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Do Spatial Navigation and Episodic Memory Rely on the Same Systems? Evidence From a Naturalistic Experience With Children and Adults

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Navigation and episodic memory are foundational cognitive processes that guide future decisions and are often linked to one another due to their behavioral and neural similarities. However, the extent and nature of their interdependence is unclear. We investigated this question using a real-world encoding experience with 8- to 13-year-old children and young adults. Participants were guided on a tour during which they learned the spatial locations of a series of objects and had various experiences with them. Factor analysis of three measures commonly used to assess spatial memory and four tests commonly used for episodic memory revealed two highly correlated latent factors. The first factor, which we termed *spatiotemporal structure*, included measures that require simultaneously representing all or part of the environment (finding routes, mapping the space symbolically, free recall of the experience, and spatial–temporal recognition). The second factor, which we termed *perceptual/factual/locale*, included perceptual and semantic recognition along with onsite pointing. These findings show that episodic memory and spatial representations are intertwined in naturalistic encoding and suggest directions for refining models of the function of these two systems.

Public Significance Statement
Think about the journey from your home to your favorite Italian restaurant. You may not want to take a major highway during rush hour, and the last time you went on a Saturday night, there was no parking. Memory of episodic events and navigational experiences join to guide your decisions. We find evidence that human behavior does not cleanly separate into "episodic" or "spatial" in a naturalistic experience both for older children and young adults. These data constrain models of the relations between memory and navigation.

Keywords: episodic memory, spatial navigation, factor analysis, temporal clustering, naturalistic testing

Navigation is an adaptive function required of all mobile animals, and the neural circuitry for mammalian navigation shows substantial cross-species similarity (Bevandić et al., 2024). In humans, and perhaps other mammals, much of this circuitry also supports episodic memory, which helps our species adapt to specific contingent circumstances and share socially relevant moments to create cultural solidarity (Burgess et al., 2002; Ekstrom & Ranganath, 2018; Epstein et al., 2017; Nardini, 2021; Tolman, 1948). Jointly, these two systems enable children and adults to make well-informed decisions about the future (Tansan et al., 2022). Deficits in these systems during childhood can lead to lifelong difficulty in cognitive functioning (Riggins et al., 2012; Riggins & Nelson, 2013; Vargha-

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The data set is available on the Open Science Framework at https://osf.io/uvnj3/. Parts or all of the work in this article have been presented at the 2024 Interdisciplinary Navigation Symposium as a data blitz talk and on the Open Science Framework as a preprint at https://doi.org/10.31234/osf.io/wgva9.

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Khadem et al., 1997). Conceptually, spatial navigation and episodic memory are linked, not only because accurate retrieval of spatial and temporal context supports episodic recall but also because integration of different types of information is the foundation of both processes (Newcombe & Nguyen, 2025). However, how intertwined are these behaviors both in development and adulthood?

One theory is that episodic memory and spatial skills are independent. This view comes from a study in which participants rated their own spatial memory, episodic memory, future thinking, and semantic memory (Fan et al., 2021). Principal component analysis found little overlap of spatial and episodic items. However, these findings should be interpreted cautiously, as there was no true assessment of episodic memory and spatial cognition; rather, data were from self-reports and thus subject to bias. Another limitation is the lack of controls for other cognitive abilities.

A second proposal comes from Buzsáki and Moser (2013), who proposed that navigation is tightly linked to memory and, more specifically, that path integration gives rise to episodic memory and map-based allocentric navigation to semantic memory. Memory of previous experiences guides future navigation, while successful navigation updates and reinforces memory. This bidirectional interaction is supported by synchrony in the medial temporal lobe. The prominence of theta rhythms found in rodent hippocampal–entorhinal interactions that support temporal information, future positioning, and mapping of landmarks may have evolved to support similar memory functions (Buzsáki & Moser, 2013). Real-world or mental navigation depends on the hippocampal system, which sifts through detailed neocortical representations to piece together sequences of memory (Buzsáki et al., 2022).

A third idea is that there is partial overlap of episodic memory and navigation and that the degree of their relationship depends on task demands that are particular or common to both (Ekstrom & Hill, 2023). For instance, they suggest that verbal free recall—a classic episodic memory task—does not rely on any sort of spatial knowledge. Similarly, estimating distances does not require any sort of episodic memory. In contrast, something like scene construction, that is, the ability to imagine a detail-rich scene (Hassabis & Maguire, 2007), has crucial intersecting task demands. Clark et al. (2019) found that autobiographical memory, or the self-recall of life events, and spatial navigation are related, and this relationship is mediated by scene construction.

There is also work from neuroimaging that supports the hypothesis of partial overlap. Spatial navigation has been functionally linked with the posterior hippocampus (Maguire et al., 2000), and autobiographical episodic memory has been functionally linked to the anterior hippocampus (Zeidman & Maguire, 2016). A meta-analysis found distinct functional activation in the retrosplenial cortex and precuneus for navigation versus the hippocampus and prefrontal cortex for memory (Teghil et al., 2021). But the same meta-analysis suggested overlapping activation for egocentric navigation and autobiographical memory in the posterior parahippocampal cortex. Neural findings provide some answers for brain–behavior interactions, but it is crucial to resolve behavioral nuances.

Taking a developmental lens, we know that episodic memory and spatial skills arise in synchrony, between 18 and 24 months. Beginning around 21 months, children use relational information to retrieve previously learned associations when shown a strongly associated cue (Newcombe et al., 2014). Although infants can use rudimentary navigation systems such as egocentric responses, place learning also emerges at around 21 months (Balcomb et al., 2011; Newcombe et al., 1998). As children grow older, the case for tandem development becomes less clear. In some relational binding studies, 6-year-olds can perform as well as young adults in retrieving all parts of learned episodic events (DeMaster et al., 2013; Ngo et al., 2019; Riggins, 2014). But other behavioral indices of episodic memory, such as autobiographical recall, show sustained improvement through adolescence (Willoughby et al., 2012). Children rarely reach adult levels of allocentric navigation performance before at least the age of 12 and perhaps later (Broadbent et al., 2014; Brucato et al., 2022; Murias et al., 2019; Nazareth et al., 2018; Nguyen et al., 2023).

The Present Study

Collectively, this limited but growing literature suggests the need to study when and why navigation and episodic memory align and diverge. This literature is still sparse, and developmental trajectories of spatial and episodic memory in children have never been clearly evaluated for comparability (Newcombe, 2019; Newcombe & Nguyen, 2025). To understand the relationship between spatial cognition and episodic memory, we need to examine their behavioral development in parallel. Hence, we aimed to determine if naturalistic episodic and spatial memory behaviors are distinct, overlapping, or strongly correlated. We opted for a real-world encoding design due to previous findings in adults that naturalistic memory recall (Diamond et al., 2020) and spatial integration (Weisberg et al., 2014) differ from computer-based. We tested 8- to 13-year-old children and young adults using a real-life tour that included episodic and spatial experiences. We employed factor analysis to reduce the dimensionality of seven memory measures and examine behavioral clustering of memory. To further probe temporal recall, we used conditional response probability (CRP) analysis. In sum, this study explored whether we would find separate "episodic memory" and "spatial memory" factors, or not.

Method

Participants

This study included 130 (88 children ages 8–13 years and 42 adults) participants from the greater Philadelphia area across three age groups: 8–10 years ($n = 46$, $M_{\text{age}} = 9.36$ years, 22 female), 11–13 years ($n = 42$, $M_{\text{age}} = 12.25$ years, 20 female), and adults ($n = 42$, $M_{\text{age}} = 23.19$ years, 23 female; see Table 1 for demographic breakdown). The study protocol, recruitment, compensation, and consent/assent procedures were approved by the Temple University Institutional Review Board. To recruit children, we used Facebook ads targeting parents, local flyers, and the Temple Infant and Child Lab database. To recruit adults, we used on-campus flyers and word of mouth. All participants were screened by phone for their age, lack of psychological or developmental diagnoses, and normal or corrected-to-normal vision and hearing. If eligible, participants were scheduled for two 2.5–3 hr sessions in the lab with no more than 7 days between the sessions. There was additional screening for magnetic resonance imaging eligibility, but magnetic resonance imaging data are not discussed here. Consent was obtained from the

Table 1
Demographic Information for Study Sample Split by Age Groups

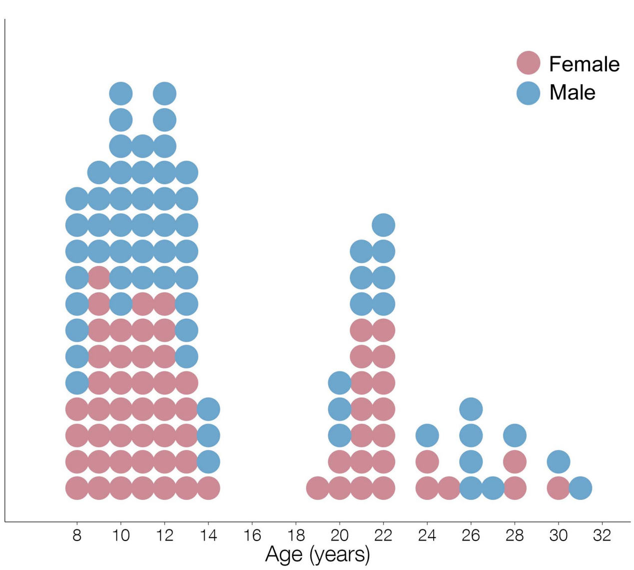
Variable	8- to 10-year-olds	11- to 13-year-olds	Adults	All
N	46	42	42	130
Gender				
Female	21 (46%)	20 (48%)	21 (50%)	63 (48%)
Male	23 (50%)	22 (52%)	18 (43%)	62 (48%)
Nonbinary/missing	2 (4%)	0	3 (7%)	5 (4%)
Race				
American Indian/Alaska Native	0	0	0	0
Asian/Asian American	4 (9%)	5 (12%)	7 (17%)	16 (12%)
Black or African American	14 (30%)	12 (29%)	5 (12%)	31 (24%)
Native Hawaiian or Other Pacific Islander	0	0	0	0
White	17 (37%)	15 (35%)	28 (67%)	60 (46%)
More than one race	5 (11%)	5 (12%)	1 (2%)	11 (8%)
Other or not reported	6 (13%)	5 (12%)	1 (2%)	12 (9%)
Hispanic	9 (20%)	9 (21%)	7 (17%)	25 (19%)

Note. The percentages are rounded to the nearest whole number.

adult participants and from parents/legal guardians, and assent was obtained from the children. All participants received monetary compensation at a rate of $25/hr; parents were reimbursed for parking expenses, and children received an additional small toy prize. Two adult participants and one child were excluded from analysis due to missing data.

Participants were asked for gender identification with the options of female, male, nonbinary, and other and were able to type their preference if not listed (Table 1). They were also asked for sex information as a part of the magnetic resonance imaging scan screener, choosing female or male (Figure 1). Race and ethnicity information was queried as two questions, first giving race based on the options presented in Table 1 and second for Hispanic ethnicity. Each question had an option to not respond.

Figure 1
Numerical Age and Reported Sex Breakdown



Note. See the online article for the color version of this figure.

Transparency and Openness

The data set and analysis code for this publication are available on the Open Science Framework at https://osf.io/uvnj3/. A power analysis using semPower in R (Moshagen & Bader, 2024) with a moderate effect size of .15, α of .05, assumed regression slope between latent variables of .20, and the smallest degrees of freedom for planned factor analysis models ($df = 12$) revealed a sample size of at least 66 was adequate for power of .80. Our sample size of 130 has sufficient power for the planned factor analysis.

Task Design

Stimuli Norming

There were two sets of image stimuli used in this experiment, each with 16 pictures of real-life objects (32 total). Sets A and B were actual objects participants saw in person during the encoding experiences. Each set had object categories that were semantically matched such that Object A1 (basketball) semantically matched Object B1 (volleyball). Similarity of pairs of objects was tested on an independent sample of 87 adults using Amazon Mechanical Turk on an institutional review board-approved protocol. Participants completed the task online using Qualtrics and Pavlovia links and were compensated $5. Participants rated on a 5-point Likert scale if the two images of the objects were dissimilar or similar based on how they perceived the two objects. Semantically matched pairs were consistently rated as highly similar, while nonmatched pairs were more dissimilar (e.g., volleyball and giraffe).

Tour Encoding (Onsite)

Participants were led on an 8-min tour by an experimenter during which they encoded 16 real-life objects (Set A or B) and learned the spatial layout of the objects. The tour encoding had both spatial and episodic information embedded within the experience. This tour was set up on the third floor of the psychology building at Temple University. The layout of the floor allowed for a rectangular-patterned setup of the objects where light gray areas on the overhead map were corridor hallways and dark gray areas were unentered rooms, except at the start and end locations (Figure 2B). Each object was set on a black stool in the same position for each participant. There were two object sets, A and B, which were counterbalanced across participants, such that half the participants saw Set A and half saw Set B. Participants did not see any objects before starting encoding. Participants were instructed to remember what the objects looked like, the facts they heard, and where the objects were located while being led through a predetermined route. An experimenter accompanied the participant during the tour, keeping the pace at each object consistent by reading from a script. At each object, participants are told what the object is (e.g., stuffed giraffe), asked to examine and interact with the object, and then told a fun fact about the object (e.g., giraffes talk to each other by humming, but they only do it in the middle of the night). This task was designed to be a child-friendly version of the Baycrest Tour (Diamond et al., 2020).

Episodic Memory Tests

Tour Free Recall

Participants completed an audio-recorded free recall of the tour experience (Figure 3A). This task used the autobiographical interview method (Levine et al., 2002) with some modifications based on the staged nature of the experiment. The interview questions were asked either by a second experimenter for the adults or by a parent for the children. This design ensured that the children were not confused as to why the tour guide wanted the child to remember the events that they experienced together. Participants were asked to remember the events of the tour and to give as much detail as possible about what they saw or learned from the tour. Participants were given 5 min to recall as much as possible, and then, the experimenter/parent asked general probing questions (e.g., Can you tell me more?) until the participant indicated they were done. Audio recordings were transcribed using Otter.ai and then double-checked by a research assistant. Recall transcripts were scored by a reliable rater using the autobiographical interview method to extract a count of internal and external event details (Levine et al., 2002). Internal details pertained directly to the tour, and external details did not relate to the tour. One point was given for each correct piece of information mentioned that pertained to the tour encoding (e.g., I saw a teapot [1 point] that was red [1 point]). External details unrelated to the tour did not count as internal details, even if they were episodic (e.g., I parked in the lot before coming to the lab).

Recognition (Qualtrics)

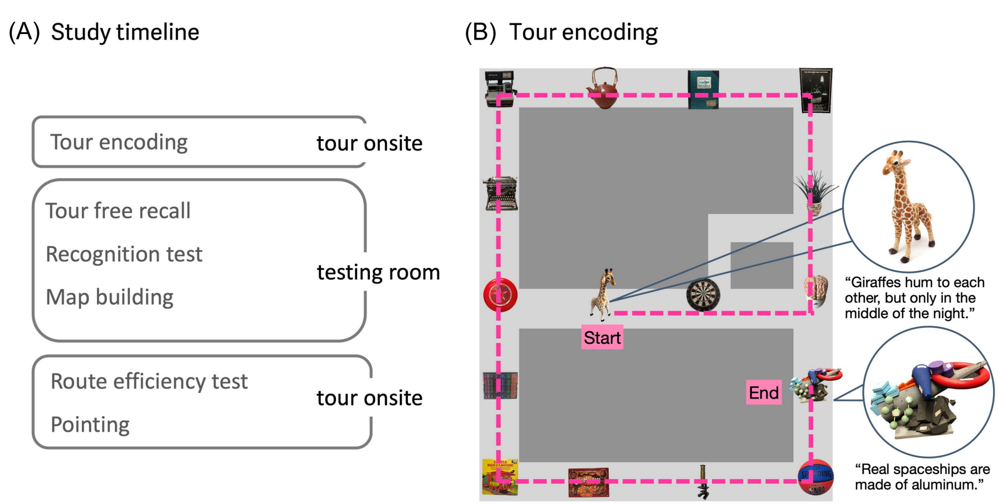
This test contained 40 four-alternative-forced-choice questions. There were 16 perceptual detail questions (such as “what color was the brain?”), eight questions asking about staged event details (such as “what word did you type on the typewriter?”), and 16 questions about spatiotemporal details (such as “what item did you see one before the dartboard?”; Figure 3B). Spatiotemporal questions were always last since these questions included pictures of the objects. Each question cued the participant into thinking about an object or an event from the tour. Children had the option for the experimenter to say each question-and-answer choice out loud. The scores were the proportion of questions correct from each question category or overall with chance at .25.

Spatial Tests

Map Building (PsychoPy)

Participants were tasked to recreate the tour environment from a bird’s-eye view by placing pictures of the 16 objects onto a blank

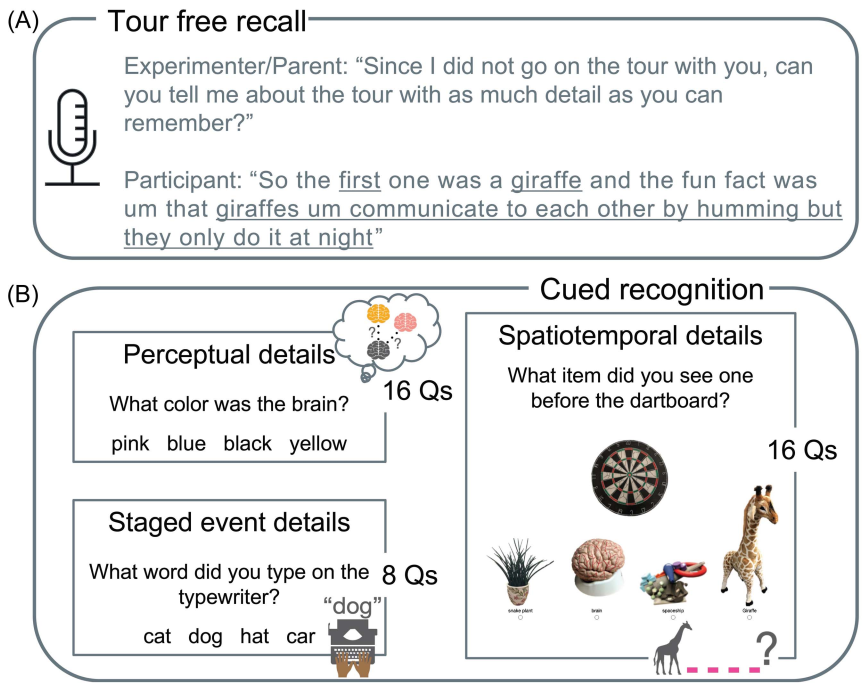
Figure 2
Study Timeline and Tour Setup



Note. (A) Timeline of encoding and testing. All behavioral encoding and testing occurred on Day 1 and Kaufman Brief Intelligence Test (KBIT) on Day 2 (not shown). (B) Schematic of the environment with 16 object stimuli along the tour path (dotted line). Light gray areas were walkable hallways, and dark gray areas were rooms and offices. The participants only went into the lab areas at the start and end locations. See the online article for the color version of this figure.

Figure 3

Episodic Memory Measures

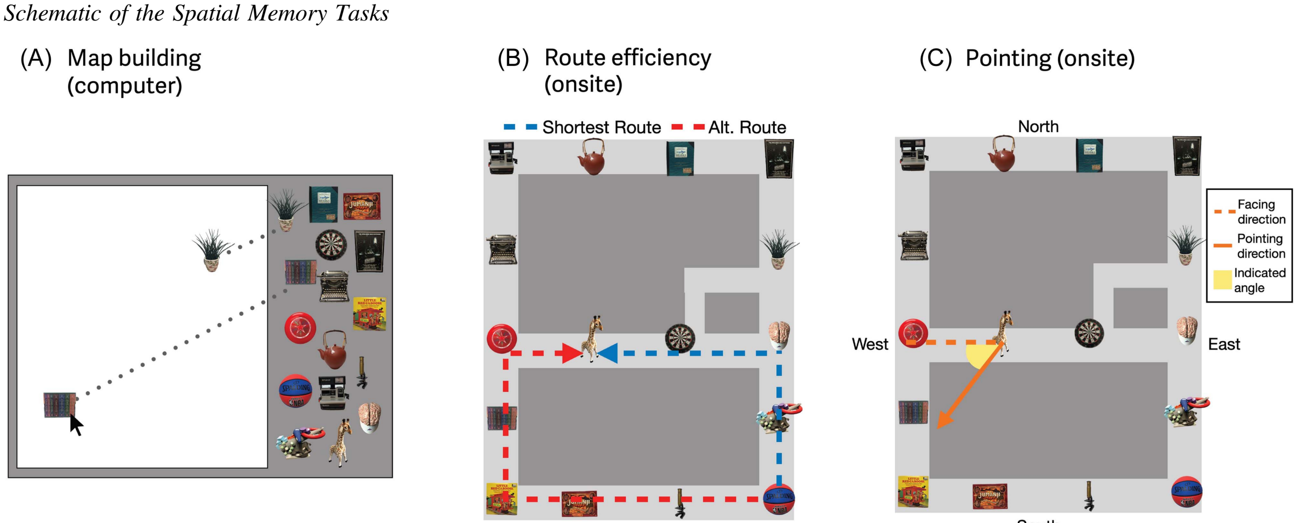


Note. (A) The autobiographical free recall procedure and scoring were modeled after Levine et al. (2002). Each piece of unique information relevant to the tour encoding was scored once (underlined). (B) The recognition test was administered on Qualtrics with three question categories. "Qs" indicate the number of questions in each category. See the online article for the color version of this figure.

white screen (Figure 4A). Object pictures were visible all at once on the right side of the screen and could be moved by the cursor. Participants pressed a button to indicate satisfaction with the map they built. The configuration of each participant's map was compared to a correct map using bidimensional regression to get the R^2 (Friedman & Kohler, 2003). The R^2 is the variance of the correct map that is explained by the participant's map, with scores closer to 1 indicating better mapping of object positions.

Figure 4

Schematic of the Spatial Memory Tasks



Note. (A) Map building task was completed on a computer. (B) Route efficiency with the shortest route and an alternative (alt.) route and (C) the pointing tasks were completed in the real-life tour environment with experimenter guidance. See the online article for the color version of this figure.

Route Efficiency (Onsite)

Participants were led back into the environment where they started at one object and navigated to 12 other objects on the tour, sequentially (e.g., basketball to giraffe, giraffe to plant, plant to teapot). All objects remained in the same position as during encoding. They were asked to take the shortest route they can to each object, and the routes traversed were recorded by the researcher on paper (Figure 4B). Distance was measured by the number of objects passed along a route and then averaged across all 12 trials. A perfect distance average score was 4.32. The efficiency score was calculated by dividing the participant's average number of objects passed by the perfect score (e.g., 5.00/4.32). Efficiency scores closer to 1 were more efficient; scores were reversed such that higher values indicated better performance.

Pointing Task (Onsite)

Participants completed 10 trials of an onsite pointing task where they stood at one object and were told to face a cardinal direction (Figure 4C). While in this facing orientation, they were asked to think about the location of a target object in the tour and then indicate the direction of the target object using a 360° digital protractor (e.g., standing at the giraffe facing west, point to the record). Indicated angles were recorded by the experimenter on paper. Angular error (indicated angle − actual angle) was calculated for each trial and averaged; error was reversed such that higher values indicated better performance.

Kaufman Brief Intelligence Test Second Edition (Kaufman & Kaufman, 2004)

The Kaufman Brief Intelligence Test (KBIT) was completed on the second testing day. Participants completed the verbal, riddles, and matrix reasoning subtests to generate a general IQ score (KBIT IQ). Test stimuli were presented on a computer screen, and riddles were read aloud by an experimenter. Participants started each test at their designated age start and continued until they got four consecutive trials wrong or until the end of the test. One participant did not complete the KBIT but was still included in analyses not including the KBIT.

Procedure

Figure 2A shows the timeline of the sessions relevant to this article. During the first session, participants completed the tour encoding, followed by questionnaires and behavioral testing on a computer in a testing room. Then, they went back into the tour environment for two navigation tests (pointing and routes). After, they returned to the testing room to finish behavioral testing. On the second day, participants completed the KBIT. Parents completed the demographic and pubertal development forms on the second day. Computer tasks in Qualtrics or PsychoPy (Peirce et al., 2019) were completed on a 13-in. MacBook Air. Onsite tasks were completed in person in the tour environment.

Data Analysis

All statistical analyses were completed in RStudio Version 4.2.3 (R Core Team, 2023), Python 3 (Van Rossum & Drake, 2009), and Jupyter Notebook (Kluyver et al., 2016). Data and analysis scripts are available at https://osf.io/uvnj3/ (Nguyen, 2024).

The seven memory measures included spatial measures of pointing ($M = 45.6$, $SD = 22.9$), route efficiency ($M = 1.4$, $SD = 0.33$), and map building ($M = 0.25$, $SD = 0.31$) and episodic memory measures of perceptual details ($M = 0.78$, $SD = 0.14$), event details ($M = 0.79$, $SD = 0.15$), spatiotemporal details ($M = 0.57$, $SD = 0.19$), and free recall ($M = 18$, $SD = 12.6$). Descriptive statistics for these continuous variables are presented in Table 2, along with age ($M = 14.8$, $SD = 6.27$) and KBIT IQ ($M = 105$, $SD = 15.3$), split by child and adult. Independent t tests between female and male participants were run for each continuous variable (except age), but all results were nonsignificant ($ps > .05$); thus, sex effects were not considered further.

Bivariate correlations between continuous variables were run to gauge linear relationships. Linear models controlling for age and KBIT IQ were run between the seven memory measures to determine the strength of behavioral relationships. Bonferroni correction was applied to these linear comparisons using $p < .0008$ (.05/57 comparisons). To extract temporal memory from the free recall data, CRP analysis (Kahana, 1996) was run, specifically lag-CRP, using the Psifr package in Python (Morton, 2020). CRP analysis extracted the probability of recalling each of the 16 items in the tour, and lag-CRP determined a pattern of recall order.

To determine if a factor analysis was appropriate for these data, we ran the Kaiser–Meyer–Olkin factor adequacy test and the Bartlett test of homogeneity of variances. We ran a parallel analysis with oblimin rotation of actual and simulated (100 iterations) data to determine the optimal number of latent components. This was a Monte Carlo simulation with the same number of measures and observations as the actual data, but with random values. Next, principal factor analysis (PCA) and confirmatory factor analysis were conducted using the psych package (Revelle, 2023). PCA with oblimin rotation revealed data-driven clustering of memory measures using factor loadings. Confirmatory factor analysis showed us how the memory measures contributed to data-driven and theory-driven latent factors and how the latent factors of memory related to each other. Five factor models were run; Models 1–3 were based on the PCA factor loadings, Model 4 added age and KBIT IQ to the optimal factor model, and Model 5 grouped the memory measures to latent variables of "episodic memory" and "spatial memory." All factor models were tested for goodness of fit using the root-mean-square error of approximation (RMSEA) and chi-square test against the null hypothesis that the RMSEA is less than or equal to .05 (excellent fit). Good fitting factor model statistics include an excellent RMSEA value of <.05 and a nonsignificant p value. Factor congruence tested how similar the factors were within the three age groups (Lorenzo-Seva & ten Berge, 2006; Revelle, 2023).

Results

Age-Related Changes and Behavioral Correlations

There were age-related improvements in all measures except for perceptual details (Figure 5A): pointing ($r = .48$, $p_{\text{Bonferroni}} < .0008$), route efficiency ($r = .45$, $p_{\text{Bonferroni}} < .0008$), map building ($r = .54$, $p_{\text{Bonferroni}} < .0008$), tour free recall ($r = .75$, $p_{\text{Bonferroni}} < .0008$), event details ($r = .36$, $p_{\text{Bonferroni}} < .0008$), and spatiotemporal details

Table 2

Descriptive Statistics for Age, Navigation and Episodic Memory Measures, and KBIT IQ

	8- to 10-year-olds					11- to 13-year-olds				
Variable	*n*	*M*	*SD*	Min	Max	*N*	*M*	*SD*	Min	Max
Age	46	9.36	0.822	8.05	10.8	42	12.3	0.823	11	13.9
Pointing (error)	46	58.8	22.7	17.3	146	42	46.6	19	15.8	90.3
Route efficiency	46	1.59	0.284	1.02	2.34	42	1.39	0.329	1	2.22
Map building	46	0.084	0.095	0.0001	0.435	42	0.211	0.277	0.003	0.977
Perceptual details	46	0.732	0.159	0.188	1	42	0.81	0.115	0.562	1
Event details	46	0.704	0.161	0.25	1	42	0.801	0.133	0.375	1
Spatiotemporal details	46	0.471	0.15	0.062	0.688	42	0.557	0.18	0.25	0.875
Free recall	46	10.5	6.63	0	32	42	13.4	7.95	3	34
KBIT IQ	45	111	15.8	67	136	42	104	15.8	75	138

	Adult					Overall				
Variable	*n*	*M*	*SD*	Min	Max	*N*	*M*	*SD*	Min	Max
Age	42	23.2	3.22	19.5	31	130	14.8	6.27	8.05	31
Pointing (error)	42	30	16.5	9.29	101	130	45.6	22.9	9.29	146
Route efficiency	42	1.22	0.265	1	2.12	130	1.4	0.329	1	2.34
Map building	42	0.458	0.383	0.01	0.995	130	0.246	0.314	0.0001	0.995
Perceptual details	42	0.814	0.109	0.562	1	130	0.784	0.135	0.188	1
Event details	42	0.86	0.108	0.625	1	130	0.786	0.15	0.25	1
Spatiotemporal details	42	0.68	0.172	0.25	1	130	0.566	0.187	0.062	1
Free recall	40	31.3	11.5	12	56	128	18	12.6	0	56
KBIT IQ	42	101	12.7	81	134	129	105	15.3	67	138

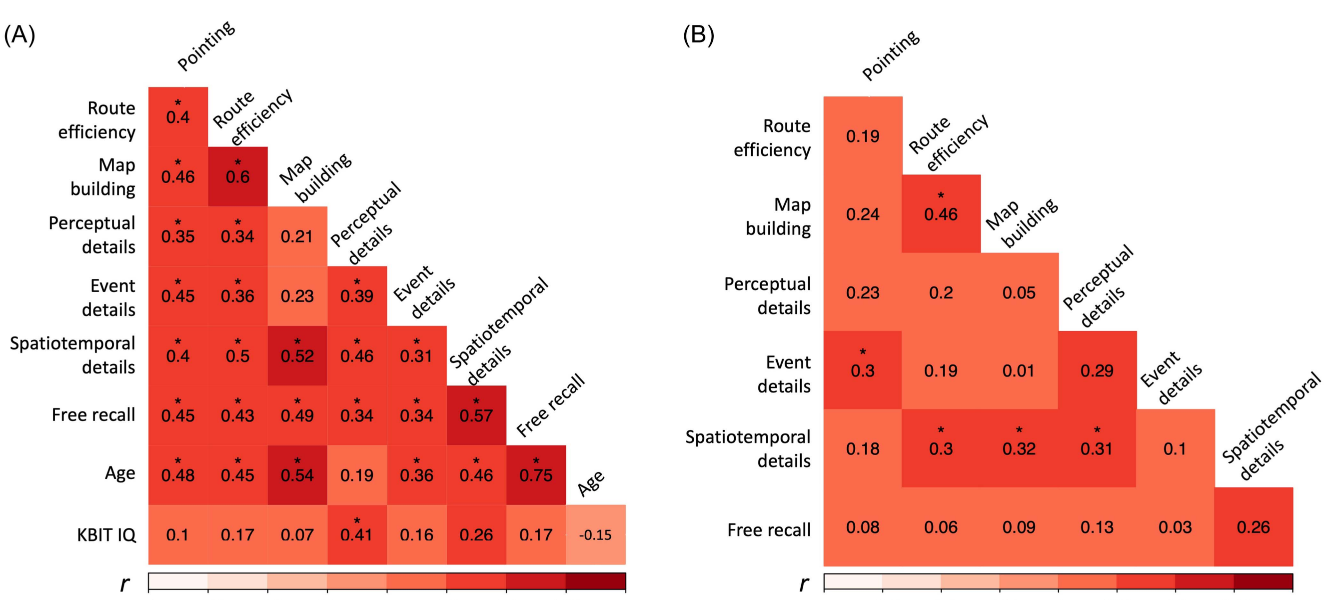
Note. Two adults are missing free recall data, and one child is missing KBIT IQ data. KBIT IQ = Kaufman Brief Intelligence Test; Min = minimum; Max = maximum.

($r = .46$, $p_{\text{Bonferroni}} < .0008$). The IQ measure is age-standardized, so we did not expect any relationship with age.

Bivariate correlations between most continuous behavioral variables showed significant correlations among episodic and spatial measures (rs ranging .31–.6, $p\text{s}_{\text{Bonferroni}} < .0008$), except for map building and perceptual details ($r = .21$, $p = .02$) and map building and event details ($r = .21$, $p = .008$; Figure 5A). When partial correlations between behavioral measures controlled for age and KBIT IQ, some

Figure 5

Behavioral Bivariate Correlations and Models Controlling for Age and KBIT IQ



Note. (A) Bivariate correlations between behavioral measures of memory, age, and KBIT IQ. (B) Linear relationships between memory measures while controlling for age and KBIT IQ. Bonferroni correction for multiple comparisons was applied at the $p < .0008$ level. KBIT IQ = Kaufman Brief Intelligence Test. See the online article for the color version of this figure.

* $p < .0008$ (passing correction).

relationships changed (Figure 5B). Spatiotemporal details remained linearly related to route efficiency (r = .30, $p_{\text{Bonferroni}}$ < .0008), map building (r = .32, $p_{\text{Bonferroni}}$ < .0008), and perceptual details (r = .31, $p_{\text{Bonferroni}}$ < .0008). Map building and route efficiency (r = .46, $p_{\text{Bonferroni}}$ < .0008) as well as pointing and event details (r = .30, $p_{\text{Bonferroni}}$ < .0008) survived correction as well. Taking age and IQ into account, we see relationships across episodic memory and spatial measures remain tightly correlated, albeit not as ubiquitous as bivariate comparisons.

Dimensionality Reduction of Memory Measures

Due to the high correlation between memory measures, factor analyses were used to reduce the dimensionality of these correlated variables. The Kaiser–Meyer–Olkin (overall measure of sampling adequacy [MSA] = .82, variable MSAs > .77) and Bartlett test ($K^2 = 4682.7, p < .001$) results showed these data are appropriate for a factor analysis. The parallel analysis simulation showed that two components were sufficient and accounted for 85.6% of the variance above and beyond random simulated data. Next, a PCA was run to identify loadings of the seven memory measures onto two factors (Table 3). Based on the PCA factor loadings, three confirmatory factor analysis models were run due to almost equal loading of the pointing variable onto both factors (−.41 and −.43). These models varied with how the pointing contributed to the two factors: (a) with Factor 1, (b) with Factor 2, and (c) shared between the two factors (see Table 4 for full model stats).

Model 2 with pointing contributing to Factor 2 was the optimal model (Figure 6B), χ^2 = 29.21, comparative fit index (CFI) = .94, RMSEA = .098 (p = .05), Bayesian information criterion (BIC) = 2403.07, p = .006. Model 2 was determined as the optimal model due to (a) a nonsignificant RMSEA indicating that the model is a good fit for these data and (b) overall stronger model estimates when the pointing is contributing to Factor 2. Although Model 1 (Figure 6A), χ^2 = 29.2, CFI = .94, RMSEA = .098 (p = .05), BIC = 2403.07, p = .006, was a plausible model, when the pointing is shared between the two factors in Model 3 (Figure 6C), χ^2 = 27.64, CFI = .95, RMSEA = .10 (p = .048), BIC = 2406.36, p = .006, pointing only significantly contributed to Factor 2 (r = .43, p = .03) and not to Factor 1 (r = .28, p = .095). Thus, in the optimal model, Factor 1 consisted of route efficiency (r = .71, p < .001), map building (r = .72, p < .001), spatiotemporal details (r = .74, p < .001), and tour free recall (r = .70, p < .001) and was named "spatiotemporal structure." Factor 2 consisted of pointing (r = .69, p < .001), perceptual details (r = .57, p < .001), and event details (r = .61, p < .001) and was named "perceptual/factual/locale memory." The two factors were significantly correlated with each other (r = .81, p < .001).

A factor congruence analysis was run to determine if the two factors were distinct within each of the three age groups. Indeed, Factors 1 and 2 have low congruence within each age group (Table 3). Given the two factors and their loadings, it seems likely that the factors are distinct and that development does not alter how our measures contribute onto the factors.

Age and KBIT IQ correlated with most of the seven memory measures (age more so than IQ), so we built Model 4 to include age and KBIT IQ as variables that may affect the two memory factors and to ensure that the relationship between the two factors was not dependent on age and KBIT IQ (Figure 6D). Unsurprisingly, age was strongly correlated with both spatiotemporal structure (r = .88, p < .001) and perceptual/factual/locale memory (r = .65, p < .001), while KBIT IQ was moderately correlated (r = .38, p < .001; r = .43, p < .001, respectively). The extent to which the two factors correlated reduced to r = .56 (p = .001). However, since this model did not pass a goodness-of-fit test with a significant RMSEA, χ^2 = 78.02, CFI = .88, RMSEA = .14 (p < .001), BIC = 2277.47, p < .001, we mainly used the results of this model to show that age and IQ do not significantly alter the relationship between the factors and their respective measured variable contributions.

Last, we tested an a priori fifth model that divided the seven measured variables into the preconceived categories of episodic (free recall, spatiotemporal details, perceptual details, event details) and spatial (pointing, route efficiency, map building) memory (Figure 6E). This model was not a good fitting model with a significant RMSEA of .11 (p = .025), further indicating that this data set is best represented by Model 2 where the measured variables were not so cleanly delineated based on "episodic" or "spatial" task demands (Table 4).

Table 3
Principal Component Analysis Loadings and Factor Congruence Within Age Groups

Variable	Factor 1	Factor 2
Spatial memory		
Pointing	−0.41	*−0.43*
Route efficiency	*−0.75*	−0.1
Map building	*0.95*	−0.17
Recognition		
Perceptual details	0.00	*0.81*
Event details	−0.01	*0.82*
Spatiotemporal details	*0.61*	0.28
Free recall	*0.64*	0.22
SS loadings	2.57	1.84
Proportion variance	0.37	0.26
Cumulative variance	0.37	0.63
Proportion explained	0.58	0.42
Cumulative proportion	0.58	1
Factor correlations		
Factor 1	1	0.4
Factor 2	0.4	1
Model statistics		
RMSR	0.1	
χ^2	57.3	
Factor congruence within age groups		
8–10 years	0.182	
11–13 years	0.059	
Adult	0.099	

Note. Factor loading in italics indicates preferential loading to Factor 1 or 2. SS = sum of squares; RMSR = root-mean-square residual.

Recall of Events Follows a Temporal Organization

To examine temporal memory, we examined the lag-CRP of the free recall data. Findings show that participants tended to follow a pattern of recalling items that were temporally close together (Figure 7A). The 8- to 10-year-olds and adults showed a similar pattern where the likelihood of mentioning a +1 lag is highest with decreasing probability of higher order lags (e.g., −4 and +4). The 11- to 13-year-olds showed a similar pattern; their lag

Table 4
Factor Model Statistics

Model	χ^2	CFI	RMSEA	RMSEA 95% CI	BIC	AIC	*df*
Model 1	29.2**	.94	.098†	[.05, .146]	2,403.07	2,339.98	13
Model 2	29.21**	.94	.098†	[.05, .146]	2,403.07	2,339.98	13
Model 3	27.64**	.95	.10*	[.051, .15]	2,406.36	2,340.41	12
Model 4	78.02***	.88	.14***	[.10, .17]	2,277.47	2,203.12	23
Model 5	32.14**	.93	.11*	[.06, .15]	2,405.99	2,342.91	13

Note. CFI = comparative fit index; RMSEA = root-mean-square error of approximation; CI = confidence interval; BIC = Bayesian information criterion; AIC = Akaike information criterion.
† $p = .05$. * $p < .05$. ** $p < .01$. *** $p < .001$.

probabilities were more variable but not significantly so. The serial position curves indicate that the first four items and the final two items on the tour have the highest probability of being recalled across all age groups (Figure 7B). When these probabilities are superimposed on a map of the tour, we can see that the items with the highest probability of recall are spatially close, even though they were not experienced as temporally close (Figure 7C). For example, the first item was always an animal (either giraffe or kangaroo), and the final item was always a spaceship model, which were temporally far apart but spatially relatively close together. This finding motivated labeling Factor 1 as "spatiotemporal structure," encapsulating memory that is structured by spatial relations and temporal clustering.

Discussion

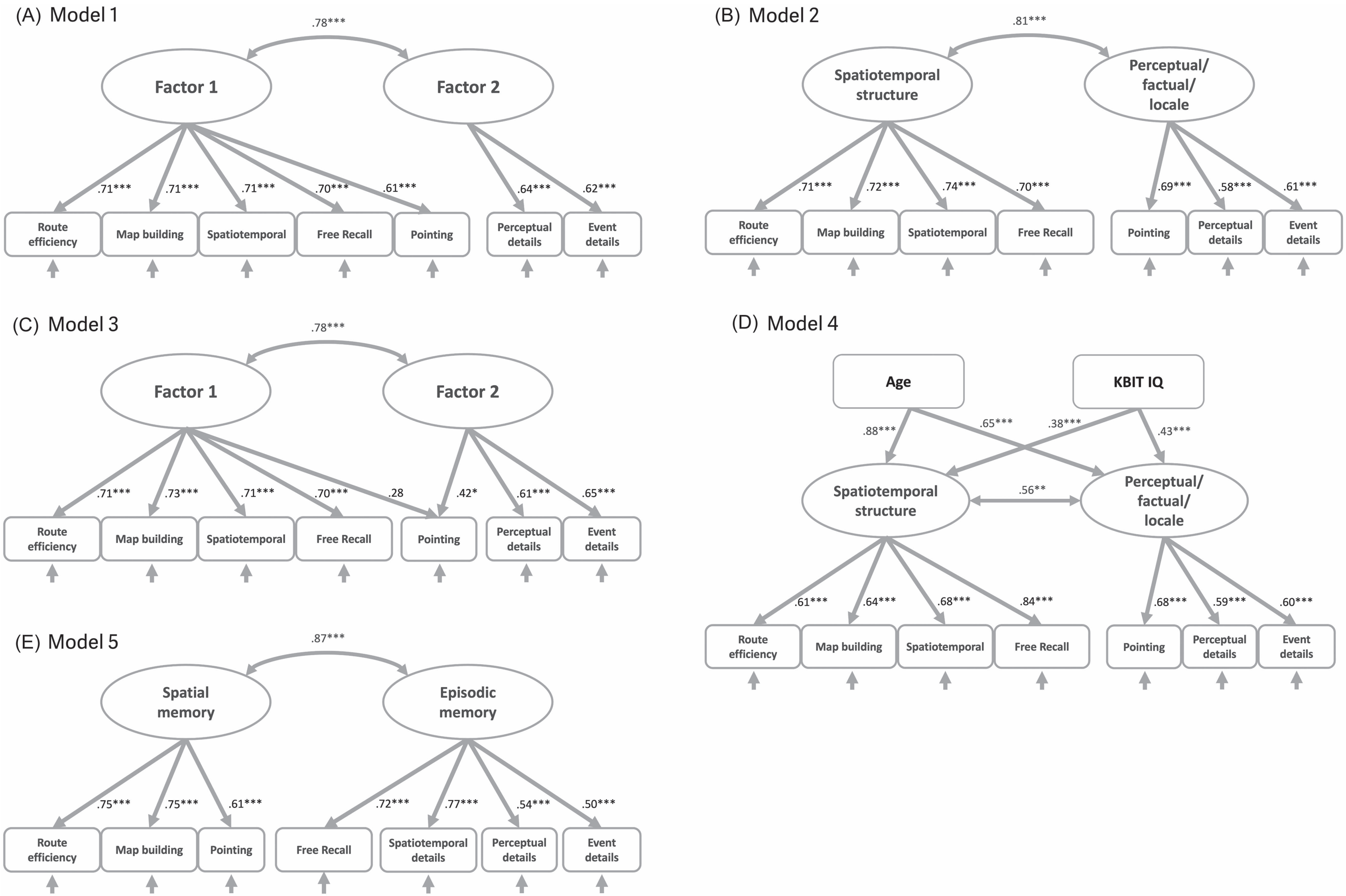
In this study, we investigated the relationship between episodic memory and spatial cognition in adults and in children at the ages at which development is continuing in these two domains. To do this, we took participants on a real-world tour that included objects placed in different locations. We found that spatial and episodic memory overlapped across two distinct latent factors, which mixed tasks traditionally associated with one or the other. For instance, the measures defining the factor labeled "spatiotemporal structure" involved overall representations of the sequence of events and the layout of the environment (Robin & Moscovitch, 2017). The "perceptual/factual/locale" factor included perceptual and semantic information along with pointing. Including age and IQ in models did not significantly change how the measured variables contributed to their respective factors, nor did it change the relationship between the two factors.

The results for the pointing task deserve comment because tasks like this are commonly used in navigation research and routinely correlate with other dependent variables such as map building. For example, one of our own recent studies found that pointing loads well with map building and route efficiency to contribute to a common factor across three navigation paradigms, including this real-world paradigm (Lader et al., 2024). However, here, we did not see this pattern. Pointing as measured here differs from traditional judgment of relative direction designs that have participants imagine perspectives (Shelton & McNamara, 2001) as opposed to standing at the location. This ensured that the children in our study would be able to complete the task with adequate accuracy. This design introduced an egocentric perceptual component to solving object relative locations, even though the target items were never visible from where participants were standing. Thus, they still had to imagine and draw from memory the relative item locations to be successful in the task. A traditional judgment of relative direction task can be solved using a mental map (Huffman & Ekstrom, 2019), which makes the interrelations between items in the environment readily available. This often requires additional training and exposures to the environment (Weisberg & Newcombe, 2016; Zhang et al., 2014), which was not the case in this study. Another strategy may draw from scene and viewpoint of episodic memory and adopting an egocentric perspective (Zhang et al., 2014) or some combination of the allocentric and egocentric. We infer that our pointing task loaded more in the perceptual factor due to the second strategy and added perceptual cues from being onsite in the environment. This task differs from map building and route efficiency by requiring flexible changes in perspective (Geva & Henik, 2019). Such differences may explain why pointing loaded as it did here, although we also note that it was the only variable teetering between the two factors. A future study could simultaneously query participants' internal strategy while completing pointing trials. It is plausible that if the pointing tasks were administered off-site on a computer, it may affect performance and internal strategy. This is an important research question that needs investigating to ensure that the field is measuring these cognitive skills with fidelity across all ages. In any case, we see memory for perceptual and event details as centrally defining Factor 2.

The dimensional structure we found is contrary to the idea that episodic memory and spatial navigation have little or no overlap (Fan et al., 2021), perhaps because self-report is unreliable or perhaps because Fan et al. did not include many contrasting cognitive abilities, such as verbal fluency, in their work. We present early findings that are incompatible with models that separate episodic and spatial memory when encoding of such information occurs concurrently. When considering naturalistic designs, the overlap in cognitive demands is addressed in our study and shows that in the real world, it is harder to separate episodic and spatial cleanly (Fan et al., 2023). Whereas, studies that use individual tasks or self-report items, either measured or survey-based, may not be able to address how episodic memory and navigation directly relate.

The relations proposed by models involving interdependencies of semantic and episodic memory with allocentric and egocentric navigation (Buzsáki et al., 2022; Buzsáki & Moser, 2013) are less clearly addressed by our work. We did not test semantic memory because it would not have shown sufficient variance in the age range of this study. However, given that semantic memory develops *earlier* than episodic memory, reaching peak rates of change in

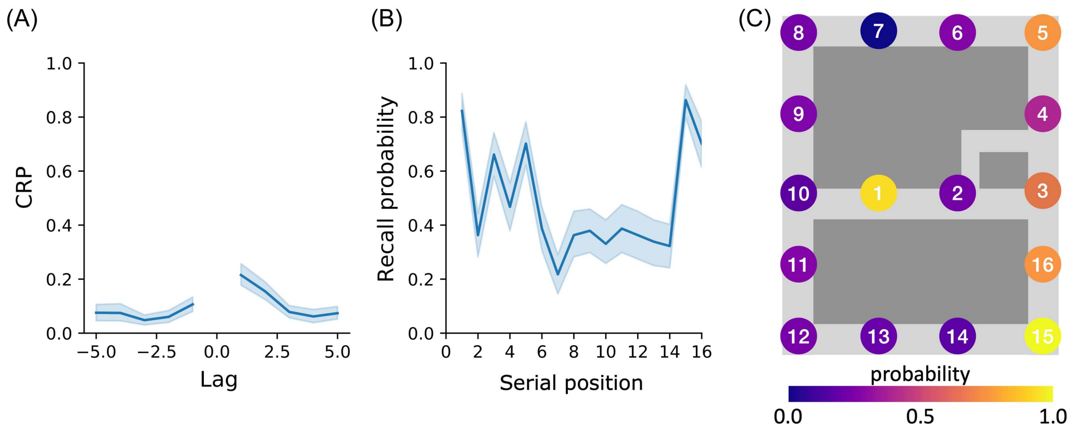
Figure 6
Factor Models



Note. (A) Model 1 incorporated the pointing task into Factor 1 (root-mean-square error of approximation [RMSEA] = .098, $p = .05$). (B) Model 2 incorporated the pointing into Factor 2 (RMSEA = .098, $p = .05$) and was the optimal model. (C) Model 3 incorporated the pointing into both Factors 1 and 2 (RMSEA = .10, $p = .048$). (D) Model 4 included the effects of age and KBIT IQ on the memory factors with contributing measured variables of Model 2 (RMSEA = .14, $p < .001$). (E) Model 5 was an a priori model grouping measured variables by the episodic and spatial memory task demands (RMSEA = .11, $p = .025$). KBIT IQ = Kaufman Brief Intelligence Test.
$^{*} p < .05$. $^{**} p < .01$. $^{***} p < .001$.

Figure 7

Overall Tour Free Recall Temporal Order CRP



Note. (A) Lag-CRP curve showing the probability of recalling previous items (negative) and subsequent items (positive) along the tour. Participants recalled items more often when they were close together, temporally. (B) Plot showing recall probability for each of the 16 objects shown in serial position. (C) Recall probability results from (B) superimposed onto a map of the tour to show the spatial location and temporal order (circle numbers) of the objects. CRP = conditional response probability. See the online article for the color version of this figure.

children within the first 5 years of life (Roebers, 2022), their model is, we have argued elsewhere (Newcombe & Nguyen, 2025), an unlikely way to think about the relations among the systems.

Our findings are most compatible with overlapping process theories, but we note that those approaches need considerably more specification. For instance, we did not directly address the proposal of scene construction as a mediator of the relationship between episodic and spatial memory (Clark et al., 2019). The main reason was that the scenes on our tour were hard to distinguish from item memory, given the great similarity among the halls of an academic building. Future research with more distinctive contexts could examine this interesting area of overlap.

As another example of a future direction, there needs to be care taken in delineating processes that may overlap. Ekstrom and Hill (2023) considered verbal free recall to be episodic but not navigational, but they were discussing list recall, rather than the temporal ordering of real-world events. Free recall of lists and of events structured in space differs in many ways, with one key point being that events can be temporally distant, but their locations can be close in space. We showed a combined effect of contextual closeness and temporal clustering on memory. This led to attributing the free recall data as a metric of spatial and temporal memory, but it is valid to consider the perceptual aspects of free recall. Although participants can recall perceptual details, the recognition tests captured details participants could have neglected in the free recall phase. Additionally, during the pilot phase, we saw that young children recalled less than adults and were less likely to self-recall perceptual details at all. Since we incorporated a separate and specific test of perceptual recognition, we did not further subdivide the free recall to extract perceptual details. Thus, the free recall task could be seen as overall memory and the recognition test as more detailed memory. Additionally, since free recall loaded more cleanly onto Factor 1, we did not consider it as a fit for Factor 2 especially because Model 5 did not yield a good fit.

Effects of recency for list learning tasks (i.e., recall of most recent events first) and temporal clustering are reliably found in adults (Healey & Kahana, 2014; Kahana, 2020). They also appear in 8- to 10-year-olds (Lehmann & Hasselhorn, 2010; Vicari et al., 1999). Studies with real-world events, especially with children, are rarer. Pathman et al. (2023) recently found stable recency across ages 4–10 years for memories of experiences in a zoo but increasing temporal organization. Coughlin et al. (2024) used images of cartoons and objects associated with a scene context and found that, by age 7, items within the same context are perceived as being closer in time and that, by age 10, items across different contexts are perceived as farther in time. Both studies suggest temporal organization increases with age, and Coughlin et al.'s study suggests increasing organization of time by context—not precisely spatial, but akin to it. These studies are consistent with our finding that, by 8–10 years, temporal and spatial clustering of real-world recall are comparable to adults.

Limitations

We were underpowered to run factor congruence analysis between the age groups (required group $n = 63$) to ensure that the factor loadings were consistent across age. Model 4 attempted to clear up this pitfall; however, this model did not address the issue head-on. Future work would need much larger sample sizes across ages to address the issue of measurement equivalence.

Due to the nature of some measurements (e.g., pointing), the single encoding exposure may have undercut our participants' capacity to form precise mental maps, especially the children. Other studies using virtual paradigms often repeat exposures in the environment, albeit much more easily virtually than in the real world. In the future, we may improve upon this study design by enabling repeated exposure, possibly even walking participants through the tour a second time in reverse order. Additionally, we may consider randomizing the object order per participant to prevent bias in temporal and spatial order (Ekstrom et al., 2011) or memory for more interesting objects, although the latter point is somewhat addressed with counterbalancing two sets of objects across participants. The former point could give us cleaner metrics of temporal order memory and spatial clustering derived from the same encoding.

Constraints on Generality

We examined memory development in a cohort of 8- to 13-year-olds and a comparison group of young adults. Thus, we have gaps in the developmental trajectory for children younger than 8 years and for adolescents from 14 to 17 years. In addition, our participants came from an urban/suburban population in and around Philadelphia, and thus, findings may not be generalizable to rural populations or to participants from other cities and countries. Participants were led on a specified route rather than freely exploring. The size of our real-world environment was relatively small and was indoors, reducing generalizability to larger scale real-world navigation outside, where distal landmarks are typically more available.

Conclusion

Using naturalistic encoding, this study aimed to explain how episodic memory and spatial knowledge are related in development and adulthood. Humans take in everyday events in a continuous manner as they move in the world, and thus, we studied episodic and spatial functioning using a common experience (Maidenbaum et al., 2024; Weisberg et al., 2014). We found evidence of considerable intertwining of these two systems, across the age range from 8 years to early adulthood. Our findings constrain future models of the relations between these two systems, often analyzed separately and yet discussed together.

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