it into their daily activities thanks to the portability of music playback devices, the ways in which music influences the memories we form over our lifetime is an increasingly relevant topic for psychologists to address.

Liking versus core affect

An interesting question, more broadly, concerns whether and how the positive evaluative judgment of a stimulus may influence episodic memory, when other key factors – like the core affect the stimulus induces – have been accounted for. Core affect has been described as those elements of a current mood or emotion that are accessible to conscious awareness, and is most simply organised into a two-dimensional model with emotional valence (feeling positive or negative) on the horizontal axis and arousal (calm or excited) on the vertical axis (Russell, 1980, 2003). Critically, both the emotional valence and arousingness of a context or background have been shown to influence memory for concurrent stimuli, with, for example, items or objects superimposed over positive visual scenes tending to be better remembered than those superimposed over negative or neutral ones (Smith, Dolan, et al., 2004; Smith, Henson, et al., 2004).

In contrast to core affect, which pertains to an individual's affective state, the act of liking a stimulus entails holding a judgment about its rewardingness. In models of aesthetic experience, liking is held to reflect personal judgments about the aesthetic value of a stimulus (Leder et al., 2004; Skov, 2019), and is argued to be distinct from affect (e.g., Leder et al., 2004, 2013). According to Skov (2019), liking is a form of evaluation in which individuals assign hedonic value to sensory stimuli, whereby the tagging of such stimuli with an affective "gloss" later assists decision-making around said stimuli. Indeed, across domains, the act of liking a stimulus seems to facilitate and speed up its choice over less-liked alternatives (e.g., Bielser et al., 2016). Similarly, in the context of music listening specifically, music liking ratings given by listeners not only reflect participants' evaluation of the excerpt's hedonic value, but also co-vary with broader related musical behaviours such as choosing to attend

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an associated concert, or recommending the liked music to a friend (e.g., see Anglada-Tort et al., 2019).

A large number of studies have examined how music-related emotions, (both the emotions perceived in music, and those induced by the music (see Gabrielsson, 2001; Schubert, 2013 for a discussion of how these differ)) may influence the formation of episodic memories. Indeed, amongst other distinctions, studies have examined how pleasant versus unpleasant, or joyful versus touching music, may differentially influence episodic memory encoding (e.g., Ferreri & Verga, 2016; Proverbio et al., 2015). Recently, it has been suggested that the presence of music can enhance episodic memory performance due to its ability to induce reward in listeners (see Ferreri & Verga, 2016 for a review); a claim in line with the theory of reward-driven learning more generally (Adcock et al., 2006; Lisman et al., 2011; Ripollés et al., 2016). However, given the tendency for music-induced reward to show associations with musical emotion and familiarity – for example, it has been suggested that pleasurable music is often highly arousing (Salimpoor et al., 2009) and familiar (Van Den Bosch et al., 2013) – it seems relevant to examine the unique and specific effect of liked background music on memory for concurrently unfolding events.

Towards testing episodic memory in a rich spatiotemporal context

Music psychology has long concerned itself with the influence of music on different aspects of human memory (Snyder & Snyder, 2000). For instance, whether and how music is special in its ability to trigger autobiographical memories in typical and clinical populations has been of considerable interest (Belfi et al., 2016; El Haj et al., 2012). Considered a subsystem of autobiographical memory (Conway, 2001), episodic memory is widely described as a memory system that allows re-experience of past experiences through autonoetic awareness (Tulving, 2002). However, even though Tulving's definition of episodic memory (storing "information about temporally dated episodes or events, and temporal–spatial relations among these events" (Tulving, 1972, p. 385)) emphasises spatiotemporal information as an important part of this form of memory, very limited research exists on how background music may influence encoding of spatial and temporal details.

Instead, the so-called old/new paradigms and remember/know tests have been commonly used in the music psychology literature (Yonelinas, 2002). In such old/new paradigms and remember/know tests, participants are presented with stimuli during an encoding phase and are later required to say whether stimuli presented in a recall phase are either old (were present during the encoding phase) or new (were absent during the encoding phase). If the stimulus is classified as "old", participants are further probed to say whether they remember (test of episodic memory) or know (simply recognise or feel familiar with) the stimuli.

To date, old/new paradigms and remember/know tests studies in music psychology have tended to use facial or verbal stimuli as the objects to be remembered. In a recent example of one such study, participants were presented with a series of words alongside experimenter-selected pleasant or unpleasant music, before having their memory for those words tested in a recall phase (Cardona et al., 2020). The authors were able to show (albeit only for participants possessing high sensitivity to musical reward) enhanced memory performance for words encountered in the presence of pleasant musical stimuli, and accordingly that certain music stimuli (and individual differences in listeners) may influence specific aspects of memory. However, as it has been suggested that list-learning episodic memory paradigms may not correlate with real world episodic memory performance (Plancher et al., 2008), further paradigms are arguably still needed to determine the effects that music's presence may have on everyday episodic memory.

Against this context, so-called What-Where-When paradigms, which test participants' ability to remember detailed information from rich spatiotemporal contexts, may have special relevance. Indeed, the Real world *What-Where-When* paradigm, which typically involves participants first hiding a number of cued objects in specified locations around a room and then recalling at a later stage what objects they hid, and where and when (or in what context) they hid them, is increasingly used to try to improve the ecological validity of lab-based episodic memory research (Smulders et al., 2017). In addition, computerised versions of the task have been developed, allowing memory for rich spatiotemporal contexts to be evaluated even in online data collection contexts (e.g., Silva et al., 2020).

In allowing spatial and temporal aspects of episodic memories to be tested, *what-where-when*-like paradigms may be argued to have a lot to offer with regard to illuminating how music heard in everyday life influences the encoding of rich episodic memories. In a recently developed musical version of the online What-Where-When paradigm, participants were guided to drag cued objects to pre-defined locations in different scenarios while music was presented in the background. In a consequent recall phase, they then had to indicate what objects they moved, and to what location (where) and in what context (when) they moved them using the same dragging action (Nawaz & Omigie, 2022).

That study was promising in showing a tendency for low arousal pleasant musical stimuli, (as well as stimuli associated with less negative aesthetic emotions), to result in superior episodic memory encoding. However, it was arguably limited by only using two unrelated scenarios as encoding sessions, and by only using music that had somewhat reduced ecological validity with regard to what people commonly listen to (being instrumental, low in familiarity and experimenter-selected). Specifically, with regard to the former concern, as real-life events and experiences are highly rich in nature, episodic memory tasks should arguably also aim to immerse participants in a rich experience or context (Diemer et al., 2015; Gorini et al., 2011). Similarly, given that the music people are exposed to in everyday life often includes popular music (which almost always contains lyrics and often becomes very familiar due to its ubiquity), it is highly important to use such music in episodic memory experiments.

The current study

Taken together, the aims of the current study were fourfold. First it aimed to examine how episodic memory is influenced by positive aesthetic evaluation (liking) of a background musical stimulus, as different from how it is influenced by a listener feeling more or less happy, or more or less energised as a result of listening to the stimulus. Second, it aimed to broaden the paradigms currently used to explore the influence of background music on episodic memory performance, such that memory for contextually rich spatio-temporal information is also assessed. Third, it aimed to use a type of musical stimulus that participants are very likely to hear in everyday life, namely popular music, so as to increase the ecological validity of the study. Finally, it aimed to explore the role of individual differences in music reward sensitivity (Mas-Herrero et al., 2013) on episodic memory encoding in the presence of music.

To allow examination of how aesthetic evaluation (liking) influences episodic memory beyond the role of other key factors (Aim 1) we recorded the liking, valence, arousal and familiarity ratings that individual listeners gave a set of musical stimuli, before presenting them with an individualised subset of those musical stimuli in a consequent episodic memory task. Critically, we required participants to report on their *felt* valence and arousal, rather than the emotion they perceived in the music (see Gabrielsson, 2001; Schubert, 2013 for a discussion of how these differ) as this idiosyncratic, subjective felt emotional experience seemed most relevant to disentangle from the similarly idiosyncratic, subjective experience of music liking.

With regard to the aim of broadening the paradigms currently commonly used to explore the influence of background music on episodic memory performance (Aim 2), we adapted an online musical What-Where-When paradigm (Nawaz & Omigie, 2022) to include four encoding sessions containing scenario-relevant objects that were held together by an immersive storyline. Critically, since previous studies have speculated that What, Where and When-like (temporal / order) memory may be subserved by different systems (Holland & Smulders, 2011), we explored the influence of music on these aspects of the task separately. Further, since the majority of memories encoded in everyday life are not encoded intentionally, we examined the extent to which non-intentional memory (memory for un-cued details of the encoding sessions/ scenarios) were influenced by music liking.

With respect to our next aim – namely using commonly heard music so as to increase the ecological validity of our findings (Aim 3) – all the musical stimuli selected for the current study constituted well known popular music from the previous decade. Finally, to explore the role of individual differences in music reward sensitivity on episodic memory (Aim 4), participants' music reward sensitivity levels were measured using the Barcelona Music Reward Questionnaire (BMRQ; Mas-Herrero et al., 2014)

In line with the hypothesis that the presence of music can enhance episodic memory performance due to its ability to induce reward in listeners (see Ferreri & Verga, 2016 for a review), we predicted that exposure to liked musical pieces during the encoding phase of our task would improve later recall (and vividness) of episodic memories, over and beyond any influences of valence (sadness vs happiness), arousal (calm vs excitement) and familiarity. Further we predicted that listeners with the highest levels of music reward sensitivity may benefit the most from the presence of music, especially liked music, as has been suggested in previous work (Cardona et al., 2020).

Methods

Participants

Fifty-five participants, recruited via Prolific (www.prolific.co): an online participant recruitment forum, took part in the study in exchange for monetary compensation. Four participants were removed from analysis as a result of having been presented with incorrect music during the episodic memory task. A further 5 completed only 3 out of 4 recall phases of the task but were kept, leading to 51 participants (Age $M = 28.65$; $SD = 9.43$; Range = 18–67; *Males* = 18; *Females* = 33) being included in the final analysis. These participants showed a range of musical training levels ($M = 20.7$, $SD = 9.2$, Range = 8–38) on the Musical training subscale of Goldsmiths Music Sophistication index (GoldMSI; Müllensiefen et al., 2014), which, using self-report items, measures the amount of music training an individual has undergone.

The study was approved by the host institution's ethics committee and all participants provided informed consent before participating. In the absence of any specific previous study that could be used to inform power and sample size calculations, 55 participants were aimed for since this number exceeded, by several participants, the sample size used in similar work (i.e., studies showing music influences on episodic memory performances such as Ferreri et al., 2015; Ferreri & Rodriguez-Fornells, 2017; Proverbio et al., 2015). The data that support the findings of this study are available from the corresponding author upon reasonable request.

Procedure

An overview of the procedure and of the episodic memory task used in the current study can be seen in Figure 1. The study was designed as a two-part study. The first part – an *online stimulus rating survey* – served to determine the most appropriate musical stimuli (customised for each participant) for the episodic memory task, while the second part – the *episodic memory task,* then allowed investigation of the influence of music responses on episodic memory performance.

Part One: Online stimulus rating survey and selection of stimuli: The online questionnaire administered in Part 1 not only recorded participants' demographic information and their level of musical training (musical training subscale of the Goldsmiths-Musical Sophistication Index (Gold-MSI)) (Müllensiefen et al., 2014) but also allowed participants to rate the popular music that had been preselected by experimenters.

With regard to the latter, participants were presented with 15-second clips of a selection of pop excerpts that featured in the top ten of the year-end billboard charts between the years 2010 and 2020 (see Table 1). For each of the 15 musical excerpts, ratings of Familiarity were taken with the question "How familiar are you with this music?" with possible responses being 1 = "As far as I know, I've never heard the excerpt before", 2 = "This excerpt seems somewhat familiar", 3 = "I've heard this excerpt for sure, but I know neither the performer/composer nor its title", and 4 = "I know the excerpt. It is called/by … ".

In turn, ratings of Liking were elicited with the question "How much do you like this music?", where responses from 1 = "Not at all" through 4 = "Neither Like or dislike" to 7 = "Very much" were possible. Finally, using the self-assessment manikin (Bradley & Lang, 1994), ratings of Valence were taken with the question "On the scale below from sad to happy, how did this music make you feel?" where possible responses ranged from 1 = "Sad/Melancholic" to 5 = "Happy/ Joyful" while ratings of Arousal were taken with the question "On the scale below from calm to excited, how did this music make you feel?" where possible responses ranged from 1 = "Calm" to 5 = "Excited".

For each excerpt, participants were required to provide additional information; to indicate the extent to which the music brought back memories from a specific time and place, to rate how vivid the memory was, and finally to describe the experienced memory. However, that data will be analysed and reported elsewhere. Finally, at the end of the survey, participants were asked to indicate two tracks they really liked ("Tell us 2 songs you really like (popular song in the last 10 years, in the top 20 billboard charts)") or really disliked ("Tell us 2 songs you strongly dislike (popular song in the last 10 years, in the top 20 billboard charts)") so that these tracks could be used as stimuli if necessary (See Supplementary materials for full list of final stimuli). Note that, as we did not expect that accuracy of arousal and valence ratings for the volunteered stimuli would be comparable to those for the stimuli we had presented them, we did not require these ratings to be provided for self-chosen

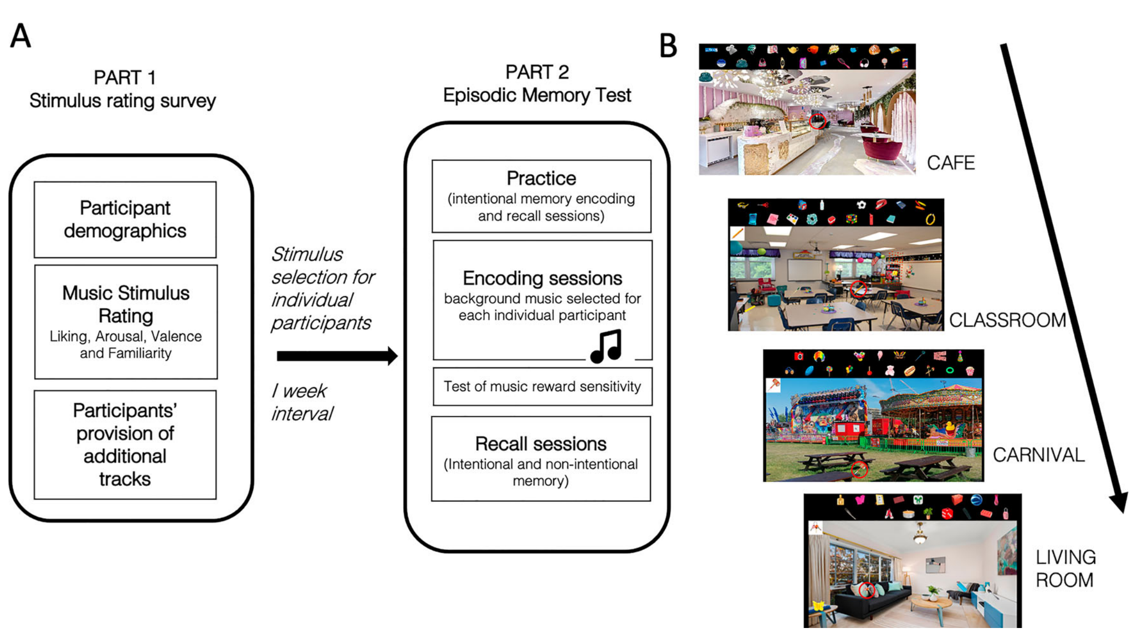

Figure 1. Showing an overview of the study design. (A) Participants completed an online survey in which they rated popular music excerpts in terms of liking, valence, arousal and familiarity. Following stimulus selection for each participant (such that the most and least liked stimuli were presented as far as possible), participants completed the Episodic memory task one week later. (B) Participants encoded and later reported on information presented in the context of four different scenarios.

Table 1. Musical stimuli which participants rated for Liking, Valence, Arousal and Familiarity, and from which stimuli were individually selected for the episodic memory task.

Title	Artist	Genre
Blinding Lights	the Weeknd	Pop
Bad Guy	Billie Eilish	Canadian pop
Blurred Lines	Robin Thicke	Electropop
Dark Horse	Katy Perry	Dance Pop
Despacito	Luis Fonsi	Dance Pop
We are Young	Fun	Latin Pop
Glad You Came	The Wanted	Modern Rock, Pop
Hello	Adele	Dance Pop
Love Yourself	Justin Bieber	Pop Soul
Old Town Road	Lil Nas X	Canadian Pop
Shut Up and Dance	Walk The Moon	Hip Hop
Someone You Loved	Lewis Capaldi	Dance Pop
Superbass	Nicki Minaj	Pop
Stay With Me	Sam Smith	Dance Pop
Uptown Funk	Bruno Mars	Dance Pop

excerpts. Highest levels of familiarity ("I know the excerpt. It is called/by … ") were nevertheless assumed based on the way in which the information was elicited.

Based on the survey ratings, musical stimuli were individually selected for each participant in accordance with the need for two mostly liked (a rating ≥5 on the 7-point scale) and two mostly not liked (a rating ≤4 on the 7-point scale) excerpts for each participant. Critically, efforts were made to ensure that levels of arousal, valence and familiarity covaried as little as possible with liking ratings by roughly balancing the levels of these variables across the two liking categories when selecting stimuli for each participant. For example, for every highly liked track with high arousal, valence and familiarity, a low liked track with similarly high arousal, valence and familiarity levels was sought. Note though, that as this manual selection of stimuli, however careful, could only be imperfect, our statistical approach did not make any assumptions about the strength of the relationship between variables (i.e., did not assume that liking indeed showed no covariation with other variables). In the case that a participant's ratings did not present enough songs that fit the criterion for liked and disliked music, one or two songs named by the participant as particularly liked or disliked were used as the stimuli to be presented.

Part 2: Completing the episodic memory task: A week after completing the online survey, participants were invited to take part in the second stage of the study which consisted of the online What-Where-When episodic memory task (further details of the task provided in the section below). Participants were instructed to complete the task in a quiet space that was free from distraction, and in which they would be able to hear the presented music clearly. Participants were also informed that they were taking part in a memory task that involved dragging objects around a space and would be asked to recall what objects they moved, where they moved them, and in what order. Participants completed a practice encoding and recall session in the absence of any musical stimuli to familiarise themselves with the detailed procedure. Participants then completed four encoding sessions, which unfolded over the course of a hypothetical day, and which comprised a unique music excerpt (selected to be more or less liked by the participant) played in the background for each session. After the encoding phase of each scenario, participants were instructed to stare at a fixation cross on the screen while the music excerpt continued to play for 10 s. Randomisation measures were taken to combine the four musical backgrounds with the four different settings/scenarios, such that pairing and order effects were avoided.

Before progressing to the recall phase, participants were presented with the Barcelona Musical Reward Questionnaire (BMRQ; Mas-Herrero et al., 2014), which measures individual differences in musical reward experiences using 20 items across 5 subscales (Musical Seeking, Emotion Evocation, Mood Regulation, Social Reward and Sensory-Motor). For each item, possible responses range from 1 = *completely disagree* to 5 = *completely agree*.

Then, in each of the four recall phases of the experiment, participants provided three types of information. They indicated (i) their intentional memory of both *What* and *Where* using the same drag-and-drop mechanism as in the encoding phase, and *When* using text field entries that inquired after the first and last object they moved in each scenario, (ii) the vividness with which they recalled the memories ("Indicate the response that best describes how well you were able to visualize the objects and locations on average during the recall task") by choosing one of the items 1 = "You only "know" that you are thinking of the objects and locations", 2 = "No image at all", 3 = "Vague and dim", 4 = "Moderately clear and vivid", 5 = "Clear and reasonably vivid", 6 = "Perfectly clear and as vivid as normal vision" and (iii) their incidental memory (they were not aware they would be tested) of details of the given scenario by responding to multiple choice questions (MCQs) that asked about such details e.g., "In the CAFÉ, what colour were the walls painted?" with possible responses being *Pink*, *Green* and *Cream* and "In the CLASSROOM, what was on the centre back wall?" with possible answers being *Whiteboard, Blackboard and Poster* (see Supplementary materials for full list of questions).

Details of the episodic memory task

The online *What-Where-When* episodic memory task used here – was built using PsychoPy (Peirce et al., 2019), and run online using Pavlovia (Pavlovia, 2020).

Encoding phase: Here, the paradigm employed a "drag-and-drop" method, where participants were required to drag a number of different objects to specific locations as cued by the experimental programme. A storyline was used to link four different encoding sessions such that participants were brought through a virtual day in their life; commencing in a café setting, followed by a classroom, a carnival and a living room setting. The story line (5 line-vignettes, presented prior to each setting) was used to create context for the scenarios and allow the participants to feel like they were entering a situation that was hypothetically similar to a real-world experience (see Supplementary materials for detailed instructions and the text of the storyline).

In each of four scenes or encoding sessions, participants were presented with 20 objects at the top of the screen, before being prompted to drag six cued objects to six cued locations around the scene. The to-be-dragged object appeared in the top left corner of the screen just below the full set of objects, and the destination for each indicated object was cued by a red circle that appeared on the scene. The 20 objects presented in each setting/ scenario (see Figure 1) had been selected to be relevant and appropriate for the setting (e.g., a credit card in the café, a calculator in the classroom environment, candy floss in the carnival and a vase in the living room). However, to increase the challenge of remembering what items were dragged where, and when they were moved, hiding locations, and the order in which objects were cued for dragging, were randomly determined (i.e., not chosen to be congruent or meaningful).

Recall phase: Subsequent to the 4 encoding phases associated with the 4 different scenarios (café, classroom, carnival and living room), participants entered the memory recall phase. There, participants were tested on their ability to remember what objects they moved (*What* component) and where they moved them (*Where* component) using the same drag-and-drop mechanism. In addition, so as to also measure how well temporal aspects of episodic memory were encoded (*When* component), participants were asked to indicate, by filling out text fields, what object they moved *first* and what object they moved *last* in each scenario.

Here it is important to note that the fact that we used a distinct set of 20 setting-relevant objects in each of the 4 scenarios precluded the adoption of the most commonly used method for evaluating memory for *when* (e.g., Holland & Smulders, 2011; Smulders et al., 2017): In many previous studies, a sub-selection of a single larger set of objects are required to be hidden in each of two sessions, and performance on the *when* component is indexed by participants' memory of the specific occasion (e.g., first room/ session or second room/session) in which they had moved specific objects. It is also important to note, however, that many previous iterations of the What-Where-When paradigm have measured temporal information in alternative ways (e.g., see Eacott & Norman, 2004, where "when" is operationalised in a way that accommodates the abilities of the animal species being tested). Justification of our operationalisation of the *when* component as memory for the first and last object moved in each scenario is that this approach offered important insights into how the heard music influenced memory for temporal order effects: this, while allowing us to study the encoding of memories within an enriched set of encoding contexts.

Analysis

Scoring: Memory for what objects were moved, where they were moved to, and the order of movement was estimated for each of the four scenarios separately. The score for *what* objects were moved, which was the number of all correctly identified objects, had a possible minimum of 0 and maximum of 6. In order to estimate a score for *where* objects were moved to (also a possible minimum of 0 and maximum of 6), the coordinates of all objects in the specific recall scenario were compared against the target destinations. Here, a given *where* scores action was considered correct if the distance between the location of the dragged object in the recall phase was less than .07 units (where units are defined in PsychoPy as relative to the height dimension of the participant's window) from the destination provided in the corresponding encoding phase. Finally, scores for the order of movement (possible values being 0 and 1) were based on whether both the first and last object moved was correctly indicated (score = 1), or not (score = 0). Finally, with regard to the score for incidental memory, one point was awarded for each correct answer given, with a maximum possible score of 0 and maximum of 3 possible for each scenario.

Statistical analysis: All analyses were carried out using R in the R studio environment (R Studio Team, 2020). Linear mixed effects models were estimated using the *lme4* package (Bates et al., 2015) with the Maximum Likelihood method of estimation employed whenever model comparison was carried out (otherwise Restricted Maximum Likelihood method was used), and degrees of freedom and *p*-values obtained using the Satterthwaite's method implemented in the *lmerTest* package (Kuznetsova et al., 2017).

First, associations between Arousal, Valence and Familiarity were analysed using Pearson correlation analysis before their influence on Liking ratings were investigated using a linear mixed effects models with Participant ID and Song title as random effects. Next, we assessed the effect of Liking, along with Valence, Arousal and Familiarity ratings, on the three components of what-where-when episodic memory. For memory for *what* objects were moved and for *where* they were moved to, separate linear mixed effect models with each score as dependent variable (DV), Liking, Valence, Arousal and Familiarity ratings as fixed effects and Participant ID and Scenario as random effects were run. In turn, to assess the *when* memory component, or more specifically, memory for the temporal order of movements made (first and last items moved correctly identified), a logistic mixed effects model with Liking, Valence, Arousal and Familiarity as fixed effects and Participant ID and Scenario as random effects was run. Last but not least, the effect of Liking and the three other ratings on vividness of memories were evaluated with similar models.

Critically, for all models, we confirmed, as relevant, any significant effect of Liking on episodic memory, by comparing the performance of a model with all four fixed effects (Liking, Valence, Arousal and Familiarity) to the performance of one with only Valence, Arousal and Familiarity as fixed effects. This model comparison type allowed us to achieve our main aim of establishing whether music liking has an influence on episodic memory performance and vividness over and beyond any influence of music emotion and familiarity.

A final set of analyses assessed (i) the effect of Liking, Arousal, Valence and Familiarity on incidental/ non intentional memory performance and (ii) the role, if any, reward sensitivity plays on intentional and incidental episodic memory encoding. With respect to the former, a linear mixed model with incidental/ non intentional memory score as DV, Liking, Valence, Arousal and Familiarity as fixed effects and Participant ID and Scenario as random effects was estimated. With respect to the latter, participants were first assigned to low, intermediate and high BMRQ groups in line with their belonging to three tertiles. This grouping variable was then allowed to interact with Liking in two final linear mixed models (one for intentional and one for incidental memory) in which Liking, Valence, Arousal, Familiarity and BMRQ group served as fixed effects and Participant ID and Scenario served as random effects.

Results

Descriptive statistics and associations between subjective variables

Table 2 details Pearson correlations between Arousal (M = 3.45, SD = 1.01, Range = 1–5), Valence (M = 3.55, SD = 0.99, Range = 1–5), and Familiarity (M = 3.77, SD = 0.55, Range = 1–4), and shows that while there was a strong positive relationship between Arousal and Valence (r = 0.70, p < 0.01), neither of these correlated with Familiarity.

A linear mixed effect model, with Restricted Maximum Likelihood (REML) as the method of fitting, was used to examine the extent to which Valence, Arousal and Familiarity, (taken as fixed effects, with Participant ID and Song title as random effects), influenced the DV, Liking (M = 4.10, SD = 2.64, Range = 1–7). This analysis revealed a significant effect of Valence (B = 0.85, SE = 0.22, t (144.45) = 3.81, p < 0.001), and Familiarity (B = 0.68, SE = 0.28, t (141.77) = 2.44, p = 0.02) but no effect of Arousal (B = 0.36, SE = 0.23, t (145.93) = 1.62, p = 0.11) on Liking.

Table 2. Means, standard deviations, and correlations (with confidence intervals) of Valence, Arousal and Familiarity.

Variable	*M*	*SD*	Valence	Arousal
Valence	3.55	0.99		
Arousal	3.45	1.01	.70** [.61, .77]	
Familiarity	3.77	0.54	−.02 [−.18, .13]	−.04 [−.20, .12]

Notes: *M* and *SD* are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. * indicates p < .05. ** indicates p < .01.

Intentional memory performance: memory for What-Where-When

We first examined influences of Liking along with Valence, Arousal and Familiarity on intentional episodic memory encoding for What (M = 5.42, SD = 1.15, Range = 0–6), Where (M = 4.52, SD = 1.51, Range = 0–6) and When (temporal information correctly remembered in 46% of scenarios, Range = 0–2) components of the tasks. Table 3 shows the results of statistical analysis while Figure 2 displays the relationship between recall performance and Liking, Valence and Arousal subjective variables (once Familiarity and the other two variables as relevant had been regressed out; Note that for "Where", the Liking line is obscured by the Valence line).

A linear mixed effect model estimation, with Maximum Likelihood (ML) as the method of fitting, showed only Liking to be a significant predictor (B = 0.09, SE = 0.03, t(52.14) = 2.59, p = 0.01) of memory for the objects moved ("What"). Further, comparing this model (containing all four fixed effects) to one with only Arousal, Valence and Familiarity as fixed effects showed that the model that included Liking was superior to the model that did not ($\chi 2$ *(1)* = 6.44, p = 0.01; AIC $_{\text{Model with Liking}}$ = 450.95, AIC $_{\text{Model without Liking}}$ = 455.39; BIC $_{\text{Model with Liking}}$ = 475.19, BIC $_{\text{Model without Liking}}$ = 476.61). In contrast, neither the linear mixed model examining memory for *Where* (locations moved to) nor the mixed effects logistic regression examining memory for *When (*or more specifically, whether participants successfully remembered the first and last objects moved) showed an influence of any four of the fixed effects (all ps > 0.05).

Finally, a linear mixed model with Vividness ratings as DV, Liking, Valence, Arousal and Familiarity as fixed effects, and Participant ID and Scenario as random effects was estimated but, again, did not reveal a significant effect of any of the variables (all ps > 0.05).

Table 3. Influence of Liking, Valence, Arousal and Familiarity on memory for object ("What"), location ("Where") and first and last objects moved ("When").

	Fixed effect	*B*	*SE*	*df*	*t / z*	*p*
What	(Intercept)	6.24	0.84	128.67	7.39	<0.001
	Liking	**0.09**	**0.03**	**52.14**	**2.59**	**0.01**
	Valence	−0.05	0.12	150.51	−0.43	0.67
	Arousal	−0.1	0.12	151.74	−0.85	0.4
	Familiarity	−0.19	0.18	142.42	−1.01	0.32
Where	(Intercept)	5.52	1.13	117.5	4.86	<0.001
	Liking	0	0.05	116.76	0.05	0.96
	Valence	−0.02	0.17	150.61	−0.11	0.91
	Arousal	−0.04	0.16	150.87	−0.24	0.81
	Familiarity	−0.22	0.25	128.61	−0.87	0.39
When	(Intercept)	1.74	1	86.58	1.74	0.09
	Liking	−0.04	0.05	135.7	−0.82	0.42
	Valence	−0.03	0.18	147.84	−0.16	0.87
	Arousal	0.08	0.17	147.41	0.47	0.64
	Familiarity	−0.08	0.23	92.98	−0.36	0.72

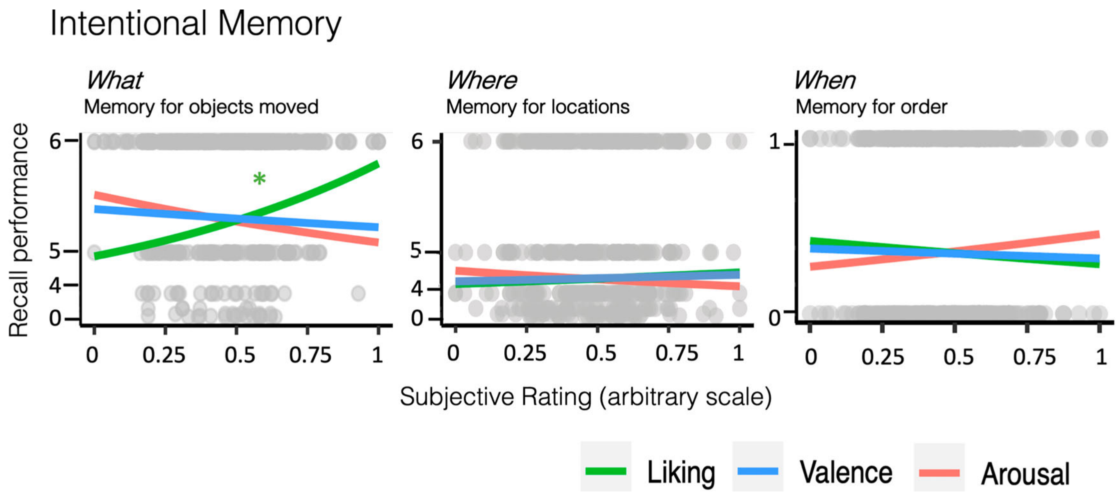

Figure 2. Illustrating intentional memory performance for what objects were moved, where they were moved to and the order of movements (first and last moved objects) as a function of Liking, Valence and Arousal once Familiarity and the other two subjective variables had been regressed out. For illustration purposes, the *y* axis is presented on an exponential scale, and Liking, Valence and Arousal on the *x* axis are scaled to between 0 and 1. * indicates $p < 0.05$. Note that for "Where", the Liking line is partially obscured by the Valence line.

Incidental memory performance

Next, we asked if and how Liking and the other three variables influenced the extent to which participants remembered those details of the scene that they had not been prompted to try to encode (see Figure 3). A linear mixed model with incidental memory score as DV, Liking, Valence, Arousal and Familiarity as fixed effects, and Participant ID and Scenario as random effects revealed no influence of either Liking, Valence or Familiarity. However, it did reveal a significant effect of Arousal ($B = -0.24$, $SE = 0.11$, $t(145.48) = -2.24$, $p = 0.027$) whereby higher arousal was associated with poorer incidental memory performance (see Table 4).

While the main aim of the current study was to determine whether music liking has an influence on episodic memory over and beyond emotion variables and familiarity, the robustness of this effect of arousal on incidental memory performance was further explored. Specifically, we compared a model with Liking, Valence, Arousal and Familiarity as four fixed effects to one with only Liking,

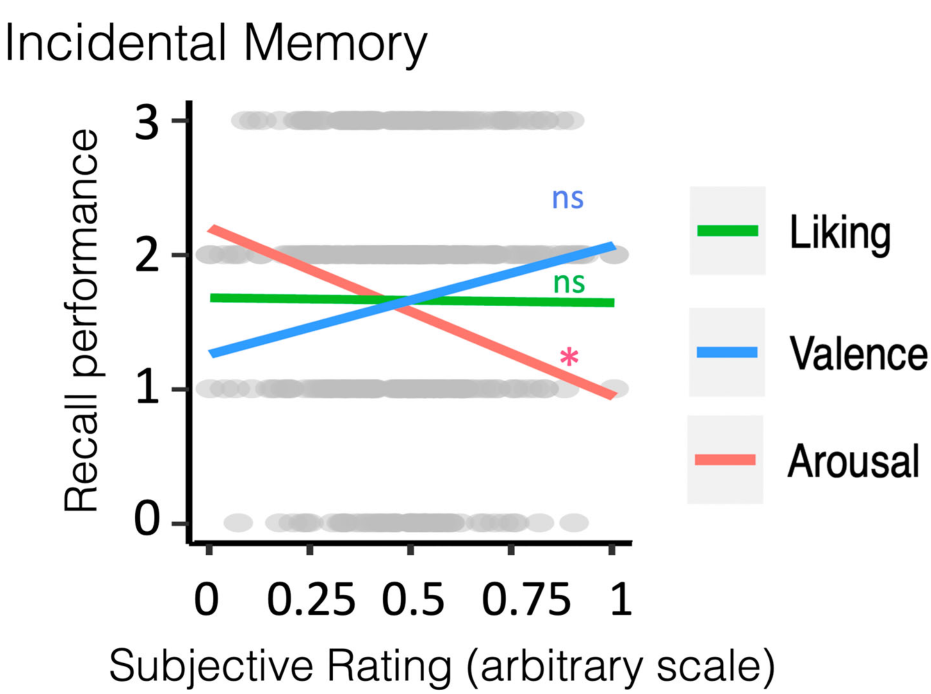

Figure 3. Illustrating non-intentional (incidental memory recall) as a function of Liking, Valence and Arousal once Familiarity and the other two subjective variables had been regressed out. * indicates $p < 0.05$. ns = not significant.

Table 4. Influence of Liking, Valence, Arousal and Familiarity on incidental memory.

Fixed effect	*B*	*SE*	*df*	*t*	*p*
(Intercept)	0.97	0.63	84.52	1.54	0.13
Liking	−0.03	0.04	101.23	−0.7	0.48
Valence	0.2	0.11	145.04	1.76	0.08
Arousal	**−0.24**	**0.11**	**145.48**	**−2.24**	**0.03**
Familiarity	0.25	0.14	91.16	1.79	0.08

Valence and Familiarity as predictors. This analysis showed that the model that included Arousal could be considered superior to the model that did not include Arousal (χ^2 (1) = 4.81, $p = 0.03$; AIC $_{\text{Model with Arousal}} = 432.09$, AIC $_{\text{Model without Arousal}} = 434.90$) albeit not with respect to the Bayesian Information Criterion (BIC $_{\text{Model with Arousal}} = 456.43$; BIC $_{\text{Model without Arousal}} = 456.20$).

The role of music reward sensitivity on episodic memory performance

Finally, we explored whether music reward sensitivity had an influence on intentional and incidental memory performance (Figure 4); specifically, whether music reward sensitivity levels were associated with episodic memory performance (hypothesis 1) and/ or whether those with higher reward sensitivity especially benefited from the presence of liked music (hypothesis 2).

There was no support for hypothesis 2 (that those with high reward sensitivity especially benefited from the presence of liked music) for either incidental or intentional memory. There was also no support for hypothesis 1 with regard to incidental memory. However, for intentional memory, we found partial evidence for hypothesis 1 with regard to memory for *what* was moved. Specifically, in a linear mixed model with *What* scores as DV, BMRQ group, Liking, Valence, Arousal and Familiarity as fixed effects (where only Liking and BMRQ group were allowed to interact) and participant ID and Scenario as random effects, Liking ($F = 5.48$, $p = 0.02$) and BMRQ group ($F = 3.09$, $p = 0.049$) were shown to be significant. The significant effect of BMRQ group reflected that those in the intermediate reward sensitivity group showed poorer performance than those in both the low ($B = 0.82$, $SE = 0.31$, $t(45.5) = 2.65$, $p = 0.03$), and high reward ($B = -0.89$, $SE = 0.31$, $t(46.4) = -2.86$, p 0.02) sensitivity groups, but that there was no difference in performance between the low and high reward sensitivity groups ($B = -0.06$, $SE = 0.32$, t (48.8) = −0.20, $p = 0.98$). To confirm what seemed to be a u-shaped (quadratic) relationship between What memory performance and reward sensitivity, we estimated a regression model with What episodic memory as DV and both BMRQ scores and BMRQ scores squared (i.e BMRQ scores ^2; the quadratic term) as predictors, alongside a regression model with just BMRQ scores as predictor. Indeed the model with the quadratic term was significant ($R^2 = 0.071$; $F(2,196) = 7.20$, $p < 0.001$) and the BMRQ quadratic effect confirmed a u-shaped pattern ($B = 0.002$, $SE = 0.0006$, $t = 3.74$, $p < 0.001$). In contrast the model without the BMRQ scores squared as a predictor was not significant ($R^2 = 0.002$, $F(1,197) = 0.42$, $p = 0.52$).

Previous work has grouped individuals into anhedonics, hedonics and hyperhedonics based on their score on the BMRQ (Mas-Herrero et al., 2014). When grouping participants based on the boundaries reported there (whereby for *Anhedonics, BMRQ < 65; for Hedonics 65 < BMRQ < 87*, for *HyperHedonics, BMRQ > 87)* we obtained only a small number of Anhedonics and Hyperhedonics (11 and 7 participants respectively) compared to hedonics (33 participants) making the running of statistics based on this grouping questionable. However, worthy of note is that mean scores when using this grouping nevertheless showed the same pattern as our grouping based on tertiles, and our findings when exploring for a u-shaped (quadratic) relationship; specifically, lower mean memory

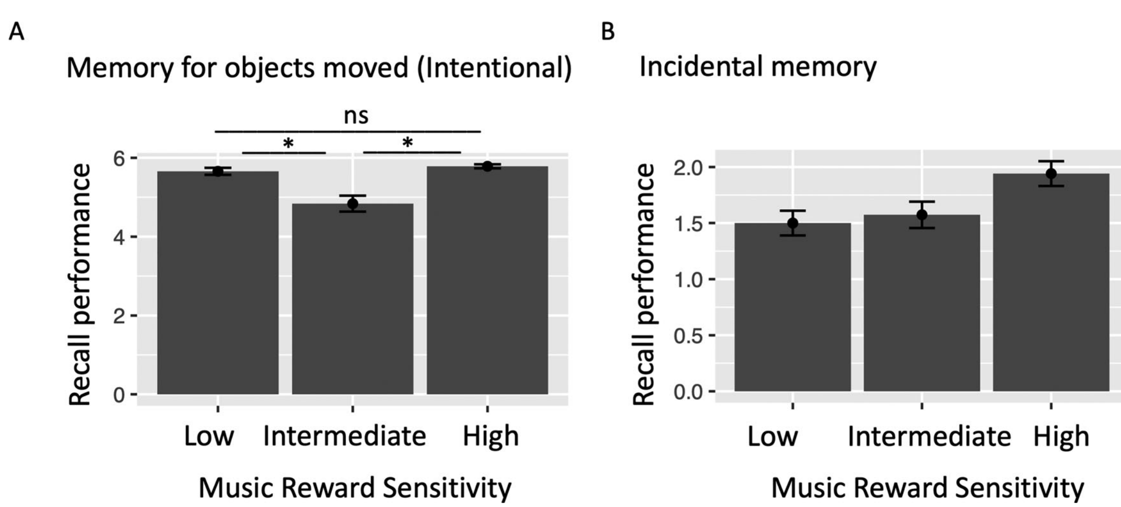

Figure 4. Illustrating how (A) intentional memory for what was moved and (B) incidental memory for scenario details differed as a function of music reward sensitivity. * indicates $p < 0.05$. ns = not significant.

scores for the hedonic group (possessing medium BMRQ scores) than for the anhedonic (possesing lower BMRQ scores) and hyperhedonic (possessing higher BMRQ scores) groups.

Discussion

Given the ubiquity of musical stimuli in the environment, how it influences memory for events unfolding in everyday life can be considered a question of key relevance. A key aim of our study was thus to better understand the effect that liking of music has on episodic memory encoding. Given empirical evidence that music-induced aesthetic reward may have an influence on memory, but that aesthetic reward from a piece of music may in turn be related to factors like emotion induced by, and familiarity with, the given piece of music, a particular aim of the present investigation was to isolate the effect of liking from these other related factors.

Our results provided evidence that hearing music that is liked positively influences intentional episodic memory learning: albeit that effect was only observed with regard to memory for *what* information, or more specifically, memory for physical objects or items in an environment. While we did not see an effect of liking on non-intentional memory scores, exploratory analysis suggested that felt arousal influenced this type of memory, whereby musical stimuli experienced as arousing were associated with poorer memory of un-cued scenario details. Finally, we saw that reward sensitivity was associated with overall levels of intentional memory performance, again particularly in relation to memory for what was moved. However, we found no evidence that this individual difference interacts with degree of liking of heard music, when exerting its influence on episodic memory performance.

Liked music promotes memory for "What" is remembered in a rich spatio-temporal context

Liking of a stimulus is widely accepted to be associated with the evaluative judgment an observer makes, rather than with any specific pattern of emotional or physiological responding. Indeed, it has been shown that while individuals may like aesthetic stimuli that induce positively valenced emotions, they similarly report liking stimuli that make them feel sad (Eerola et al., 2016) or that are challenging or hard to process (Mencke et al., 2019). Similarly, it is important to note that while reward from music has been associated with high arousal in some studies (Salimpoor et al., 2009), positive aesthetic judgments of music have also been associated with feelings of low arousal (e.g., Omigie et al., 2021). It was due to this evidence of a complex relationship between aesthetic reward and emotion that our study sought to more closely examine the extent to which liking influences memory performance. Indeed, our results showed that liking ratings were able to predict intentional episodic memory performance in a way that is independent of felt arousal and valence, as well as independent of familiarity.

In music psychology, a clear distinction is made between listener's perception of the emotion expressed by a piece of music and their feelings in response to said piece of music. While it can be difficult for listeners to distinguish between these two aspects of musical emotions (e.g., Gabrielsson, 2001; Schubert, 2013), we required participants to report on their felt emotion. Accordingly, this allowed us to see how the idiosyncratic, subjective experience of liking influenced memory separately from the (when compared with the perception of emotion) more idiosyncratic, subjective experience of felt emotion.

In contrast to our findings in terms of liking, our failure to see a positive influence of valence on memory performance may seem contrary to the findings in other domains where, for instance, items or objects presented over positive visual scenes were shown to be better remembered than those presented over negative or neutral ones (Smith, Dolan, et al., 2004; Smith, Henson, et al., 2004). It is important to note, though, that those studies selected positive and negative stimuli from the IAPS (Lang et al., 1999) where valence is more closely linked to the "pleasantness" or "unpleasantness" of experienced stimuli. Indeed, studies in which the effects of pleasant and unpleasant background music on episodic memory have been compared have suggested a positive influence of pleasant background music (e.g., Cardona et al., 2020; Ferreri & Verga, 2016). As feelings of unpleasantness (vs pleasantness) are arguably rare in response to music commonly heard in everyday life, our study operationalised valence in terms of feelings of positivity (happy or joyful) or negativity (sad or melancholic) in response to the heard music. There is rich evidence that listeners enjoy and appreciate sad music (Eerola et al., 2016) – a phenomenon that is reflected in trends in the evolution of popular music (e.g., Interiano et al., 2018) – and, as such, how liking influences memory independently of this aspect of valence was deemed a particularly critical one to establish.

In any case, we saw that while liking heard music may influence *what* is remembered, it plays less of a role on spatial (in this case, where objects were moved) and temporal (the order in which they were moved) aspects of episodic memory. Previous work had shown differences in how these three different components of what-where-when memory paradigms are correlated with different factors: specifically, it had been seen that while performance in a task that involved simply answering questions about un-cued details of a scene correlated with *What memory* performance, it did not correlate with *Where* and *When* memory performance (Holland & Smulders, 2011). As this distinction between components was not seen in a passive version of the *What-Where-When task*, those authors speculated that when participants are asked to actively encode information, systems other than the episodic memory system (for instance the semantic memory system) may become involved in storing *When* and *Where* information (Holland & Smulders, 2011). In our study, participants were all made aware that they would be tested on what, where and when information. It would therefore be interesting to observe whether *not* informing participants that they would be tested on this information (i.e., having a passive condition as was the case in Holland & Smulders, 2011) would lead to a different pattern of results with regard to how liking influences episodic memory.

In addition to our tests of what, where and when information, which were tests of intentional memory encoding, we also explored how non-intentional memory may be influenced by liking of background music. Here, we failed to see an effect of liking on non-intentional episodic memory condition, but, interestingly, we observed a tendency for music-induced arousal to negatively influence this type of episodic memory. As such, our results are in line with the well know Cognitive Capacity Hypothesis that posits that high arousal contexts can be deleterious for task performance (Kahneman, 1973).

Here it is important to note that, only by concurrently evaluating the effect of felt arousal and valence in response to the musical stimuli, could the effect of music liking be clearly seen. Our results thus speak to the importance of careful characterisation of musical stimuli, such that when making inferences in terms of any given subjective variable, as many as possible other variables are matched, or controlled for. Here, our studies suggest that previous studies that failed to control for arousal and valence levels (for example when examining how the rewardingness of musical stimuli impacts episodic memory) may have failed to observe the true nature of the studied effect.

Here it is interesting to consider the current results in light of recent findings regarding music-induced pleasure and memory performance (Ferreri et al., 2021; Ferreri & Rodriguez-Fornells, 2022). These studies outline the essential role dopamine release plays in pleasurable responses to music listening, and the knock-on effect those neural processes can have on memory formation. Reward responses have been shown to activate both the dopaminergic mesolimbic pathway and the hippocampus (Ripollés et al., 2018) – with midbrain dopaminergic neurons in the ventral tegmental area and their projections to the ventral striatum modulating this hippocampal activity. The Neo-Hebbian framework suggests that interaction between reward processing centres and the hippocampus underlie reward-induced memory formation; indeed, evidence that disrupted dopaminergic signalling diminishes both music-induced pleasure and memory outcomes provides evidence for this interaction (Ferreri et al., 2021).

Findings linking music-induced pleasure and memory via dopamine are significant from an evolutionary perspective as they show how music-induced pleasure might influence higher cognitive function, and accordingly, how music may be adaptive. However, to date, studies showing that interaction between reward processing centres and the hippocampus underlie reward-induced memory enhancement have mainly used simple facial or verbal stimuli. We propose it would be useful to use the what-where-when task in order to simulate more real-world contexts. While our findings do not provide direct evidence for dopamine's involvement in such neural processes, they provide some support for the notion that dopaminergic transmission, arising in response to musically induced pleasure, may have specific implications in promoting memory for "What" is remembered in rich spatio-temporal contexts.

The role of music reward sensitivity in episodic memory encoding

Our results showed an interesting pattern of association between musical reward sensitivity and performance on intentional memory encoding, whereby not just those with high levels of musical reward sensitivity performed better than others, but rather both those with low and high levels performed better than those with intermediate sensitivity levels. One possibility is that those with intermediate levels compared to those with low levels of music reward sensitivity experience greater levels of distraction by the presence of music when engaging in an active memory task. Indeed, it is possible that those with low music reward sensitivity are better able to block out or ignore heard music (thus reducing cognitive load to a greater extent) than those with intermediate levels (who may not be able to help but engage with the music). In turn, it is possible that the high reward from music experienced by those with the highest music reward sensitivity, may have their memory performance enhanced in the presence of music thanks to well-described dopaminergic pathways (Adcock et al., 2006; Ripollés et al., 2016). These interpretations are nevertheless highly speculative and it will be important to investigate them more carefully in future work. Specifically, rather than the typical sample evaluated here, future studies could recruit anhedonic, hedonic and hyperhedonic participants as characterised in previous work (Mas-Herrero et al., 2014), so as to increase the possibility of seeing reward sensitivity effects more clearly.

We did not see a clear effect of music reward sensitivity/ BMRQ on non-intentional memory encoding suggesting that if reward sensitivity to music influences memory, it may do so particularly for memory of those events that are consciously engaged with and actively committed to memory. We also did not see a tendency for those with higher levels of reward sensitivity to perform better when listening to liked compared with unliked music as has previously been reported (Cardona et al., 2020). Indeed, while we showed that those with highest levels of reward sensitivity (similar to hyperhedonics) generally performed better than those with intermediate levels of reward sensitivity (similar to hedonics), our statistical analysis did not show a significant interaction between reward sensitivity level and degree of music liking. One reason for this discrepancy may be the different stimuli used in the two studies: Cardona et al. (2020) used instrumental classical music pre-selected to be highly pleasant or lowly pleasant for all participants in the same way. Here, it is important to note, as pointed out by those authors, that selecting participants with a specific preference for the classical music used, that collecting subjective ratings after each excerpt was presented (so as to account for individual differences in reward from the individual excerpts) and, finally, that pre-selecting the music to meet the extremes for each participant, may have led to stronger effects of reward being shown. Another possible reason for the discrepancy is that Cardona and colleagues excluded participants considered to be "anhedonic" from their sample whereas we considered the full sample of participants in our analysis. That their sample excluded anhedonics and thus showed a higher overall level of music reward sensitivity (BMRQ mean of 83.69) compared with our sample (BMRQ mean of 75.09) may have led Cardona and colleagues to see a reward sensitivity – liking interaction that was not possible with our wider sample of participants.

The importance of considering individual differences and not conflating liking with emotion

Our study was highly motivated by the observation that previous studies that have reported episodic memory enhancement in responses to rewarding music have tended to use experimenter-selected music and – in doing so – have thus failed to take into account the important role of individual differences. Critically, patterns of aesthetic appreciation may be expected to closely reflect individual differences. For example, while there is evidence that listeners tend to favour or like moderate levels of complexity, jointly captured by information content and uncertainty (Cheung et al., 2019; Gold et al., 2019), the ability to deal with the stress of uncertainty also seems to play an important role in how appreciation of music unfolds over time (Omigie & Ricci, 2022). Furthermore, yet other individual differences (e.g., trait empathy in the case of liking sad music) have been shown to influence aesthetic judgments as a function of music's affective properties (Eerola et al., 2016), highlighting the importance of considering individual differences when preparing musical stimuli in memory paradigms.

To avoid the biases that may exist when experimenters select music, previous studies have sometimes required participants to bring in their own music (e.g., Lingham & Theorell, 2009; Salimpoor et al., 2009). Indeed, that approach has been invaluable in ensuring that the extremes of the dimensions of interest are able to be reached. i.e., that when considering music liking effects, for example, every single participant would hear music that really was liked and disliked. Here our compromise of having participants rate a large number of pre-selected musical stimuli in an initial online survey and then carefully selecting stimuli to span the full range of their liking ratings ensured that the effect of liking, which was of particular interest, could be reliably investigated.

Collecting valence and arousal ratings at the same time as liking ratings meant that our study was also able to control for the effect of these affective dimensions when examining the role of aesthetic reward on episodic memory. That listeners can find sad music rewarding (Sachs et al., 2015) and that musical passages identified as rewarding can vary widely in arousal levels (Bannister & Eerola, 2021; Omigie et al., 2021) emphasises the need to acknowledge the complex relationship between emotion and reward. Indeed, our finding that liking ratings influenced intentional episodic memory performance more than how good / bad or calm / excited music made participants feel highlights the importance of distinguishing between aesthetic evaluation and emotion variables in music listening studies.

A useful paradigm for exploring episodic memory

Perhaps one of the most important contributions of the current research is extending the range of paradigms that are currently being used to study the effect of background music on episodic memory encoding. Our experimental paradigm is novel in a number of ways including using a rich visual environment with spatiotemporal complexity to allow tracking of different forms of memory (what, where, when and intentional and non-intentional memory), while employing an engaging narrative that encourages participants to stay motivated through-out the task.

Indeed, our use of an immersive story line, able to draw participants into a kind of virtual reality, is congruent with the field of Psychology's move in this general direction (Bohil et al., 2011). Virtual reality (VR) allows the simulation of naturalistic situations while still providing the experimental control that is necessary for reliable results. VR-related tests have been shown to be superior to traditional measures in assessing cognitive functioning (Davison et al., 2018), and recent experimental research using VR has shown that key psychological processes (such as working memory) likely look very different in the real world compared to in simple lab experimental studies (Draschkow et al., 2021). Here, our study relied mostly on storytelling for promoting immersiveness in the task. However, future paradigms would benefit from allowing participants to become immersed in a 3-dimensional virtual reality while they carry out a wide range of embodied actions.

Future research could also adapt our paradigm to investigate whether liked music has the ability to further improve memory performance when it is also presented in the retrieval phase. Music's ability to trigger memories is seen as one of the most powerful ways in which music influences memory and a common paradigm used in music and memory research involves having participants recall the elements of a story from their past while music is presented (Irish et al., 2011). Indeed, a large body of research has now examined the extent to which the presence of music of different qualities influences the amount and vividness of autobiographical memory retrieval (Belfi et al., 2020; El Haj et al., 2012; Jakubowski et al., 2021). However, since memory responses provided in such paradigms are hard to assess for accuracy (the remembered events in question rarely having been objectively recorded anywhere), the need for lab-based episodic memory paradigms that offer both spatiotemporal richness and the ability to evaluate memory accuracy remains important. An extension of our paradigm to contain music in the retrieval phase promises better understanding of the extent to which liked music may not only influence episodic memory encoding, but also episodic memory retrieval. A few studies have begun to examine the role of the presence of music during retrieval (Panteleeva et al., 2021) but none have examined the influence of liked music in particular.

Limitations and future directions

Whilst it provides insights into how memory is influenced by music, our study has a number of limitations that extensions to this research should seek to address. A first limitation is that participants tended to perform very well on the intentional memory task. While this was most prominent for the memory performance of *what* was moved, this pattern was also seen with regard to memory for *where* and *when* information. With regard to the *when* variable, we required participant to indicate only the first and last objects moved in each scenario since piloting of the task suggested that participants lacked confidence in their ability to retain detailed temporal order information. (Indeed, even with the recency and primacy effects likely obtained by inquiring after the first and last objects, our data still comprised several trials in which participants failed to remember this temporal information). However, as several participants did manage to perform well on the task, future studies using our paradigm would not only benefit from increasing the number of items participants must move around the scenarios, but also from requiring participants to report the order of all objects moved. By so increasing the range and variability of *what*, *where* and *when* scores, future studies would provide invaluable corroboration of the findings reported here. (Indeed, a number of our models had *p* values that were close to the threshold.)

Another limitation of the current study is that we did not evaluate memory for *when* information in the same way as memory for *what* and *where* information due to our decision to only sample the first and last objects. Future versions of the paradigm could require participants not only to endeavour to remember the order of all events but also to present memory of this information in the same way as they provide memory for what and where information, namely through dragging actions in the appropriate order.

It is also worth noting both the short time interval between encoding and recall phases (only a little more than the time taken to fill out the 20-item BMRQ questionnaire) and the failure of our paradigm to examine how long-lasting the impact of liked music is on recall. Patil and colleagues (2016) suggest that reward plays an extended role in the consolidation of memories whereby enhanced memory occurs24 h after the encoding of the material (even if not immediately after). It is possible that increased duration between encoding and recall phases in our task would have allowed more effective examination of the effect of aesthetic appreciation on where and when aspects of memory performance.

With regard to stimuli, while we aimed for music that was high in ecological validity and customised to each individual, it is important to note that the current study does not offer insights into any significant musico-acoustic features of the music that was liked and that was therefore beneficial to listeners' memory encoding. In any case, it is important to note that we did not aim to present participants with music that they would tend to use to aid memory performance but rather music that they liked and disliked and that they were highly likely to hear in everyday life. As such, it was less important how conducive the music really was for memory encoding, and more important that participants indeed had familiarity with the music (this was demonstrated by the high Familiarity levels reported). Last but not least, yet another limitation of the study is the difficulty of controlling the quality of participants' listening experience given the online nature of the task. We suggest that a lab-based version of the current task would therefore be beneficial for corroborating the pattern of results seen here.

With regard to future directions, an interesting question that remains is how participants would perform if they were not asked to actively encode the What, Where and When memories as was the case in our study. Conclusions about the positive influence music can have on episodic memory have tended to be drawn from intentional memory paradigms in which participants are specifically asked to memorise information (e.g., see Ferreri et al., 2015; Ferreri & Rodriguez-Fornells, 2017; Proverbio et al., 2015). Critically, as many memories in everyday life are not intentionally encoded, it will be important for future studies to use more passive versions of the paradigm used here (e.g., see Holland & Smulders, 2011).

Closing remarks

Our results provide evidence that, when controlling for affective dimensions and familiarity, there is a clear influence of liked music on intentional episodic memory. Interestingly, we also observed that high arousal led to poorer incidental memory for details that were not intentionally encoded.

A better understanding of how, and under what conditions, music is able to improve memory could allow for more effective music-based rehabilitation paradigms targeting clinical populations with memory deficits (Ferreri & Verga, 2016). Episodic memory has been argued to be more vulnerable to neuronal deterioration than other memory systems (Tulving, 2002) and episodic memory is usually the first form of memory affected in the early stages of various types of dementia (Irish et al., 2011). However, viral videos of patients displaying enhanced memory and cognitive function when music is heard suggest music may be especially important for supporting episodic forms of memory. Here we show that aspects of episodic memories may be better encoded during liked music than when music that is not liked is present. One important next step may be to consider how such effects can be used to promote memory in a variety of contexts.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, DO, upon reasonable request.

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