Developmental changes in memory structure and precision alter the use of retrieved episodes during decisions for reward

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Abstract

How do we make efficient use of limited past experience to guide our present choices? Most widely-studied option evaluation strategies rely on knowledge accumulated across numerous repeated experiences. One possible alternative strategy in unfamiliar environments is episodic sampling, in which a decision maker retrieves a small number of memories of similar past decisions to estimate the value of present options. Such a strategy would be particularly useful for children and adolescents who, by virtue of their younger age, inherently have less experience to draw on than adults. On the other hand, the effectiveness of episodic sampling derives from its precision and context sensitivity—properties of episodic memory that continue to develop into adolescence and young adulthood. This raises a key question: do developmental changes in episodic memory produce changes in episodic sampling? To address this, 106 participants, ages 8-25, completed a two-day choice task that dissociated the influence of a single episodic memory on choice from the influence of multiple episodes sharing a common context. Across all ages, single evoked episodes biased choice, but only adults showed sensitivity to the broader evoked episodic context. Developmental gains in memory precision fully explained these differences, and paralleled a shift in the relationship of memory to forward planning. Together, these findings suggest that episodic memory guides decision making throughout development, but the character of its influence evolves as memory becomes more precise and richly structured.

Significance Statement

Reward and memory process interact closely and reciprocally in adults. Reward and motivation enhance memory, while memory informs decisions for reward. Both decision-making and memory systems change dramatically across childhood and adolescence. However, the development of these processes has largely been studied independently. Here we show that from middle childhood the memory of a single, fleeting event can systematically bias choices a day later. With age, decision makers increasingly draw on richer episodic context to guide their choices. Age-related improvements in memory precision drive this shift. Our findings position episodic memory as a key driver of developmental change in decision making.

Introduction

Humans regularly make adaptive decisions in new environments despite limited experience. This ability is especially remarkable in children and adolescents, for whom many environments are novel. Episodic memory has been proposed as a key ingredient to humans' "sample efficiency" (Hassabis, Kumaran, Summerfield, & Botvinick, 2017; Botvinick et al., 2019; Kumaran, Hassabis, & McClelland, 2016; Lengyel & Dayan, 2007; Blundell et al., 2016; Pritzel et al., 2017; Lin, Zhao, Yang, & Zhang, 2018). Episodic memory records past decisions in rich detail, preserving what an individual chose, when and where they chose it, and the choice's immediate and long-term consequences. These details allow people to go beyond their direct past experience and vividly imagine counterfactual pasts and distant futures as they make decisions (Gershman & Daw, 2017; Biderman, Bakkour, & Shohamy, 2020; Schacter, Addis, & Buckner, 2007). A growing body of work has demonstrated that adults draw on episodic memory to guide their decisions (Wimmer & Shohamy, 2012; Duncan & Shohamy, 2016; Botvinik-Nezer, Bakkour, Salomon, Shohamy, & Schonberg, 2021), particularly in uncertain or volatile environments (Nicholas, Daw, & Shohamy, 2022) and even when recency-based evaluation strategy should dominate (Bornstein & Norman, 2017; Bornstein, Khaw, Shohamy, & Daw, 2017). Children and adolescents, given their more limited experience, stand to benefit the most from episodic memory. But despite the growing evidence in adults, little is known about how episodic memory guides decision making during childhood and adolescence and how this relationship changes with age.

Research on developmental changes in decision making to date has focused largely on incremental learning. In incremental learning, the value of an action is estimated by averaging over many past outcomes, thereby discarding the idiosyncratic features of each contributing experience. Incremental learning strengthens across development, growing more flexible and context sensitive (Nussenbaum & Hartley, 2019). Episodic sampling is an alternative decision strategy with episodic memory at its core. In episodic sampling, action values are instead estimated by averaging over a subset of past decisions drawn from memory. The number of memories recalled can vary. At the extreme, a decision maker may rely on a single memory when they have few relevant ones to draw on. For example, a decision maker might remember a particularly delicious meal they enjoyed a decade ago at a Japanese-Peruvian fusion restaurant during a trip to Peru. That memory alone could push the decision maker towards trying a new ramen shop across town rather than returning to their favorite halal cart down the block. But, when multiple memories are recalled, the initial memory can cue the retrieval of other memories sharing a similar context, such as time or place. Building on the example, recalling one meal from Peru may trigger the recollection of other meals from the same trip, causing the decision maker to forgo both the ramen shop and the halal cart for a Peruvian restaurant instead. In this way, a handful of memories from the distant past can exert an outsized influence on present choice, producing systematic departures from the predictions of incremental learning (Bornstein & Norman, 2017).

Episodic sampling should be a particularly useful strategy for children and adolescents given their relative lack of experience. But, the features of episodic memory from which episodic sampling derives its efficiency—its context sensitivity and precision— are also among the slowest to develop. Before reaching adolescence, children are able to recall individual items on par with adults but continue to struggle to remember contextual details (Sluzenski, Newcombe, & Kovacs, 2006; Riggins, 2014; Bauer et al., 2012; Lorsbach & Reimer, 2005; Demaster & Ghetti, 2013; Lee, Wendelken, Bunge, & Ghetti, 2016; Picard, Reffuveille, Eustache, & Piolino, 2009; Lloyd, Doydum, & Newcombe, 2009), organize experiences around overlapping contexts (Coughlin et al., 2024), and to bind people, places, objects, and time into coherent events (Olson & Newcombe, 2014; Ghetti, 2017). With age, these contextual features are better retained and used to structure memory. During the same period, the precision of memories and their spatiotemporal context also strengthens (Canada, Ngo, Newcombe, Geng, & Riggins, 2019; Ghetti, DeMaster, Yonelinas, & Bunge, 2010; Lambert, Lavenex, & Lavenex, 2015; Ribordy Lambert, Lavenex, & Banta Lavenex, 2017; Ngo, Newcombe, & Olson, 2018; Ngo, Lin, Newcombe, & Olson, 2019; Peng et al., 2023; Rollins & Cloude, 2018; Vijayarajah & Schlichting, 2025). Under a "value of information" account (Bera, Mandilwar, & Raju, 2019; Callaway, Rangel, & Griffiths, 2021; Callaway, Griffiths, Norman, & Zhang, 2024), higher-fidelity memories provide more precise information and hence, exert a stronger influence on choice (Wang, Feng, & Bornstein, 2021). If memory's structure and fidelity determine its contributions to choice, then episodic sampling should change in tandem with memory.

Here, we asked: Do developmental changes in episodic memory produce changes in episodic sampling? To address this question, we recruited a large, age-continuous sample of 8- to 25-year-olds to complete a task designed to dissociate the influence of a single sampled episode from the influence of multiple episodes linked by a common context (Bornstein & Norman, 2017). We hypothesized that these effects would follow distinct developmental trajectories. Participants completed two additional tasks, measuring memory precision and forward planning, two processes thought to be related to memory-guided decision making. Because more precise memories should provide more information during option evaluation (Wang et al., 2021), we predicted that greater memory precision would be associated with stronger episodic influences on decision making. And because episodic memory captures long-range dependencies between actions and outcomes (Gershman & Daw, 2017), we predicted that greater episodic influences on choice would be associated with greater forward planning. In brief, we examine three central questions: How does the influence of a single episode versus a broader episodic context differ with age? Can developmental differences in episodic sampling be explained by parallel changes in episodic memory itself? Does episodic sampling support forward planning across development?

Methods

Participants

We recruited 124 participants between the ages of 8 and 25 (M age = 16.71, SD = 5.06, 62 female) for an online study consisting of four sessions. The encoding phase of the memory and decision-making task was completed in Session 1, and the test phase in Session 2 the following day. Participants then completed the memory precision task in Session 3, one to two weeks later, and the forward planning task in Session 4, an additional one to two weeks after that.

Participants were recruited from the Hartley lab database which includes individuals recruited through ads on social media (e.g., Facebook and Instagram), word of mouth, local science fairs, and flyers on New York University's campus. Participants who had not previously completed an in-person study with our lab completed a brief Zoom call with a researcher. During this call, participants (and their parent or guardian, if the potential participant is under 18 years) were required to be on camera and confirm their full name and date of birth. Adult participants and parents of child and adolescent participants were additionally required to show photo identification.

Participants were recruited to ensure even coverage of the age range. Participants reported no history of psychiatric or learning disorders. Based on self- or parent-report, 43.55% of participants were White, 33.06% were Asian, 13.71% were more than one race, and 9.68% were Black. Additionally, 12.01% of the sample identified as Hispanic.

Eighteen participants were excluded for their behavior in the main task (M age= 15.20 years, SD = 4.44, range = 8.77 to 25.01, 8 females). Exclusion criteria included: failing to respond on more than 10% of trials in either the encoding or test phase (4 excluded), selecting one of the three options on fewer than 5% of trials in either phase (8 excluded), responding on average in less than 250 milliseconds (1 excluded), interacting with their browser more than 10 times in either phase (10 excluded). Data from one additional participant were not analyzed because of technical issues during data collection. This left a final sample of 106 participants (mean age= 16.96, SD= 5.09, range=8.03 to 25.97, 54 females). Our target sample size of 100 was based on power analyses using the effect sizes obtained from previous variants of the task. Bornstein & Norman (2017) performed a one-sample t-test of participants' individual estimates of the influence of context memory on choice against 0. With their obtained effect size, d=0.79, a sample size of 15 would be needed to achieve 80% power at α=.05. Noh et al. (2022) examined individual differences in memory-guided decision making, finding a moderately strong correlation (ρ_τ=0.22) between memory precision and the influence of episodic memory on choice. To achieve 80% power at α=.05, 66 participants would be necessary. Our sample size surpasses both these targets and is larger than many previous studies of age-related variation in memory and decision-making strategies (Nussenbaum, Prentis, & Hartley, 2020; Cohen, Nussenbaum, Dorfman, Gershman, & Hartley, 2020; Rosenbaum, Grassie, & Hartley, 2022; Raab, Foord, Ligneul, & Hartley, 2022).

A subset of the included participants (N=67) also completed the mnemonic similarity task, indexing memory precision, and the two-step task, indexing forward planning. For each of the four sessions, participants were compensated with a $10 Amazon gift card and had the opportunity to earn up to $2 in bonus payment based on task performance.

Memory and decision making task

Instructions

Before beginning the task, participants received written, audio, and interactive instructions, and completed practice choice and memory trials. They also completed an instruction comprehension quiz and could not begin the task until they answered all four questions correctly.

Encoding Phase

We adapted a three-armed restless bandit task from a prior adult study (Bornstein & Norman, 2017). In our version, participants acted as captains of a pirate ship (Figure 1AB). The ship traveled to a series of islands, each distinguished by a unique background image (i.e., the context). As the captain, participants chose, within a three-second response window, which of the three crew members—Red Beard, Black Beard, or White Beard—would attempt to rob the next passing cargo ship. After each choice, a trial-unique image of the cargo, always an object, was displayed for 1 second. Participants were instructed to encode this object image in conjunction with the island's background image. Participants then received feedback that indicated whether the robbery was successful. A pile of gold coins signaled that the crew member was successful and a red "X" signaled that they were not. Feedback remained on screen for 1.5 seconds. The three crew members differed in their probability of success, and these probabilities changed over time according to Equation 1 below (see Reward Structure). Participants were incentivized to track the success of crew members over time, because their bonus payment was tied to the amount of gold they collected. The encoding phase comprised 240 choice trials across six islands, with islands changing every 40 trials. Upon leaving an island, participants were offered an optional break of up to two minutes.

Test Phase

The next day participants completed an additional 180 choice trials of the three-armed bandit task (Figure 1C). In the test phase, no background images or trial-unique object images were shown. Participants were told that the "fog" on the island obscured this information. Interleaved pseudorandomly between choice trials were 60 memory probe trials. On each probe trial, an object image from the previous day was shown, and participants had up to 3 seconds to indicate their confidence in having seen the image (definitely saw, maybe saw, maybe did not see, definitely did not see). Participants earned additional bonus pay for correct responses. Fifty of the 60 probe images were shown during the encoding phase and served as reminders of specific past trials. Recognizing the probe could

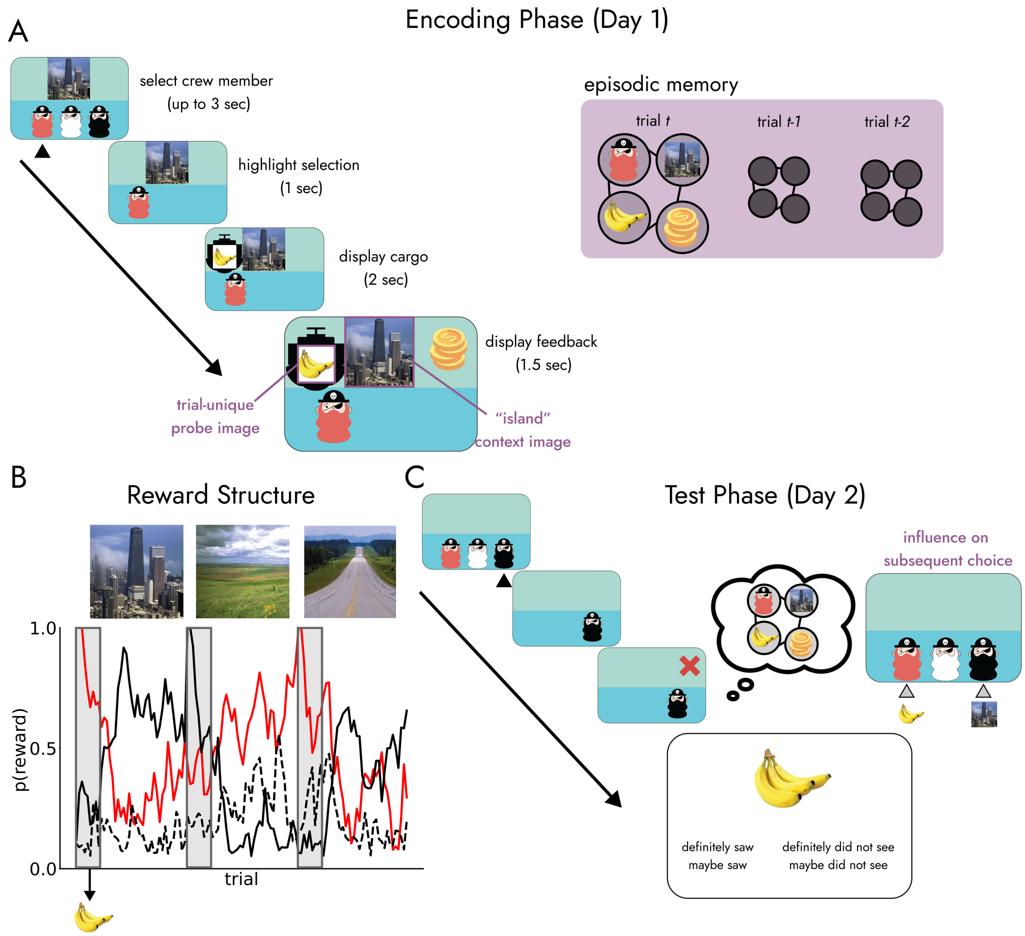

Figure 1: **Task design.** Task design. Participants completed a two-session three-armed bandit task, consisting of an encoding phase and the test phase. **A. Encoding phase.** Participants completed 240 choice trials across six consecutive "islands." Participants experienced each island, distinguished by a unique background image, for 40 trials. On each trial, participants chose one of three crew members to rob an incoming cargo ship. After selecting a crew member, a trial-unique image of an object (the ship's "cargo") was displayed, followed by feedback indicating whether or not the crew member was successful in robbing the ship. If they were successful, a pile of gold coins was shown; if not, a red "X" was shown. Participants were instructed that their bonus payment would depend on the total amount of coins collected. We hypothesized that the trial-unique image, the context image, the chosen crew member, and the outcome of the choice were bound together as an individual episode and stored in episodic memory. **B. Reward structure.** Each crew member had a distinct, gradually changing probability of success. At the beginning of each phase, crew members were initialized with 60%, 30%, and 10% success rates. These probabilities varied across trials according to a Gaussian random walk. After the first 10 trials of each island, the probabilities were shuffled so that the most successful crew member changed. These new mappings persisted through the remainder of the island and into the next, until the next shuffle 10 trials into the new island. **C. Test phase.** The following day, participants completed 180 choice trials on a "foggy" island, during which the background image and object images were obscured. Crew member success probabilities continued to drift and were reshuffled every 40 trials, despite the background remaining unchanged. Interleaved between these 180 choice trials were 60 memory probe trials. On 50 of these trials, images from the prior day's encoding task were shown and on 10 trials, novel images were shown. The key measure of interest was the extent to which choices directly following the memory probe trials were biased by the probes and the reward information associated with them. Critically, the reward structure allowed us to isolate the contributions of a single retrieved trial from the contributions of multiple trials from a shared context. In the example displayed here, the retrieved trial should bias the participant to select Red Beard because he was rewarded on that trial while the retrieved context should bias the participant towards selecting Black Beard because he most often led to reward on the island with the cityscape background, in which the retrieved trial occurred.

trigger reinstatement of its associated episode, including the action taken, the outcome received, and the broader context in which the trial occurred.

Unlike the original task, which was administered in a single session, we split the task across two days, with the encoding phase occurring on Day 1 and the test phase occurring on Day 2. This modification extended the delay between encoding and test from minutes to a day, ruling out the possibility that results were driven by a form of visual working memory and making the task sessions more manageable for children.

Reward Structure

During both the encoding and test phases, each crew member's probability of success drifted over time. At the beginning of each phase, crew members were assigned unique initial success probabilities of 60%, 40%, or 10%. These probabilities drifted independently according to a decaying Gaussian random walk with reflecting bounds at 5% and 95%, centered on the target probability (θ_i) assigned to each crew member i.

$$\pi_{i,t+1} = \lambda \pi_{i,t} + (1 - \lambda)\theta_i + \nu \tag{1}$$

Where λ (stickiness) was set to 0.6, ν (diffusion noise) was a zero-mean Gaussian with SD = 8.

A key feature of the reward structure was that, on each island (with the exception of the first in each phase), the crew members' target reward probabilities (θi) were shuffled after the first 10 trials. This new mapping of crew members to reward probabilities continued for the next 40 trials, the transition on the next island. Importantly, memory probes were only drawn from the first 10 trials of each island, before shuffling. This design allowed us to dissociate the reward outcome associated with the probed trial from that of the overall distribution of rewards across the entire context. This task feature was essential for dissociating the influence of a single episode from that of multiple contextually linked episodes.

Source Memory

Source memory was assessed after the test phase in a 50-trial task. On each trial, participants were shown an object image that had previously served as a memory probe and had three seconds to select the island on which they originally encountered the object.

Analyses

Our primary goal was to examine how episodic memory shapes decision making across development. To address this, we fit a logistic regression model predicting participants' choices from the test phase. Fixed effects included recent experience (option chosen on the previous trial; outcomes one, two, and three trials back), distant experience from the prior day (choice and outcome from the probed trial; outcomes averaged across the probed context), continuous age, and their interactions. Age was z-scored across the full sample prior to entry in the model.

We constructed the predictor matrix following the approach of Bornstein & Norman (2017). The following procedure was repeated once for each of the three crew members, yielding up to 540 rows (180 choice trials x 3 options). The number of rows could be less than this as we excluded from analysis any choice trials on which the memory probe was not accurately recalled.

To begin, one crew member was treated as the option of interest. We included seven main effects. The first four predictors coded for the influence of recent experience. The first predictor, reflecting perseveration, was coded as 1 if the option of interest was the same as the option selected on the last trial and was coded as 0 otherwise. The following three predictors reflected the influence of rewards received one, two, and three trials back. If the option of interest was chosen and rewarded t trials ago, then the predictor was coded as 1. If chosen but not rewarded, then it was coded as -1, and if it was not selected, then 0.

The next three predictors captured the influence of distant experiences from the prior day. The first of these predictors (choice on probed trial) was coded as 1 if the option of interest was the same as the option chosen on the probed trial, 0 otherwise. The second predictor (reward on probed trial) was coded as 1 if the option of interest was chosen and rewarded, -1 if it was chosen and not rewarded, and 0 if it was not chosen. The third predictor (reward across probed context) was calculated as the number of trials in the context in which the option was chosen and rewarded minus the number of times it was chosen and not rewarded, divided by the total number of times the option was chosen. If the option was never chosen in the context, the value was set to 0. If a trial did not immediately follow a recognition memory trial with a probe image, or if the probe was judged as "new", memory predictors were coded as 0. In total, the model included eight predictors, seven interaction terms, and an intercept.

The regression was conducted in R using the lme4 package (Bates et al, 2015). It included participant-level random intercepts and random slopes for the effects of reward one, two, and three trials back, as well as for the effects of choice on the probed trial, reward on the probed trial, and reward history across the probed context. To minimize Type I error, we initially specified the maximal model (Barr et al. 2013). If the model failed to converge, we iteratively simplified the model by removing random slopes until convergence was achieved.

Additional Tasks

To examine cognitive processes related to memory-guided decision making, we had participants complete two additional tasks: the mnemonic similarity task (Kirwan & Stark, 2007) and the two step task (Daw, Niv, & Dayan, 2005; Decker, Otto, Daw, & Hartley, 2016). The mnemonic similarity task indexes memory precision by requiring participants to distinguish previously seen objects from perceptually similar lures. More precise memories are more informative for value estimation and therefore are more likely to guide decisions. The two step task measures the extent to which individuals engage in forward planning, a process linked to episodic memory. Further details on the additional tasks' designs and analytic approaches can be found in the supplemental materials.

Data and code availability

All data and code are available at `https://github.com/noraharhen/HarhenBornsteinHartley2025_ContextBandits`.

Results

Decision making is guided by individual episodic memories from childhood but is increasingly informed by episodic context across development

Following Bornstein & Norman (2017), we examined how choices in the test phase were shaped by both recent experience and more distant experiences retrieved from episodic memory. As predicted by model-free reinforcement learning, recently rewarded options were more likely to be selected, with this effect decaying over time (Figure 2A; $b_{reward-1}$=0.71, SE=0.047, p <.001; $b_{reward-2}$=0.26, SE=0.026, p <.001; $b_{reward-3}$=0.18, SE= 0.024, p <.001). Participants also tended to repeat their last choice regardless of its outcome ($b_{last\,choice}$=0.99, SE=0.015, p <.001). Diverging from the predictions of model-free reinforcement learning, trials from the day prior influenced choices when these trials were evoked by a memory probe (the ship "cargo"). Participants were more likely to choose the option selected on the probed trial (Figure 2B; $b_{choice\,probed\,trial}$=0.079, SE= 0.038, p =.036), though the outcome of that trial had a non-significant effect ($b_{reward\,probed\,trial}$=0.046, SE=0.026, p =.083). They also preferred options that were frequently rewarded across the probed context ($b_{probed\,context}$ = 0.17, SE=0.059, p =.0031), an effect comparable in magnitude to a reward three trials earlier, despite the day-long delay. Strikingly, our results closely mirror Bornstein & Norman (2017)'s, even though our test phase occurred a full day after encoding rather than immediately afterward. Our findings are consistent with the proposed memory-sampling mechanism. A probe evokes a specific trial, the content of which biases choices, and in turn cues the retrieval of other trials from the same context ("island"), which collectively shape the decision. This mechanism requires that the participant recognize the probe and retrieve its associated context. Although memory performance was low overall (probe recognition - d' mean = 0.83, SD = 0.76; source - mean proportion correct = 0.18, SD = 0.07), probe recognition and source memory were both significantly above chance (probe recognition - one sample t-test against 0 - $t(105)$=11.25, p <.001; source - one sample t-test against 0.17 - $t(105)$=2.57, p =.012) and sufficiently strong to produce systematic effects on choice.

We extended Bornstein & Norman (2017)'s findings by examining how the influence of past experience varies with age. The effect of the most recent choice and its outcome, was stronger in older participants ($b_{last\,choice\,X\,age}$=0.28, SE=0.015, p <.001; $b_{reward-1\,X\,age}$=0.10, SE=0.047, p =.035), consistent with prior work showing that reward sensitivity increases from childhood into adolescence (Crone & Dahl, 2012; Urošević et al, 2012; Luna et al, 2015). However, rewards from two and three trials back showed no significant age-related differences ($b_{reward-2\,X\,age}$=0.0042,

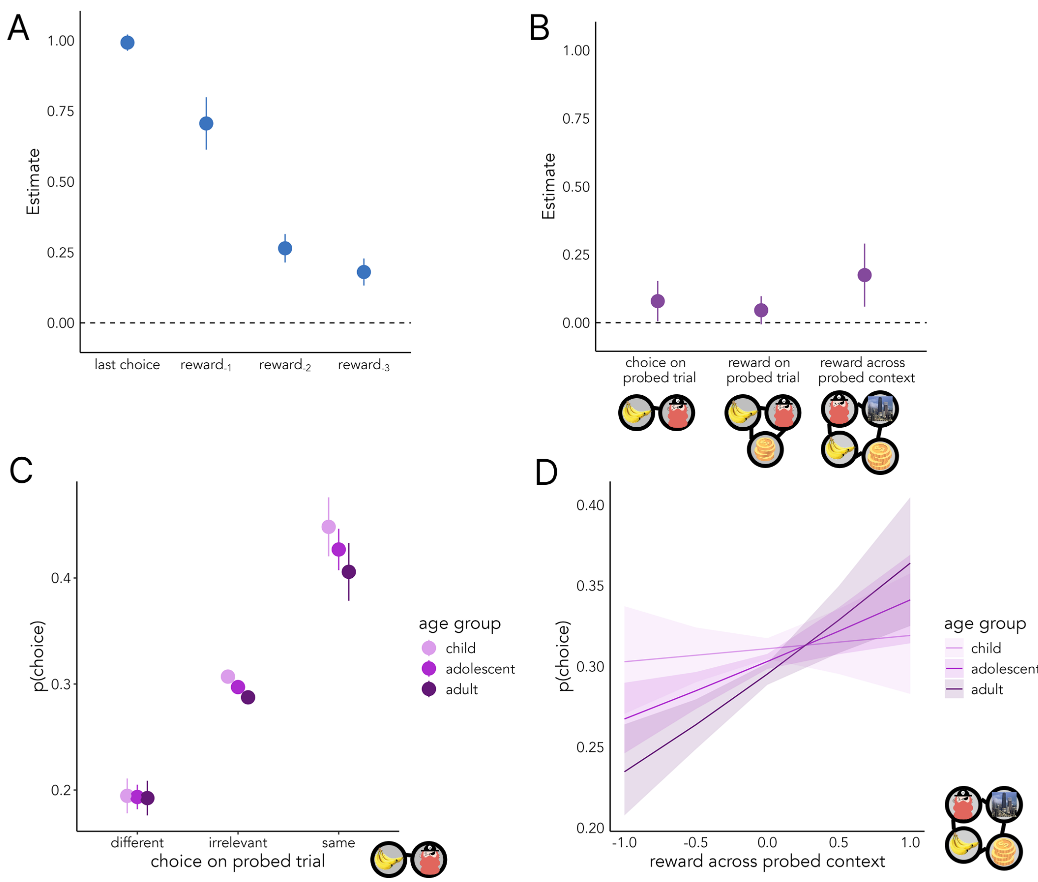

Figure 2: **Episodic memory guides choice in middle childhood and continues to strengthen into young adulthood. A-B.** Episodic memory guides choice in middle childhood and continues to strengthen into young adulthood. A-B. Estimates of β weights from a mixed-effects logistic regression are shown with medians and 95% confidence intervals. **A. Recent experience shapes choice.** Participants tended to repeat their selection on the last trial, regardless of its outcome ("last choice"), and to choose options rewarded up to three trials earlier (reward-1, reward-2, reward-3). **B. Episodic memories of distant experience shapes choice.** On trials directly following a memory probe (the ship's "cargo"), participants favored the option chosen on the trial evoked by the probe ("choice on probe trial"), while the evoked choice's evoked outcome did not affect their choice ("reward on the probed trial"). Participants also favored options that were frequently rewarded across the context ("island") associated with the evoked trial. **C. The influence of a single evoked trial is stable from middle childhood to young adulthood.** Markers show the estimated probability of choosing an option when it was selected on the evoked trial ("same"), was not selected ("different"), and when no trial was recently evoked ("irrelevant"). Error bars denote 95% confidence intervals. Age is plotted discretely (child being ages 8 to 13 years old, adolescent 13 to 18, and adult 18 to 25) but was included as a continuous variable in the statistical model. **D. The influence of an evoked context strengthens with age.** Lines show the estimated probability of choosing an option as a function of the average rate it was rewarded in the context ("island") evoked by the probe. Shading denotes 95% confidence intervals.

SE=0.026, p =.87; $b_{reward-3\,X\,age}$=0.018, SE=0.024, p =.47). For distant experiences retrieved from episodic memory, single-episode and multi-episode effects followed distinct developmental trajectories. The influence of the probed trial, including its choice and outcome, did not vary with age (Figure 2C; $b_{choice\,probed\,trial\,X\,age}$=-0.040, SE=0.038, p =.29; $b_{reward\,probed\,trial\,X\,age}$=-0.0089, SE=0.026, p =.74). Even the youngest participants' choices were biased by the memory probe. In contrast, the influence of the probed context did increase with age (Figure 2D; $b_{probed\,context\,X\,age}$=0.14, SE=0.059, p =.02). Adults' choices were more strongly guided by context-specific reward histories, despite children and adolescents showing comparable probe recognition and source memory (Figure S1; probe recognition - $\rho(104)$ =0.079 , p =.42; source - $\rho(104)$ =0.14, p =.15) Together, our findings suggest that from middle childhood onward, decision makers can draw on individual episodes to guide choice, but only in adolescence and young adulthood do they integrate across multiple related episodes, linked by a shared context, to further inform decisions.

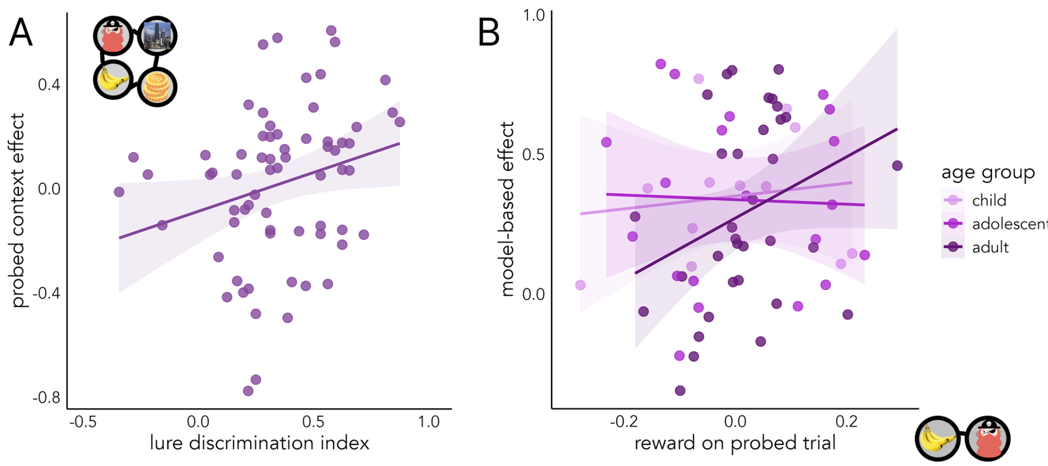

Figure 3: **Memory precision and forward planning track the influence of episodic memory on decision making.** Markers indicate individual participants and shaded bands show 95% confidence intervals. **A.** Across participants, greater memory precision (higher lure discrimination index) predicted a stronger influence of the evoked context's reward history on choice. This was the case even when taking age into account. **B.** A greater influence of the reward received on the probed trial was associated with greater forward planning (model-based effect), most strongly in adults.

Memory precision mediates the relationship between age and context-guided episodic sampling

To identify cognitive processes related to memory-guided decision making, we extracted participants' random slopes for the "distant experience" predictors ("choice on probed trial" and "average reward in probed context") to quantify individual differences in memory use. We then related these slopes to individual measures of memory precision (lure discrimination index) and forward planning (model-based effect). We hypothesized that (1) greater memory precision would predict a stronger influence of memory on choice, and (2) a stronger influence of memory on choice would predict a greater reliance on forward planning.

As predicted, greater memory precision was associated with a stronger influence of the probed context on choice (Figure 3A; b=0.30, SE=0.14, p =.039). Memory precision, however, did not significantly predict the influence of the probed trial's choice or outcome (probed choice - b=-0.23, SE=0.14, p =.096; probed reward - b=0.046 , SE=0.060, p =.45; for further information, see Tables S1-3). Next, we asked whether memory precision accounted for the age-related increase in sensitivity to the probed context. First, we confirmed that memory precision itself increased with age (b=0.064, SE=0.030, p =.037), and predicted the strength of the probed context effect even when taking into account age (b_{LDI}=0.29, SE=0.15, p=.051; b_{age}=0.004, SE=0.037, p =.92). A mediation analysis revealed that memory precision fully mediated the relationship between age and sensitivity to the probed context (b=0.019, SE=0.00029, p =.048). Improvements in memory precision may underpin the maturation of episodic sampling processes.

Use of individual episodic memories is positively associated with forward planning in adults

Consistent with our second hypothesis, the influence of probed reward—but not probed choice or context (see Tables S4-6)–predicted greater forward planning. This effect was significantly stronger in older participants (Figure 3B;$b_{reward\, probed\, trial\, X\, age}$=0.81, SE=0.38, p =.038; $b_{reward\, probed\, trial}$=0.59, SE=0.31, p =.066; b_{age}=0.048, SE=0.037, p =.20). The retrieval of specific past rewards may support the ability to plan prospectively, but only in adults.

Discussion

Adults' decisions are shaped not only by recent outcomes but also by memories of past experiences. Here, we asked whether the same holds for children and adolescents. Participants ages 8 to 25 completed a two-day, three-option choice task that dissociated two ways episodic memory can guide choice: the influence of a single retrieved episode (i.e., a trial) and the influence of multiple episodes linked by a shared context. Trials on the first day of the study were tagged with unique mnemonic content. On the second day, the mnemonic context served as an incidental reminder of trials from the first day. Across our age range, choices were biased toward the option selected on the evoked trial, demonstrating that episodic memory contributes to choice from an early age. Only older participants, however, were also biased by the broader episodic context. They favored the option most often rewarded across the context evoked by the reminder. Our results reveal that episodic memory supports decision making in at least two distinct ways, each with their own developmental trajectory.

Our findings raise a key question: Why are children's choices not influenced by the broader evoked context? Sensitivity to the episodic context hinges on successful encoding and retrieval. At encoding, the decision maker must bind together the episode's details—the chosen action (the crew member), its outcome (gold or no gold), the probe image (the ship's cargo), and the context (island). At retrieval, the probe must cue not only the specific episode but also other episodes that share the same context. Age-related limitations could occur at either or both stages. At encoding, children may form weaker links between episodes occurring within the same context. This would align with evidence that autobiographical memories become increasingly situated and organized by time, place and other contextual features during middle childhood and adolescence (Piolino et al., 2007; Picard et al., 2009; Willoughby, Desrocher, Levine, & Rovet, 2012; Coughlin, Lyons, & Ghetti, 2014). In-lab studies likewise find age-related improvements in item-context binding throughout early childhood (Ngo et al., 2018; Ngo, Lin, et al., 2019; Benear, Ngo, Olson, & Newcombe, 2021; Riggins, 2014; Yim, Dennis, & Sloutsky, 2013) and into adolescence (Ghetti & Angelini, 2008; Ghetti, Mirandola, Angelini, Cornoldi, & Ciaramelli, 2011). These behavioral changes are paralleled by changes in the neural regions supporting relational binding and rapid statistical learning (Demaster & Ghetti, 2013; Ghetti et al., 2010; Ofen et al., 2007). Beyond encoding, developmental differences may also arise at retrieval. Children may simply retrieve fewer episodes overall due to more limited computational resources (Persaud, Bass, Colantonio, Macias, & Bonawitz, 2020; Ruel, Devine, & Eppinger, 2021; Binz & Schulz, 2022; Bruckner, Nassar, Li, & Eppinger, 2025). Each retrieval carries a computational cost—particularly if the episode must then be maintained in working memory—episodic sampling is only as computationally cheap as model-free reinforcement learning when a single episode is drawn. Clarifying whether the developmental bottleneck lies in encoding, retrieval, or both will be crucial for understanding how episodic memory and reinforcement learning interact across development.

Future studies could adopt multiple approaches to disentangle whether children's insensitivity to episodic context reflects limits on encoding, retrieval or both. Source memory offers a natural index of encoding contextual features, however, we found no age-related differences in it. This raises the possibility that the memory probes shaped behavior implicitly, in ways not captured by explicit mnemonic judgments. Neuroimaging could provide a more sensitive test. By decoding the neural evidence for each context's associated image at decision time, as done in Bornstein & Norman (2017), one could ask whether children reinstate the correct context and whether such reinstatement predicts their choices. A failure of children to do so would suggest a bottleneck on retrieval. Scaffolding retrieval could provide a complementary behavioral test. For instance, one could present the context-specific background image alongside the probe during recognition trials. This might facilitate reinstatement and encourage the use of the broader context's reward history to inform decision making. If this manipulation led children to show an adult-like sensitivity to episodic context, it would suggest that their difficulty lies not in binding episodes to contexts at encoding, but in retrieving and using that contextual information to guide their memory sampling process.

Theoretical accounts propose that memory precision should shape the extent to which episodic memory guides decision making (Wang et al., 2021) and that episodic memory may underlie forward planning (Schacter et al., 2007; Gershman & Daw, 2017; Zhou, Talmi, Daw, & Mattar, 2025). Consistent with the first account, individuals with more precise memories showed a stronger influence of episodic context on choice. Moreover, memory precision fully mediated the relationship between age and the use of context, suggesting that known developmental gains in memory fidelity (Canada et al., 2019; Ghetti et al., 2010; Lambert et al., 2015; Ribordy Lambert et al., 2017; Ngo et al., 2018; Ngo, Lin, et al., 2019; Peng et al., 2023; Rollins & Cloude, 2018; Vijayarajah & Schlichting, 2025) may underpin the maturation of memory-guided decision making. Our findings parallel work in older adults showing that memory precision, rather than chronological age, predicts the context specificity of episodic sampling (Noh, Singla, Bennett, & Bornstein, 2023). Consistent with a role for episodic memory in planning, we found that sensitivity to the reward on the probed trial predicted greater reliance on forward planning, but primarily in adults. In adulthood, recalling specific experiences of reward may scaffold planning by capturing long-range dependencies between actions and outcomes (Gershman & Daw, 2017). But in childhood and adolescence, when memory is less precise and less richly organized by context, episodic content may provide less support for planning. Together, these findings highlight that changes or differences in the memory have downstream consequences for reinforcement learning computations.

In adults, reinforcement learning and episodic memory systems are known to reciprocally interact. Reward and motivational states enhance memory and consolidation (Shohamy & Adcock, 2010; Murty, DuBrow, & Davachi, 2015; Murty & Dickerson, 2016; Murty, DuBrow, & Davachi, 2019; Ruiz, DuBrow, & Murty, 2023; Sinclair, Wang, & Adcock, 2023; Qasim, Deswal, Saez, & Gu, 2024), while episodic memory is recruited to support value-based decisions (Bakkour et al., 2019; Bornstein et al., 2017; Bornstein & Norman, 2017; Wimmer & Shohamy, 2012; Botvinik-Nezer et al., 2021; Duncan & Shohamy, 2016; Murty, FeldmanHall, Hunter, Phelps, & Davachi, 2016). Recent research has extended these findings developmentally, showing that the links between episodic memory, reward, and choice are refined and strengthened with age (Hartley, Nussenbaum, & Cohen, 2021). Many of these studies have focused on how reward, motivation, and choice shape memory (Nussenbaum & Hartley, 2025; Katzman & Hartley, 2020; Cohen et al., 2022; Davidow, Foerde, Galván, & Shohamy, 2016; Ngo, Newcombe, & Olson, 2019; Ding et al., 2024; Fandakova & Gruber, 2021). Our findings complement this work by demonstrating that the reverse relationship is also present. Memory shapes decision making from middle childhood, enabling fast, flexible decisions even under uncertainty. Crucially, the form of this contribution shifts with age, as memory becomes increasingly precise and more richly structured by context. A central implication of our findings is that developmental improvements in memory scaffold the development of decision making. This raises the question: to what extent are age-related shifts in model-free reinforcement learning (Master et al., 2020; van den Bos, Cohen, Kahnt, & Crone, 2012; Palminteri, Kilford, Coricelli, & Blakemore, 2016; Eppinger, Mock, & Kray, 2009; Christakou et al., 2013; Hauser, Iannaccone, Walitza, Brandeis, & Brem, 2015; Javadi, Schmidt, & Smolka, 2014; Eckstein, Master, Dahl, Wilbrecht, & Collins, 2022) rooted in the development of memory? Recognizing memory as a driver of developmental change in decision making opens up new directions for understanding how these cognitive processes jointly develop.

Acknowledgments

We thank the Hartley and Bornstein Labs for their feedback on the task design and analysis, and Susan Benear, Rheza Budiono, Alana Jaskir, Kate Nussenbaum, and Wangjing Yu for their feedback on the manuscript. This work was supported by the National Institute of Mental Health (R01 MH126183 to C.A.H. and F31 MH134620 to N.C.H.), the Department of Defense (National Defense Science and Engineering Graduate Fellowship to N.C.H.), the Brain and Behavior Foundation (Young Investigator's Award to A.M.B.), and the NYU Vulnerable Brain Project (to C.A.H.).

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