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BRIEF REPORT

Episodic-semantic linkage for $1000: New semantic knowledge is more strongly coupled with episodic memory in trivia experts

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Abstract
Some people exhibit impressive memory for a wide array of semantic knowledge. What makes these trivia experts better able to learn and retain novel facts? We hypothesized that new semantic knowledge may be more strongly linked to its episodic context in trivia experts. We designed a novel online task in which 132 participants varying in trivia expertise encoded "exhibits" of naturalistic facts with related photos in one of two "museums." Afterward, participants were tested on cued recall of facts and recognition of the associated photo and museum. Greater trivia expertise predicted higher cued recall for novel facts. Critically, trivia experts but not non-experts showed superior fact recall when they remembered both features (photo and museum) of the encoding context. These findings illustrate enhanced links between episodic memory and new semantic learning in trivia experts, and show the value of studying trivia experts as a special population that can shed light on the mechanisms of memory.

Keywords Episodic memory · Semantic memory · Interaction of semantic and episodic memory · Individual differences in memory capacity

Statement of relevance Many people enjoy trivia, whether in a casual or a competitive setting. Some engage in trivia games just for fun, whereas others win large sums of money for their vast knowledge of obscure facts. What makes some people so much better at trivia than others? In what we believe is the first study to examine the mechanisms of trivia expertise, we hypothesized that trivia experts' superior learning of new facts may be supported by particularly strong links between these facts and the context in which they were encountered. Individuals ranging in trivia expertise completed a museum-themed task in which they encoded facts paired with a unique photo in one of two virtual museums. Trivia experts, but not non-experts, showed superior memory for novel facts when they also remembered multiple details about the museum exhibit. These findings suggest that trivia experts' memory for obscure facts may be associated with memory for how and when they learned them.

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Introduction

"All trivia is autobiography." –Ken Jennings

From pub quiz to primetime television, many people enjoy the pastime of competitive trivia. A striking, and common, experience in trivia competitions is the wide variability across people in the breadth of their memory for general knowledge, even when matched on other factors. For example, a bar trivia team of friends from the same grad school cohort may have a sizeable skill gap between the strongest players and the players who are "there to have fun." What can differences in trivia expertise teach us about underlying memory mechanisms?

The *Jeopardy!* champion and host Ken Jennings observes that, "I noticed on *Jeopardy!* that I could often remember with great specificity when and where I had first learned a fact: in which high school or college class, in what movie scene, in which book or magazine from my elementary school library – even down to what part of the page, or maybe the room where I was reading it" (personal communication, 31 July, 2023). This anecdote is striking because general knowledge learned long ago is typically context-free, devoid of links to the specific way that knowledge was acquired. The anecdotal episodic richness of this semantic

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knowledge in trivia experts raises the possibility that such expertise may be characterized by a particularly strong ability to encode, maintain, and/or retrieve links between general knowledge memories and their encoding context. These links may offer an additional route by which new semantic knowledge can be accessed at a later time. Here, we drew inspiration both from the personal experiences of trivia champions and from the burgeoning literature on episodic-semantic interactions (e.g., De Brigard et al., 2022). Tying together these disparate sources, we sought to study trivia experts to gain insights into how individual differences in general knowledge learning may arise from differences in how such knowledge is linked to episodic memory.

We designed a novel "museum" paradigm to test the hypothesis that trivia experts may be better able to link newly acquired semantic knowledge to episodic memories for the learning context, and that this episodic-semantic linkage may subsequently boost fact recall. This hypothesis is inspired by work showing the interplay between episodic and semantic memory, in terms of both behavior and underlying neural substrates (Renoult et al., 2019). For example, recall of general knowledge is associated with recollection just as often as with "just know" states (Pereverseff & Bodner, 2020), rich episodic detail can scaffold the encoding and retrieval of memory for general knowledge (Herbert & Burt, 2004; Westmacott & Moscovitch, 2003), and pre-existing memory schemas shape episodic memory for new schema-related information (see Gilboa & Marlatte, 2017, for a review). New general knowledge in particular is initially encoded episodically and becomes schematized to varying degrees over time (e.g., Coane et al., 2022; Conway et al., 1997; Herbert & Burt, 2004), as tested by the transition from "remembering" to "knowing" (Tulving, 1985). Thus, while general knowledge is semantic in nature, some general knowledge memories may be acquired and retrieved episodically, and then in the future might be stored and accessed as a semanticized, context-independent memory trace.

Although many studies find that semantic retrieval is associated with some episodic memory for the learning event, at least initially (Conway et al., 1997; Dewhurst et al., 2009; Herbert & Burt, 2004; also see Pereverseff & Bodner, 2020), we set out to test whether this semantic-episodic binding differs across trivia experts and the "normative" populations studied in typical psychology experiments. In particular, we hypothesized that trivia experts might show superior acquisition of semantic knowledge compared to non-expert populations, thanks to increased episodic scaffolding of new semantic learning. This increased episodic richness of semantic learning may in turn help trivia experts access obscure facts more easily than non-experts.

To test this hypothesis, we recruited individuals ranging in trivia expertise to encode novel general knowledge facts in detail-rich virtual "museum exhibits," allowing us to equate encoding context, recency, and study frequency across facts and individuals. We then assessed memory for facts as a function of memory for associated encoding details (encoding museum and paired photo), participants' trivia expertise, and the interactions between them. We expected that recall of novel facts would be more strongly associated with memory for episodic details in trivia experts versus non-experts, and that this effect would not be explained by individual differences in curiosity about the museum facts or pre-existing knowledge of them. Together, this approach allows us to illuminate interactions between semantic and episodic memory systems, and determine how those interactions differ across diverse memory phenotypes in the population.

Methods

Participants

One hundred and thirty-two participants (85 men, 43 women, two genderqueer, two not reported) were recruited online from LearnedLeague, a trivia community website where players compete daily to answer the most questions correctly (Integrity, 2023). Membership is open to people of all levels of trivia expertise, and players compete in one of five divisions sorted by performance. Many competitive trivia players and quiz show contestants participate in the higher divisions (Brooke, 2021), making the website an ideal location from which to recruit participants ranging in trivia expertise but matched in motivation levels. All participants were healthy adults aged 18 years and up (M = 39.6 years, SD = 11.2 years). Given the novelty of our paradigm, we had no a priori benchmarks for effect size and power, so we recruited as many participants as feasible, given time available for data collection. To achieve a wide range of expected trivia expertise in our sample, we stratified recruitment across the five LearnedLeague divisions to target a median in-study expertise score of 35/50, believed to be the minimum online test score to be called back as a potential contestant for the quiz show *Jeopardy!* (Nguyen, 2013; see *Task design* below). Based on an expected study duration of 2 h, participants received a $30 gift card for the retailer of their choice upon study completion.

All participants provided informed consent, and all procedures were approved by the Columbia University Institutional Review Board.

Stimuli and apparatus

Expertise assessment

For trivia expertise assessment, we curated 50 cued-recall questions from archived *Jeopardy!* audition exams

(Saunders, 2018), selected to span a range of topics. We altered the phrasing of some clues where necessary to form them as questions with sensible syntax.

Main task

"Museum exhibits" were constructed by collecting facts and photos from reference books, encyclopedias, and informational websites (see *Open practices statement* for link to list). Facts were drawn from six categories divided into two groups: (Set A) historical arms and armor, gemstone geology, and musical instrument history; and (Set B) dinosaurs and other ancient fauna, automobile components, and food and cooking techniques. Categories were chosen from topics typically not queried by general knowledge games, and chosen to maximize the semantic distance between representative Wikipedia pages about category sets A and B. We constructed 40 exhibits for each category.

For each exhibit, a two- to three-sentence "placard" was written, describing information as it might be presented in a museum. Placards were written with multiple related facts per card, and phrased so as not to clearly cue which sub-fact in the placard might be the target of later recall questions. Placards were written to take between 20 and 30 s to read out loud. Narration for each placard was recorded by one man and one woman narrator, chosen for their clear voices and distinctness from each other. Each exhibit was also presented with a relevant photograph depicting an item described in the placard. We collected two images per exhibit, with one shown at encoding and the other used as a similar lure for the retrieval test. Exhibit content was displayed over a free Unity three-dimensional (3D)-rendered background image of one of two gallery halls, named the Amber Archives and Cobalt Collections (see *Task design: Encoding*). Background images were not trial-unique, but museum exhibit trials cycled through three possible background images for each gallery hall to foster a subjective sense of motion through the museum.

The entire task was built and deployed online through Gorilla (Anwyl-Irvine et al., 2020; Gorilla Experiment Builder, 2021). All components of the main "museum task" (Fig. 1) were completed in one online session that lasted approximately 90 min.

Task design

Expertise assessment

Participants first completed a 50-question cued recall test of general knowledge (Fig. 2A). On each trial, participants had up to 15 s to type and submit an answer to a question (see *Stimuli: Expertise assessment*). After submitting their response, participants rated their confidence in their answer on a 100-point slider from "not at all" to "extremely" confident. Answers were scored as correct or incorrect by author MT. Misspelled answers were accepted when judged to be unambiguously equivalent to the correct answer. Last names were accepted for people, and titles were accepted if the answer contained all major words (e.g., "Fairy Queen" was accepted for "The Faerie Queene"). After the cued recall test, participants rated their metamemory for the general knowledge they had just been tested on (e.g., Pereverseff & Bodner, 2020; see Online Supplemental Material (OSM) for details). Metamemory ratings were not used further in the current study. Finally, participants completed the museum task (described below) within 3 weeks of the expertise assessment. The museum task and expertise assessment questions were non-overlapping. Participants' scores out of 50 questions in the expertise assessment were used as a continuous measure of trivia expertise in subsequent analyses.

Category selection pre-test

After the expertise assessment phase, we administered a museum pre-test to identify which of our encoding fact categories (see *Stimuli: Main task*) were least familiar for each participant. This was done to maximize participants' naivety to our encoding stimuli, allowing us to test memory for new general knowledge relatively uncontaminated by prior expertise (Fig. 2B). Before entering the virtual museum, participants completed a brief object name-matching task to estimate their prior knowledge of potential museum exhibit categories. On each trial of six blocks (one for each category that might appear in the museums), participants saw five object images. One at a time, the name of one of the objects appeared on-screen, and participants clicked the object matching that name. Trials within a category were blocked and randomized within-block, and category block order was randomized between participants.

Accuracy was scored from 0 to 5 for the number of correct name matches for each category. Participants were then assigned their lowest-scoring category from Set A and lowest-scoring category from Set B to be shown in the museum exhibits. Although there were some differences in how frequently a given category was assigned and fact recall accuracy across categories (see OSM, Fig. 3 and Tables 4 and 5), these differences did not vary as a function of trivia expertise and are thus not considered further.

Encoding

Participants then entered the encoding "museums." Encoding consisted of 80 "exhibit" trials, with 40 trials from each of the participant's two assigned categories shown in alternating category order. On each trial (Fig. 2C), participants saw a short paragraph "placard" describing a general

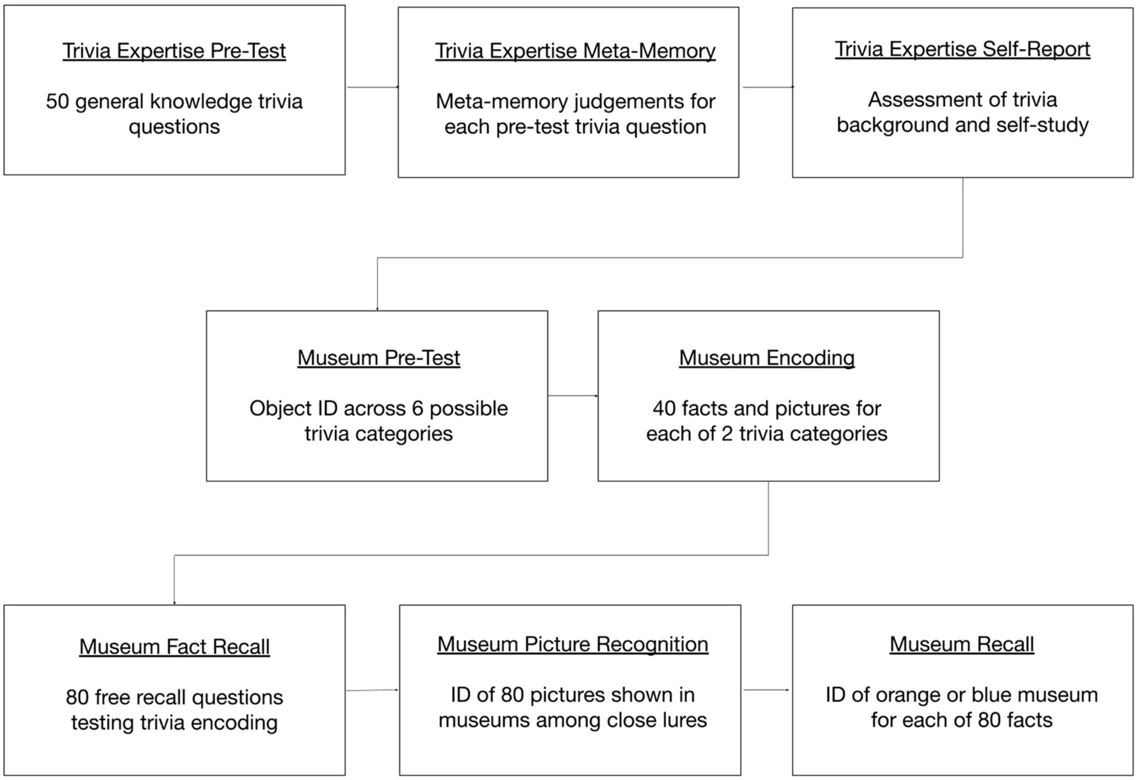


Fig. 1 Study procedure. The study consisted of three main parts aimed at assessing trivia expertise and fact encoding. All three phases were completed online. The first phase of the study (trivia expertise pre-testing, top row) was completed in one 30-min session, and the main museum task (middle and bottom rows) was completed in one 90-min session. The first phase of the study (top row) tested trivia expertise through a series of general knowledge questions and self-report measures of experience with trivia. This phase allowed us to quantify the trivia expertise of each participant. The second component of the study (middle row) consisted of a pre-test and then the main encoding task. In the pre-test, we assessed knowledge of six potential trivia categories through participants' ability to identify pictures from those categories. The two categories that a given participant performed worst on were selected for their main encoding task. In the encoding task, participants "entered" a virtual museum and engaged with (i.e., read and listened to) trivia facts from those two categories. Both categories were presented in two different "museums" and each trivia fact was accompanied by a picture. The final study phase (bottom row) was the retrieval portion, which assessed participants' memory for the museum-encoding phase: recall of trivia facts, picture recognition memory, and memory of the encoding context

knowledge fact and a photo of the item or concept discussed in the fact, atop a 3D-rendered background image of a gallery hall. They also heard a narrator reading the text of the placard. During exhibit presentation, participants judged how interesting they found each fact by clicking on a 100-point visual analog slider anchored from "not at all interesting" to "extremely interesting." A button appeared to submit the interest rating and advance the trial once the narration had finished, or once 25 s had elapsed in the trial, whichever was shorter. Each exhibit trial thus remained on-screen between about 20 and 35 s (mean trial duration = 22.5 s, SD = 7.18 s). After each exhibit trial, participants rated their pre-study prior knowledge of the fact using the forced-choice options "none," "some," or "all."

The 80 trials were presented in a fixed order across participants who received the same exhibit categories. This was done to preserve serial dependencies in semantic information among the facts for each category. Trials were presented in two "museum" encoding blocks, with a 5-min break between blocks. To make the museum contexts as distinct as possible from one another, we varied a number of perceptual features between museums. First, we varied the color scheme of the gallery hall backgrounds and placards. One museum was called the "Amber Archives" in task instructions and was orange-themed; the other museum was called the "Cobalt Collections" and was blue-themed. Color theme order was counterbalanced across participants. Second, we varied narrator identity between museums, and counterbalanced it across participants independently of color theme. Thus, the color-narrator pairing and order varied between participants, while allowing a given participant to have a stable experience of each "museum," defined by its color theme and narrator.

Fact recall

After completing the second encoding block, there was an enforced 5-min break followed by approximately 2 min of instructions for the cued recall task. Participants then completed 80 cued recall trials, one for each placard they had just encountered (Fig. 2D). On each recall trial, participants were presented with a closed-ended recall question about the information on a given placard. Trials were partially self-paced; participants had up to 15 s to type and submit their answer. Each question was designed to cue a specific one- to two-word answer from the original encoding fact, in a way that would minimize the possibility of using a process of elimination, pre-study prior knowledge, or other guessing strategies to arrive at the answer. Trials were presented in a pseudo-random order, which was itself randomized across participants. On average, the recall trial for a given fact occurred 25–30 min after it was first presented at encoding.

Answers were scored as correct or incorrect by author MT. Misspelled answers were accepted with liberal differences in pronunciation (e.g., added or deleted syllables) when still judged to be unambiguously equivalent to the minimal correct answer. Last names were accepted for people.

Photo recognition

After completing the fact-recall task, participants completed 80 forced-choice photo recognition trials, one for each museum photo they had encountered at encoding (Fig. 2D). On each recognition trial, participants saw two probe images: one previously encountered photo and one similar lure photo depicting the same item. Participants used a 100-point visual analog slider anchored by the two probe images on either end to indicate their confidence in which photo they had seen before. The midpoint was not labeled, and the slider handle did not appear until participants clicked on the slider. Trials were partially self-paced; participants had up to 15 s to click on the slider and submit their answer. Trial order was randomized, and target-lure ordering on-screen was pseudo-randomized across trials for each participant.

Each encoding exhibit trial had two possible photos associated with it. Each participant saw one as the target photo during encoding and the other as the lure at retrieval. Target-lure assignment for each pair of photos was counterbalanced across participants.

Museum recognition

Finally, after completing the photo recognition task, participants completed 80 forced-choice museum recognition trials, one for each placard encountered at encoding (Fig. 2D). On each recognition trial, participants saw the text of a placard, and used a 100-point visual analog slider anchored by the labels "Amber Archives" and "Cobalt Collections" to indicate their confidence in which museum they had first encountered that placard in. The midpoint was not labeled, and the slider handle did not appear until participants clicked on the slider. Trials were partially self-paced; participants had up to 15 s to click on the slider and submit their answer. Trial order was randomized, and slider anchors were ordered on-screen such that the anchor for the earlier museum was always on the left.

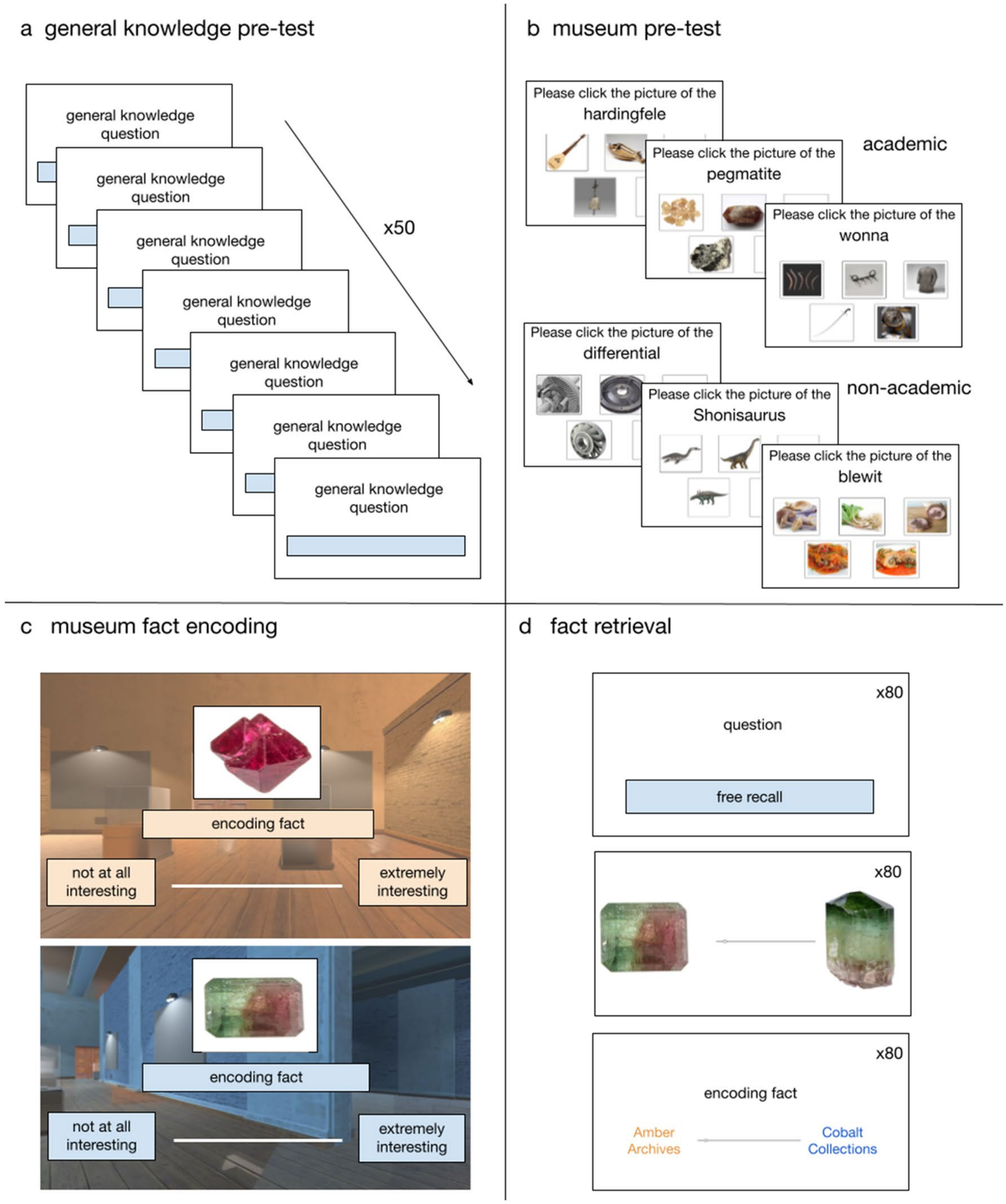
Statistical analysis

We used a Bayesian multilevel logistic regression to determine how trivia expertise and episodic memory for associated features affected trial-wise fact recall. The model was implemented via MCMC sampling in the Stan language using the tidymodels and rstanarm packages in R (Goodrich et al., 2023; Kuhn & Wickham, 2020; R Core Team, 2023; Stan Development Team, 2023). We report medians and 95% credible intervals (CIs) for all main and interaction effects on fact recall, which can be interpreted similarly to p-values; 95% CIs that do not include 0 reflect differences between conditions that are statistically significant at $p < .05$.

The model was run with four sampling chains. Each chain ran for 2,000 total iterations, with the first 1,000 iterations designated for warm-up and the second 1,000 iterations for sampling. We report point estimates for each coefficient at the median value of the posterior distribution across all sampling iterations and chains, and two-tailed 95% CIs of the same posterior distribution. All models demonstrated sufficient mixing of chains, fewer than ten post-warmup divergent transitions for any single parameter, and an effective N of at least 10% of the sampling iterations for every parameter, diagnosed visually using the shinystan package (Gabry & Veen, 2022).

Outcome variable We modeled binary fact recall, coded as 0 for incorrect and 1 for correct for each trial. We only analyzed fact recall for trials in which the participant indicated that they knew none of the encoded information prior to the study.

Predictor variables of interest We predicted trial-level fact recall using three main fixed effect variables: trial-level recognition for the associated photo, trial-level recognition for the associated encoding museum, and participant-level trivia expertise. Both trial-level recognition variables were binarized at the middle of the slider and effect-coded, with correct-side slider responses coded as +0.5 and incorrect-side slider responses coded as -0.5. Effect-coding allows for ANOVA-like interpretation of model parameters, such that the intercept can be interpreted as a grand mean and the main effects are estimated at the mean of each of the other predictors. Participant-level trivia expertise was centered at 0.7, the target median expertise level at recruitment, and



then multiplied by ten so that a unit change in the expertise variable corresponded to an expertise score increase of 0.1. We included all possible two-way interaction terms, as well as the three-way interaction term.

Covariate predictor variables We included two trial-level fixed effect covariates: trial-level interest in the fact, and a trial-level indicator for whether the fact was encountered in the first or second museum (to control for primacy or recency effects). Interest was centered at the middle of the slider and ranged from -0.5 to +0.5, and encoding museum order was effect-coded with the first museum coded as -0.5 and the second museum coded as +0.5. This allowed our primary effects to be estimated for facts of middling interest, encountered in the middle of the task.

Random effects We included a random intercept for each participant, allowing each participant's overall fact recall performance to be estimated from a normal distribution across participants.

◂**Fig. 2** Museum memory task. **A** *Pre-testing for trivia expertise.* Participants completed a general knowledge test. Questions spanned a range of categories, and did not overlap with any information presented later in the study. Participants had up to 15 s to type in each answer. **B** *Pre-testing for unfamiliar trivia categories.* We selected six possible fact categories, three of which were "academic" (i.e., relatively obscure and/or historical categories like arms and armor of the world) and three of which were "non-academic," i.e., popular categories like food and cooking techniques). Categories were divided into sets so as to maximize the semantic distance between any topic in Set A and any topic in Set B, using a combination of Wikipedia-estimated text embedding distance and experimenter discretion. Participants were pre-tested on their ability to name distinctive, uncommon objects from each of these six possible categories. For each category, participants attempted to match five object names to their images. Each participant was then assigned the two categories for which they performed the worst, one from the "academic" category and one from the "non-academic" category. **C** *Encoding.* Participants encountered facts from their two assigned categories in two "museums." On each trial, participants saw a short "placard" of information and an image of the item described in the placard. Participants also heard a narrator reading the placard out loud. Participants judged their interest on each trial from "not at all interesting" to "extremely interesting" on a 100-point visual analog scale, and then rated their prior knowledge of the information on the placard, from "none" to "some" to "all." Participants completed two encoding "museum" blocks, distinguished by different colors, font styles, and narrators. Museums were blocked (museum order counterbalanced across participants) but both fact categories were presented in each museum in alternating trials. **D** *Retrieval.* First, participants completed a cued recall test, with one question for each encoding trial placard. Participants had up to 15 s to type in their answer. Next, participants completed a forced-choice recognition memory test for the associated images. Participants placed a 100-point visual analog scale marker to indicate their confidence in which of two similar photos was the photo they actually saw during encoding. Finally, participants completed a forced-choice recognition memory test for "museum" source memory. Participants placed a 100-point visual analog scale marker to indicate their confidence in which "museum" (i.e., encoding block) they encountered a given fact

Priors We set weakly informative Cauchy priors with mean = 0 and scale = 2.5 for all terms. Cauchy priors are well suited for the coefficients of Bayesian logistic regressions, as they provide the regularizing benefits of a bell-shaped prior while allowing large values of coefficients to be estimated when appropriate, for example, when responses are separated (Gelman et al., 2008).

Data inclusion We included data from every participant who completed the study. However, as noted above, we only included data from exhibit trials in which participants endorsed knowing "none" of the fact prior to the study.

To generate more directly interpretable test statistics from our model, i.e. in units of percent accuracy as opposed to inverse logit units, we used rstanarm's posterior_linpred() function to extract inverse-logit-transformed posterior estimates of P(correct fact recall) at every level of every predictor from each iteration of the posterior distribution. We then used these fixed-effect accuracies to calculate posterior estimates of accuracy differences between various conditions of interest. We calculated test statistics reported for "experts" and "non-experts" at the 25th and 75th percentiles of trivia expertise respectively.

Results

Validity checks

Trivia expertise in our sample (see OSM, Figs. 1 and 2 and Table 1, for breakdown of trivia expertise by demographic characteristics) ranged from scores of 13 to 50/50, with a sample median of 36/50. This was near our target median of 35/50 at recruitment. We conducted two validity checks to ensure that we adequately quantified trivia expertise in our sample.

First, although we selected trivia categories to be relatively unfamiliar for each participant, one may expect that trivia expertise would be associated with more pre-existing knowledge of facts in the museum exhibits. We indeed found that individuals with more trivia expertise were more familiar with the facts in the museum exhibits (beta = .154, 95% CI = [.083, .227], see OSM, Table 2, for details). A 5-point difference in expertise score (out of 50, see *Methods: Expertise assessment*) was associated with two additional facts being rated as familiar to the participant. This suggests that our trivia expertise measure successfully captured differences in overall semantic knowledge. Importantly, however, participants generally reported that most facts were unfamiliar (mean = 57 facts, SD = 11 facts), ensuring sufficient trial counts for subsequent analyses.

As a second validity check, we asked whether higher trivia expertise is related to greater interest in the museum exhibits, as might be expected if trivia expertise partly arises from intrinsic curiosity about new information. Trivia expertise was positively associated with interest at encoding (beta = 1.67, 95% CI = [.059, 3.22]; see OSM, Table 3, for details). However, this effect was quite small, with a 5/50 expertise difference predicting a 1–2 unit difference (on a 100-point scale) in encoding interest. Thus, although this finding suggests our trivia expertise measure captured inter-individual differences in interest, it is unlikely for differences in interest to meaningfully drive expertise-related differences in memory performance. We nevertheless included interest ratings in our primary models to ensure that this did not drive our effects of interest.

Trivia expertise predicts novel fact recall, but not generally superior episodic memory

Trivia expertise was positively associated with cued recall of novel facts (beta = .083, 95% CI = [.011, .156]; Fig. 3), with a 5/50 expertise difference predicting a .08 difference in recall accuracy. Trivia expertise was also positively associated with museum recognition (beta = .061, 95% CI = [.004, .118], see OSM for details), although the effect was much smaller, with a 5/50 expertise difference predicting a .02 difference in museum recognition accuracy. Finally, trivia expertise was not associated with photo recognition (beta = -.015, 95% CI = [-.093, .062], see OSM for details). Together, this shows that trivia expertise is associated with greater memory for new semantic knowledge, but trivia experts do not show greater episodic memory across the board than non-experts. These results suggest that generally stronger episodic memory does not differentiate trivia experts from non-experts in our study; instead, trivia experts may be disproportionately better at learning new semantic knowledge. To better understand how this difference between experts and non-experts arises, we explored relationships between fact recall and memory for museum context, below.

Multi-featured episodic memory predicts fact recall in trivia experts

Across participants, trial-wise museum memory was positively associated with fact recall (beta = .231, 95% CI = [.080, .394]; Fig. 4A), with successful museum memory predicting .06 greater fact recall accuracy (Fig. 4B). This effect shows that source memory generally benefited fact recall, although our museum memory measure may index a general sense of recency in addition to/instead of recollection of encoding context. Critically, museum memory *interacted* with trial-wise photo memory to predict greater fact recall selectively for trivia experts (museum x photo memory simple effect for experts = .544, 95% CI = [.147, .948]; three-way interaction beta = .179, 95% CI = [.001, .365]; Fig. 4A) and not for non-experts (museum x photo memory simple effect for non-experts = .003, 95% CI = [-.424, .431]). For participants in the upper half of trivia expertise, remembering the photo *and* the museum predicted .08 greater accuracy than remembering either one alone or neither (Fig. 4B). However, participants in the lower half of trivia expertise showed no such superadditive benefit. These results suggest that for trivia experts, multi-featured memory for episodic details is linked to learning of associated semantic knowledge.

We speculate that trivia experts may be particularly good at recalling new semantic facts because they are better able to use episodic memory as a vehicle – i.e., they may use episodic memory to bolster access to semantic information. However, it is possible that the causal direction goes the other way: rather than episodic memory boosting access to semantic facts, it may be that strongly encoded semantic facts enhance access to episodic features from encoding. To test the latter possibility, we conducted two exploratory analyses to determine if encoding of contextual features (photo and museum) could be accounted for in terms of the strength of new fact learning. Under this scenario, facts that are particularly strongly encoded may bring with them the associated episodic context "for free." If trivia experts are

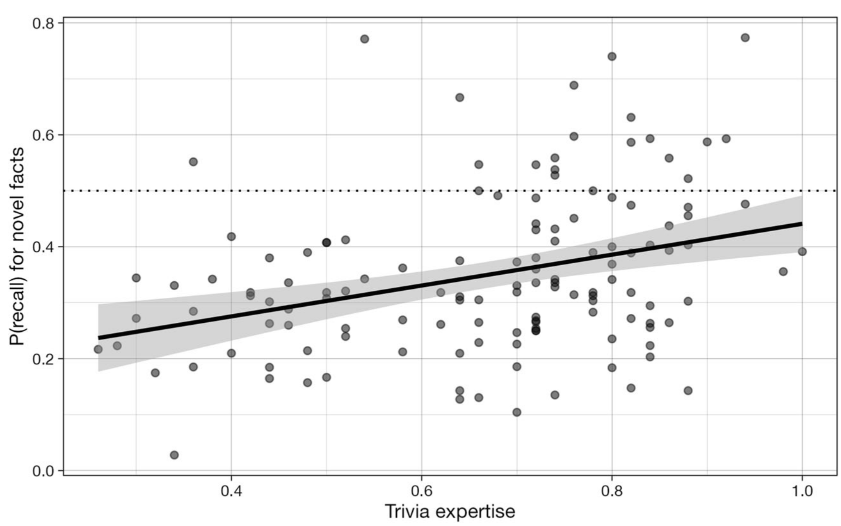


Fig. 3 Memory for new facts as a function of trivia expertise. Each point represents one participant's proportion correct fact recall. Participants with higher trivia expertise showed greater recall accuracy for novel facts encoded during the museum-encoding phase. Participants with higher trivia expertise were more likely to report already knowing "some" or "all" of the presented facts at encoding, so this figure shows recall only for facts that were judged to be novel. All main analyses were also restricted to trials reported as novel at encoding. A linear regression line with 95% CI is plotted with ggplot2's geom_smooth() to illustrate qualitatively that participants with greater expertise tended to show better fact memory

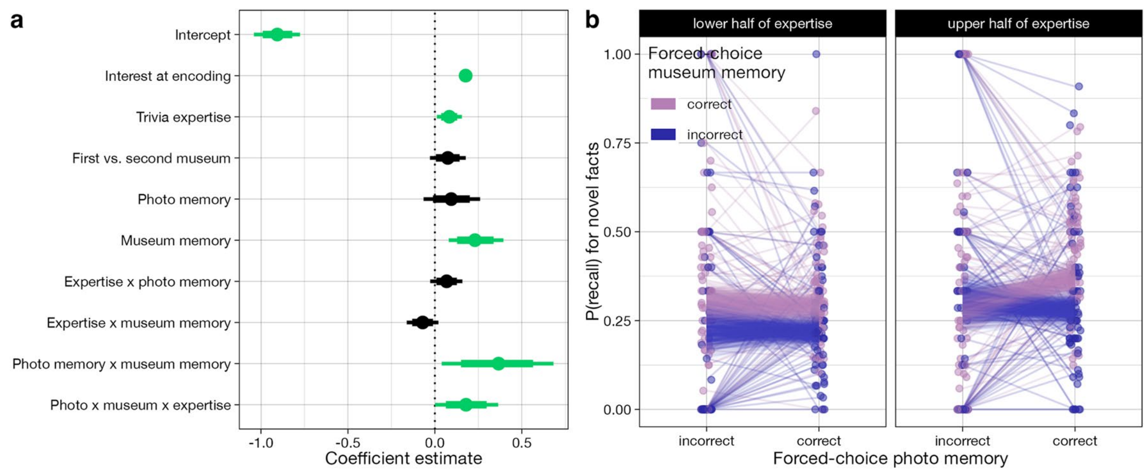


Fig. 4 Trivia experts, but not non-experts, show improved recall for new facts when multiple features of the encoding context are remembered. **A** Coefficient estimates for a Bayesian logistic regression predicting fact recall. Values are shown for the median coefficient estimate along with the 80% (thick line) and 95% (thin line) posterior intervals. Green indicates coefficient estimates with 95% posterior intervals that exclude 0. **B** Predicted across-participant fixed effects from the model. Each line represents the simple effect of photo memory on fact recall for participants in the upper or lower half of trivia expertise estimated on a particular iteration of the Bayesian regression (two lines per iteration, one for each color/museum memory level), separately for participants with lower (left) vs. higher (right) trivia expertise. The spread and overlap of the color ribbons can thus be taken as a holistic representation of effect size of any differences in predicted fact recall. Raw data for individual participants are shown behind the fixed effects, with two pairs of points and two connecting lines for each participant, reflecting their raw recall accuracy for facts presented with photos that were subsequently incorrectly vs. correctly identified, separately for trials with museum source memory incorrect vs. correct. Two main effects are visible in the coefficients (**A**) and predicted simple effects (**B**), such that trial-wise museum memory predicts fact recall for participants irrespective of trivia expertise, and participants in the upper half of trivia expertise have greater fact recall overall. A three-way interaction is also visible, such that trivia experts' fact recall is higher when they correctly recognized *both* the associated photo and encoding museum, but participants lower in trivia expertise did not show such an effect

in turn more likely to encode new semantic facts strongly, that could give rise to an enhancement in episodic memory for the facts' encoding context – but this effect would be a mere byproduct of superior fact learning.

To examine this possibility, we first analyzed only those trials associated with correct fact recall, and tested whether fact recall response times (RTs) predicted episodic memory for the associated museum and photo. If memory for episodic features is a byproduct of more strongly encoded facts, then museum and photo memory should be superior for those facts that are recalled more quickly versus those that are recalled more slowly. We did not, however, observe any meaningful difference in episodic detail memory as a function of fact recall RT (museum memory: beta = -.049, 95% CI = [-.152, .058]; photo memory: beta = .109, 95% CI = [-.013, .229]). These effects were also not different between trivia experts and non-experts (expertise by fact recall RT interaction for museum memory: beta = -.003, 95% CI = [-.060, .054]; expertise by fact recall RT interaction for photo memory: beta = -.054, 95% CI = [-.124, .016]). These results are inconsistent with episodic memory for the photo and museum being a consequence of strong fact memory, and are unlikely to account for our main finding of enhanced episodic-semantic binding in trivia experts.

Second, we analyzed only those facts that participants rated as already known before the experiment (i.e., they selected the options "some" or "all" when asked how much of the fact they already knew, see *Methods: Task design: Encoding*; note that our main analysis only included facts for which participants indicated they knew "none" of the fact prior to the experiment). If encoding of the episodic context is particularly likely when individuals (especially trivia experts) can efficiently learn the new facts, and thus have additional resources left over to devote to the episodic context, we should observe a three-way interaction between photo memory, museum memory, and trivia expertise for recall of the facts that were rated as already known; and this interaction should be even stronger than the one we observed for novel facts (reported in Fig. 4). Instead, we did not find evidence for such an analogous three-way interaction effect (beta = -.238, 95% CI = [-.546, .064]; see Table 8 in OSM).

Together, these two analyses are inconsistent with participants, and trivia experts in particular, encoding the episodic context primarily when the semantic fact is especially easy to learn or strongly encoded. Nevertheless, we cannot definitively rule out that efficient learning of new facts may have contributed to episodic encoding of the photo and museum in a way not detected by these analyses; we return to this issue in the *Discussion*.

Discussion

In trivia experts, the quest for knowledge is no *trivial* pursuit. Using a novel "museum" task, we found that trivia experts, compared to non-experts, exhibited greater memory for new semantic knowledge. Trivia experts, however, did not show generally better episodic memory than non-experts. Notably, trivia experts showed enhanced binding of episodic and semantic information. For trivia experts, but not non-experts, memory for contextual details at encoding (museum identity and associated exhibit photos) interacted to predict greater fact recall. To our knowledge, our study is the first to shed light on the mechanisms by which trivia experts may show enhanced memory for facts despite not showing generally superior memory abilities in our study.

Trivia experts' increased ability to link multi-featured memory for episodic details with novel semantic facts may bolster their ability to acquire or retain a vast amount of trivia knowledge. In other words, trivia experts may be particularly effective in using episodic memory as a route to learn or access new semantic facts. Alternatively, the causal direction may go the other way, with semantic learning boosting episodic memory. Specifically, trivia experts' ability to learn some new semantic information more efficiently or strongly – for example, due to ease of finding links between that information and knowledge they already have – may, as a consequence, lead to superior encoding of the episodic context. This may occur because encoding of the entire learning experience overall is particularly strong, bringing along the episodic details "for free," or because more cognitive resources are available to encode the context when the to-be-learned fact is absorbed more easily. We did not find evidence for these hypotheses in exploratory analyses (see *Results*), suggesting that episodic memory for the learning event may not simply be a byproduct of strong fact encoding in trivia experts. Instead, we speculate that trivia experts, compared to non-experts, may be better able to use episodic memory as a route to access semantic facts. We consider ways to adjudicate between these possibilities further below.

Our results highlight the value of studying memory in trivia experts, a population that can yield unique insights into semantic-episodic memory interactions, separately from and in conjunction with other special mnemonic populations. Research in special populations has already taught us that hippocampal amnesia is not a selective deficit of episodic memory, as initially thought, but occurs alongside deficits in semantic memory (see Duff et al., 2020, for a review). On the other hand, markedly enhanced autobiographical memory (LePort et al., 2016) does not seem to be accompanied by comparable enhancements in semantic memory. These populations have shed light on both the links and the separation between semantic and episodic memory (Tulving, 1972). Here, we found that trivia experts show superior semantic learning in the face of apparently typical episodic memory in our task, exhibiting a different pattern of semantic-episodic interactions than both amnesic patients and people with highly superior autobiographical memory. At the same time, trivia experts' memory patterns are curious when juxtaposed with those of memory champions, distinguished for their selectively strong ability to retrieve long lists of arbitrary information from episodic memory. Indeed, memory champions and trivia experts highlight the interactive nature of episodic and semantic memory from complementary angles. Memory champions use semantic memory to enhance episodic encoding: they boost episodic memorization using strategies like the method of loci, which relies on a robust spatial schema in which to anchor episodic encoding targets (Dresler et al., 2017; Wilding & Valentine, 1994). Our results suggest that trivia experts also benefit from strong coupling between their semantic and episodic memory systems, but the direction of this effect is unclear. We speculate that they may use episodic memory to enhance the acquisition of new semantic knowledge, and thus exhibit the converse pattern of episodic-semantic interactions when compared to memory champions. Additional studies, however, will be needed to rule out the alternative hypothesis that efficient semantic learning in trivia experts bolsters memory for associated episodic details (see *Results* for exploratory analyses that argue against this alternative hypothesis). Future work can also systematically compare and contrast the performance of trivia experts, memory champions, and other special memory populations to flesh out both directions of semantic-episodic memory interactions.

Our results build on prior studies of college students, which showed that episodic memory may support semantic acquisition or retrieval, at least early on in the semantic learning process. For example, episodic memory for the location of a word at encoding can support retrieval of its meaning (Davis et al., 2022). Furthermore, memory for news events and trivia is often accompanied by episodic recollection of the learning context (Coane et al., 2022; Pereverseff & Bodner, 2020). Retrieval of such episodically scaffolded semantic memories engages episodic memory processes (Renoult et al., 2014) in a manner distinct from retrieval of either decontextualized semantic information or unique episodic information (Renoult et al., 2016). The episodic richness of such semantic knowledge can fade over time even as familiarity and "just-know" memory for those news events remain stable (Petrican et al., 2010).

Together, this prior literature indicates that immediate tests of semantic learning rely at least in part on episodic memory, but that episodic memory becomes less important over time in supporting semantic knowledge (Conway et al., 1997; Dewhurst et al., 2009; Herbert & Burt, 2004). Our results support the conclusion that episodic memory may be bound to semantic knowledge on an immediate test, but go beyond these prior studies to suggest that this episodic-semantic coupling is stronger in trivia experts versus non-experts. We speculate that this episodic richness of semantic learning in trivia experts may contribute to their ability to acquire, and potentially their ability to maintain and retrieve over the long term, a large corpus of semantic knowledge. Nevertheless, it will be important for future studies to test whether the episodic richness of new semantic knowledge in trivia experts persists over long delays in a way that significantly differs from non-experts. Further below, we consider the underlying mechanisms of our findings and the importance of future work that tests episodic-semantic binding in trivia experts over longer delays than that used in the current study.

Our task also showcases the utility of the "museum" for studying memory in the lab. Although psychologists have increasingly used naturalistic paradigms for studying and measuring episodic memory (e.g., Chow & Rissman, 2017; Martin et al., 2022; Nielson et al., 2015), they have tended to study semantic memory via relatively more impoverished paradigms like object-name associations or contextless general knowledge questions, perhaps in part because of a historical push to dissociate episodic and semantic memory (Duff et al., 2020). Such experimental control may come at the cost of capturing how episodic and semantic memory interact in the real world. When we encounter new facts, we do so in a rich ecosystem of perceptual details and semantic associations. Indeed, people visit museums for the express purpose of recreational semantic learning about distinctive stimuli in attractive environments curated to optimize learning (Bitgood & Shettel, 1996). Psychologists have already leveraged the "museum" schema to study attention to, and episodic memory for, the stimuli encountered in museums (Aly & Turk-Browne, 2016; Günseli & Aly, 2020; Pathman et al., 2011; Ruiz et al., 2020, 2021; van Helvoort et al., 2020). We propose that using tasks like our "museum" encoding paradigm will allow future insights into how episodic and semantic memory interact. Such a paradigm is rich in episodic *and* semantic details, and the memory tests are designed to assess episodic *and* semantic learning at comparable levels of specificity. Future researchers can adopt and extend our task design to study episodic-semantic interactions in typical participants or in other special populations.

While our study shows a clear coupling between trivia experts' semantic and episodic learning, we cannot definitively identify the cause of trivia experts' superior fact recall. Of note, we ruled out that interest at encoding or pre-existing knowledge of the facts accounts for differences in fact recall as a function of trivia expertise. Furthermore, our results are inconsistent with trivia experts showing better memory across the board, perhaps due to more attentional resources or greater ability to encode information more efficiently. Such a general attentional or encoding benefit for trivia experts should lead to superior semantic learning *and* episodic memory in our task, but we observed larger benefits for fact recall than for episodic (photo or museum) recognition memory. Further, we observed a critical three-way interaction between photo memory, museum memory, and trivia expertise on fact recall, wherein trivia experts' fact recall was even higher when they correctly remembered context details, over and above the effect of their expertise alone. Together, these results are inconsistent with a general effect of trivia expertise on all aspects of memory, as would be predicted based on superior attention or encoding abilities. Instead, they suggest that episodic-semantic binding in particular is enhanced in trivia experts, leaving open the question of whether episodic memory boosts access to semantic memory or vice versa. We speculate that trivia experts use episodic memory as a route to semantic facts, particularly given exploratory analyses (see *Results*) that were inconsistent with the opposite direction of influence.

An open question for future research is the nature of the memory trace that trivia experts use when they recall novel facts. World knowledge is often classified as semantic memory no matter how it was learned, but it is common for individuals to learn new semantic knowledge with an initially episodic trace (Conway et al., 1997; Herbert & Burt, 2004). In our task, this may manifest as individuals answering fact recall questions by tapping *episodic memory for semantic information*. We argue, however, that such a strategy may support fact recall in both trivia experts (as noted by Ken Jennings in our *Introduction*) and non-experts (Pereverseff & Bodner, 2020) in the real world. Indeed, the field has long recognized that it is challenging to disentangle whether a given memory is episodic or semantic (e.g., Strikwerda-Brown et al., 2019). Individuals can use episodic memories to support performance on "semantic" tasks (Greenberg et al., 2009) and semanticized memories can appear episodic in content (Renoult et al., 2012). Our task allows a novel avenue for studying such episodic-semantic interactions and, combined with other approaches (like the Remember/Know task; see Coane et al., 2022; Pereverseff & Bodner, 2020) can determine when individuals are likely using semantic versus episodic traces to support fact recall. Such studies can provide further tests of our proposal that trivia experts recall rarely encountered facts by using episodic memory as a vehicle – i.e., by using episodic memory to bolster access to semantic memory. Despite the possibility that individuals can answer semantic knowledge questions purely with episodic memory, our interpretation is supported by our finding that trivia experts did not have generally superior episodic memory in our study; this argues against their trivia expertise simply being a result of exceptional episodic encoding and retrieval. Nevertheless, future studies with more extensive testing of trivia experts' episodic memory abilities will be important.

Future work can extend our findings over longer timescales. Because our museum task took part over one session, we were unable to explore how trivia experts might semanticize fact memories over time, or whether they store and retrieve fact memories episodically even over long timescales. We consider it intriguing that, even with our immediate recall test, our results align with anecdotal reports by trivia experts (see *Introduction*) of episodically rich retrieval of remote semantic knowledge. Furthermore, by having an immediate recall test, we prevented contamination by potentially differing amounts of re-exposure and rehearsal of learned information over a delay period. Nevertheless, because we did not have a recall test after a delay of weeks, months, or years, our study cannot speak to the life-long process of acquiring new semantic knowledge and how that may differ in trivia experts versus non-experts. Future studies that extend our paradigm over longer delays, and perhaps multiple retrieval tests, can assess whether trivia experts continue to retrieve semantic knowledge along with a rich episodic memory of how it was learned, consistent with the anecdote in the *Introduction*.

Future studies can also test the causal direction of our effects via memory training. From our study, it is unclear whether episodic memory boosts semantic acquisition in trivia experts or vice versa – although, as we have noted elsewhere, we speculate that it is the former rather than the latter effect. If trivia experts use episodic memory binding to enhance acquisition of, or access to, novel semantic information, then it should be possible to train non-experts to improve trivia retention by teaching them to link episodic contexts to semantic facts. If, however, trivia experts' ability to efficiently learn some semantic knowledge leads to enhanced episodic encoding as a byproduct, training non-experts to link episodic features to semantic knowledge may have no effect on new learning. Such research could also open new avenues for classroom study strategies to support academic success.

In sum, we used a novel "museum" task to discover that trivia experts may show enhanced memory for new semantic facts when those facts are bound to unique episodic features. This work adds to the burgeoning line of research highlighting the fundamentally interactive nature of episodic and semantic memory, and shows the utility of studying trivia experts as a special population that can shed insights on the mechanisms of memory.

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Data Availability We have not included a data availability statement as our open practices statement covers all of the information that would be in our data availability statement. Raw study data are available at the same linked OSF repository as our study materials.

Declarations

Conflict of interest The authors declare no competing financial interests.

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