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Memory for social interactions throughout early childhood

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ABSTRACT

Previous research shows that forming memories of not only whom we have previously encountered but also the feedback of those encounters supports adaptive behavior. However, there are dynamic changes throughout childhood in declarative memory systems, leaving open the question about the precise timing for the emergence and maturation of memory for social interactions. In this study, we characterized memory for dynamic social interactions during a computerized task in children ranging between 4 and 6 years of age. Specifically, we probed memory for the characters children interacted with, the decisions they made, and the valanced-feedback from those interactions. We found that while there were differences in discriminating between old and new characters, there were no age-related differences in the ability to remember which decision a child made or the feedback from that decision when a character was successfully identified. These findings support a model by which basic foundations of social memory develop early in childhood; however, the number of social memories and the incorporation of feedback into these memories may be limited in early childhood.

1. Introduction

To successfully navigate social environments necessitates the ability to encode memories of prior social interactions and retrieve those memories to guide concurrent behavior (Murty, Feldman Hall, Hunter, Phelps, & Davachi, 2016; Schaper, Mieth, & Bell, 2019). Critically, this type of adaptive behavior requires not only remembering who we have previously encountered, but the decisions we made and the feedback from those decisions. For example, it would be adaptive to remember which actions during encounters lead to positive social feedback (i.e., a smile) versus those that resulted in negative social feedback (i.e., a frown). While a growing body of research has detailed these social learning processes in adults, less is known about the developmental emergence of these behaviors throughout early childhood. In the current study, we characterized memory for feedback from dynamic social exchanges across 4- to 6-year-olds.

Sensitivity to social feedback and pro-social behavior is apparent as early as infancy (Simion, Di Giorgio, Leo, & Bardi, 2011; Warneken & Tomasello, 2009), such that 3-month-old infants can discriminate between individuals that were kind versus those that caused harm (Hamlin & Wynn, 2011). However, the ability to successfully execute complex social behaviors, such as resisting taking selfish actions to cooperate, continues to mature throughout childhood (Carpendale & Hammond, 2016; Malti & Dys, 2018). While most studies have investigated processes such as social perception and imitation to understand these developmental trajectories, protracted maturation may also result from enhancements in the ability to encode and retrieve memories of social interactions.

Critically, memory for social interactions is complex and involves multi-faceted, associative representations. To form a fully functional representation of a social interaction, at minimum individuals must remember the identity of individuals they have previously encountered, the actions they took during a social exchange, and the feedback from those interactions. A growing literature in adults has begun to characterize memory for social interactions. Adults both show implicit and explicit memory for feedback from social interactions (Amodio, 2019; Chang & Sanfey, 2009; Murty et al., 2016; Schaper et al., 2019). For example, a recent study showed that participants had intact memories of individuals they encountered during social exchanges and the consequences of the actions in which that individual took (Murty et al., 2016). This study further showed that participants only made adaptive choices about re-approaching fair individuals when they had intact episodic memories for these prior social exchanges. However, relatively little research has probed memories for social encounters in young children, thus leaving open questions about the precursors of social decision-making in this population.

Characterizing differences in discrete memory processes has been a focus within the early childhood literature. Research in this field has

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shown that different components of memory develop at different rates between the ages of 4 and 6. During recognition memory, studies show equivalent performance across 4 to 6 years of age (Bauer, San Souci, & Souci, 2010; Lloyd, Doydum, & Newcombe, 2009; Ngo, Newcombe, & Olson, 2018; Sluzenski, Newcombe, & Kovacs, 2006; Yim, Dennis, & Sloutsky, 2013) or show equivalent performance in identifying old memoranda but deficits in discriminating them from novel foil images (Canada, Geng, & Riggins, 2019; Geng, Canada, & Riggins, 2018; Riggins, 2014; Riggins & Rollins, 2015). A different pattern emerges when characterizing more associative or relational forms of memory, in which children have to bind information between two discrete items or an item and its context. These types of studies show marked improvements in associative memory between the ages of 4 and 6 (Geng et al., 2018; Geng, Redcay, & Riggins, 2019; Koski, Olson, & Newcombe, 2013; Lloyd et al., 2009; Ngo et al., 2018, 2019; Riggins, 2014; Riggins, Blankenship, Mulligan, Rice, & Redcay, 2015; Sluzenski et al., 2006). For example, a recent study showed that 4-year-olds were significantly worse than 6-year-olds and adults at selecting a target image that was associated with a spatial context, whereas 6-year-olds and adults did not show any differences in this type of relational memory (Ngo, Lin, Newcombe, & Olson, 2019). Broadly speaking these findings suggest that there is an imbalance in the developmental trajectories of more item-based forms of memory which are intact during early childhood and more relational forms of memory which become more refined throughout early childhood.

Within this framework, intact memory for social encounters—which require a binding between individuals, their actions, and emotional responses—may not develop until late childhood. Specifically, intact memory for social interactions would require associative memory both for the encountered individual and the decision the child made as well as the feedback from that interaction. Alternatively, research in children and adults suggests that emotional events are prioritized in long-term memory (Christodoulou & Burke, 2016; LaBar & Cabeza, 2006; Van Bergen, Wall, & Salmon, 2015; Yonelinas & Ritchey, 2015). Further, studies in adults show that there can be better associative memory amongst the most salient features of emotional events (Mather, Clewett, Sakaki, & Harley, 2016; Murty & Adcock, 2017; Rimmele, Davachi, & Phelps, 2012). Given that social interactions are often salient, associative memory for these interactions may show an earlier developmental trajectory compared to associative memory between less salient associations. Critically, prior research has focused on associative memories for item-item or item-context associations which do not manipulate salience. However, during a social encounter, an individual might find the decisions they made or the feedback from those decisions especially salient, thus facilitating associative memory for certain components of social experiences.

In this study, we characterized memory for dynamic social interactions in 4-, 5-, and 6-year-olds. Participants completed the "Incredible Cake Kids" task in which participants viewed trial-unique character customers while they played the role of a Baker at a cake shop (Fig. 1). A character would enter the bakery, and participants would select a cake they thought the character would enjoy. Participants then viewed the character and the selected cake together, which was followed by viewing the emotional response of the character to the cake. These responses were either positive (i.e., they liked the selected cake) or negative (i.e., they did not like the selected cake). Between 5 and 1.5 min after selecting cakes for 20 characters, participants were tested on their memory for the characters they encountered, the decisions they made, and their feedback from the character. In this way, we could probe recognition memory for the multi-dimensional aspects of social interaction (i.e., characters, decisions, and feedback) in a task that was appropriate for young children.

2. Materials and methods

2.1. Participants

Participants for this study were recruited from the local Pittsburgh community through print and online advertisements (including the CTSI Research Registry). Participants were healthy children ranging in age from 3 to 12 years, with no history of any psychiatric disorders, no history of head trauma or loss of consciousness, and the ability to speak and understand English at a conversational level. Children's parents or legal guardians provided informed consent before participating in this study following procedures approved by the Institutional Review Board at the University of Pittsburgh. Data presented in this manuscript included individuals that ranged in age from 4- to 6-years-old (See Table 1), and only included participants who completed our memory task (described below). The entire sample included 110 typically-developing children (55 females; 26 4-year-olds, 60 5-year-olds, 24 6-year-olds). For our primary analyses, we removed participants that showed chance levels of performance on item memory (detailed below), given that it was unclear if participants were following task instructions. After exclusion, this sample included 103 typically-developing children (51 females, 21 4-year-olds, 59 5-year-olds, 23 6-year-olds). A post-hoc power analysis based on a previous study investigating changes in associative memory across early childhood revealed that a sample of n = 46 is sufficient to detect a significant effect at a power = 0.8 (Geng et al., 2019). Thus, our sample is sufficiently powered for our planned analyses. Notably, analyses including all the participants are included in supplemental materials.

2.2. Task/procedure

All participants completed a modification of the Incredible Cake Kids Task (Fig. 1) (Grabell et al., n.d.). This modification consisted of a separate encoding and retrieval phase. During the encoding phase, participants were instructed to play the role of a Baker in a cake shop. The participant was informed that each day different characters would enter the shop and that they would have to select which of 3 cakes to present to the character. Character stimuli were trial-unique cartoon figures that were generated within the Toca Boca application (https:tocaboca.com/apps). On each trial, participants first viewed a trial-unique character that entered the cake shop. They were then presented with three trial-unique cake options. On each trial, participants were first instructed to select one cake in a self-paced manner. After making their decision, participants viewed the character and the selected cake paired together for 2 s, followed by visual feedback of the character's response to the cake. The trial ended with an animation showing the cake shop closing and re-opening the next morning which would initiate the next trial. Participants performed 20 trials, 10 with positive social feedback and 10 with negative social feedback indicated by a facial expression paired with an affective auditory response (e.g. "yuck"). Feedback was counterbalanced across participants. Following the encoding task, participants had a short break before initiating the next phase which ranged between 26 and 97 s (mean = 40.8 s). The next phase was the retrieval phase wherein participants were shown 30 characters: 20 characters originally presented during the encoding phase (10 positive feedback, 10 negative feedback) and 10 new foils they had never seen before. Including foils allowed for the separate calculation of hit, miss, correct reject, and false alarm rates. First, participants were asked whether they had seen the character before in a self-paced fashion. If the participant said yes, they were then asked which cake they chose for that character and then, in a separate question, indicated whether or not the character liked the cake. This sequence of events would also occur if a participant indicated that they had previously seen one of the foil characters, and random novel cakes were shown in this instance. During the cake selection phase, participants were shown the same three cakes that were shown during

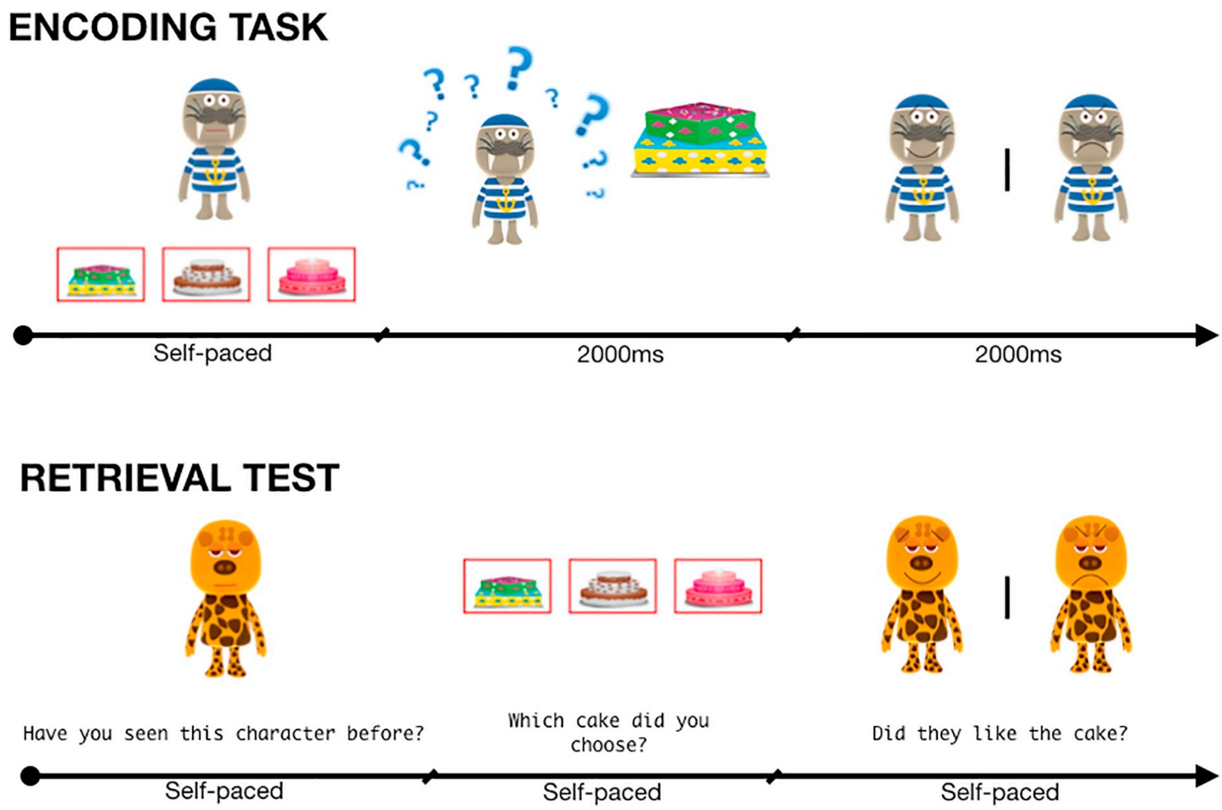

Fig. 1. *The Incredible Cake Kids Task.* All participants completed a modification of the "Incredible Cake Kids Task" which consisted of an encoding task and retrieval task. During the encoding task (top), participants viewed 20 trial-unique characters of which they had to select one of three cakes to give to them. Following their selection, the child viewed the character and cake for 2 s and then viewed affective feedback from the character which was positive or negative. After a short delay (0.5–1.5 min), participants completed the retrieval test in which they viewed 20 old and 10 new characters and were asked if they had seen the characters before (i.e., Item Memory), and if so they were also asked which cake they chose (i.e., Decision Memory) and whether the character liked the cake (i.e., Feedback Memory).

Table 1
Demographic Information.

		Full sample (N = 113)	Analysis sample (N = 99)
Sex	Female	55	49
	Male	58	50
Ethnicity	Not Latino or Hispanic	109	96
	Latino or Hispanic	4	3
Household income	Less than $20,000	17	14
	$20,000–$39,999	13	13
	$40,000–$59,999	13	10
	$60,000–$79,999	10	9
	$80,000–$99,999	18	17
	$100,000–$119,000	12	11
	$120,000–$250,000	26	21
	More than $250,000	4	4
Race	Black/African American	22	18
	White/Caucasian	81	74
	Biracial/Multiracial	7	5
	Asian/Asian American	3	2

encoding.

2.3. Statistical analysis

First, we performed analyses on a sample in which we excluded individuals with d' values (calculated using signal detection theory) equal to or less than zero, to make sure results weren't skewed by individuals who may not have completed the task correctly. This exclusion resulted in removing 19% of 4-year-olds (n = 5), 2% of 5-year-olds (n = 1), and 4% of 6-year-olds (n = 1). Given the differences in the proportion of children removed from each age group, we also report results from analyses using the entire sample of participants in the supplemental material.

We analyzed three assays of memory: item (character), decision (cake), and feedback (pos/neg). First, we analyzed item memory—whether participants recognized characters from the encoding phase—by calculating d-prime (d') and beta (ß) scores. In a signal detection theory framework, d-prime represents the sensitivity of correctly detecting old stimuli, whereas ß represents the criterion by which an individual has determined they have enough evidence to endorse an item as old. In separate models, d' and ß scores were submitted to a general linear model with age in months, encoding duration (i.e., mean RT during cake selection), and retention interval (i.e., time between the end of encoding and the beginning of retrieval) as regressors of interest.

Second, we analyzed decision memory—memory for which cake was selected—by quantifying d' scores in selecting the cake they previously selected for the character. For this analysis, decision memory was only analyzed for trials in which participants successfully identified the character identity. Decision memory d' scores were submitted to a general linear model with regressors of interest for age, item memory d', an interaction between age and item memory d', encoding duration, and retention interval.

Third, we analyzed feedback memory—memory for a character's emotional response—by quantifying d' scores in selecting if a character had a positive or negative response to the cake they selected. For this analysis, feedback memory was only analyzed for trials in which the participants successfully identified the character identity. Feedback memory d' was submitted to a general linear model with regressors of interest age, item memory d', an interaction between age and item memory d', encoding duration, and retention interval.

Finally, we analyzed whether feedback valence influenced item and/or decision memory. For each participant, we characterized item memory and cake memory for characters that administered positive and negative valence, separately. Using these values, we characterized valence memory scores by comparing d' item memory and d' selection memory in the positive versus negative feedback trials, separately. Valence memory scores were first submitted to a one-sample *t*-test to determine if there was a main effect of valence (i.e., better memory for positive versus negative feedback events). Then valence memory scores were submitted to a general linear model (GLM) with age in months as a regressor of interest. We were unable to analyze the influence of valence on feedback memory, as we did not have a neutral condition for comparison.

All of the above statistical analyses were run in RStudio Version 1.1.463. T-tests were run using the function 't.test'. For item memory, d' was calculated using 'dprime' and d' for decision and feedback memory was calculated using dprime.mAFC from the psycho and psyphy packages. Before entering data into the 'dprime' functions, edge effects for hit rates and false alarm rates of zero or 1 were corrected using 1/(2n) or (1–1/(2n)), where n is the number of trials. GLMs were run using the 'lm' function. Notably, to characterize the significance of individual regressors for our GLMs from the 'lm' function we report on t-values and their statistical significance. Analyses were considered significant if they reached a statistical threshold of $p < 0.05$ and trending if they reached a statistical threshold of $p < 0.10$. To confirm the strength of null findings, non-significant findings were submitted to a Bayes Factor analysis to determine the relative strength of the null finding using the 'regressionBF' function from the BayesFactor package as implemented in R.

3. Results

3.1. Item memory

Before testing for age-related differences in memory, we first wanted to determine if the duration of the encoding session or the interval between encoding and retrieval varied as a function of age. We did not see any significant relationships between continuous age and encoding duration (i.e., mean RT to select a cake; $t(1,101) = 1.49$, $p = 0.14$) or between age and retention interval (i.e., the time between the end of encoding and the beginning of retrieval; $t(1,101) = -0.36$, $p = 0.72$).

Next, we quantified differences in item memory across 4 to 6 years of age by comparing children's ability to successfully identify characters they previously encountered during the encoding phase. Notably, for each age group d' of item memory was significantly greater than chance (4-year-olds: $t(20) = 6.9$, $p < 0.001$; 5-year-olds: $t(58) = 16.6$, $p < 0.001$; 6-year-olds: $t(22) = 12.0$, $p < 0.001$; Fig. 2, Table 2). A linear model predicting d' of item memory by age showed significant increases in d' as age increased ($t(3,99) = 1.96$, $p < 0.05$, Fig. 2). A linear model predicting ß by age was not significant ($t(3,99) = 0.92$, $p = 0.36$, BF = 0.34). Further, there were no significant effects of encoding duration ($p = 0.09$) or retention interval ($p = .24$) on item memory. The same pattern of results reported above was shown in the sample including all individuals (see supplemental materials).

3.2. Memory for selected cakes

We next quantified differences in decision memory (i.e., memory for which cake children selected) across 4 to 6 years of age. For each age group, d' of decision memory was significantly greater than chance (4-year-olds: $t(20) = 5.6$, $p < 0.001$; 5-year-olds: $t(58) = 12.6$, $p < 0.001$; 6-year-olds: $t(22) = 6.4$, $p < 0.001$, Fig. 3a). For decision memory, d' was not predicted by age ($t(5,97) = 1.5, p = 0.14$, BF = 0.45), item memory ($t(5,97) = 1.36, p = 0.18$, BF = 0.44), or their interaction ($t(5,97) = -1.25, p = 0.22$, BF = 0.21). However, there was a significant positive relationship of d' of decision memory with encoding duration ($t(5,97) = 2.28, p < 0.05$, Fig. 3b), and a significant negative relationship with retention interval ($t(5,97) = -2.32, p < 0.05$, Fig. 3c). The same pattern of results was seen in our analyses including the entire sample (see supplemental materials). These findings should be interpreted with caution as the current task does not allow us to definitively disambiguate whether (1) children are using memory to retrieve which cake they selected or (2) they are using a preference for specific cakes to drive their choice during both phases of the task. However, given that memory performance was related to encoding duration and retention interval, our results suggest that this is a memory-related process.

3.3. Feedback memory

Next we quantified differences in feedback memory across 4 to 6 years of age, by comparing children's accuracy in remembering if a character had a positive or negative response to the selected cake. For each age group, d' of feedback memory was significantly greater than chance (4-year-olds: $t(20) = 8.9$, $p < 0.001$; 5-year-olds: $t(58) = 12.8$, $p < 0.001$; 6-year-olds: $t(22) = 7.77$, $p < 0.001$). Age-related increases in d' of feedback memory was trending towards significance ($t(5,97) = 1.67, p = 0.09$, BF = 4.3); while there were no significant relationships between d' and item memory ($t(5,97) = 0.79, p = 0.43$, BF = 0.37), or interactions between item memory and age ($t(5,97) = -0.75, p = 0.45$, BF = 1.4), Fig. 4). Further, there was a trend towards encoding duration positively predicting d' of feedback memory ($p = 0.09$), with no significant effect of retention interval ($p = 0.72$). A similar pattern of results was seen in our analyses including the entire sample; however, there were significant age-related increases in d' of feedback memory (see supplemental material).

3.4. Influence of feedback on item and cake memory

We next characterized whether the valence of feedback during the cake task influenced item memory and cake memory. Regarding item memory, a *t*-test revealed that there was no difference in item memory for characters that resulted in positive versus negative feedback ($t(102) = 1.03$, $p < 0.3$, BF = 0.18). Further, there were no age-related differences in the influence of feedback on item memory ($t(3,99) = 0.75$, $p = 0.45$, BF = 0.38). Regarding decision memory, a t-test revealed that there was a trend towards better decision memory for cakes that resulted in positive versus negative feedback; ($t(102) = 1.73$, $p < 0.08$); however, there were no age-related differences in the influence of feedback on decision memory ($t(1,101) = -0.08$, $p = 0.9$, BF = 0.36). The same pattern of results was found when examining the entire sample; however, the trend between feedback and decision memory became non-significant.

4. Discussion

In the current study, we characterized the development of memory for multiple components of a dynamic social interaction across ages 4 to 6. Using this novel behavioral paradigm, we found that children in each group showed significant memory for characters they previously encountered, the decisions they made upon those encounters, and the social feedback received because of those decisions. Although each age group had significant memories for social encounters, there were different patterns of development across our memory measures. We found that while children's ability to recognize characters they previously encountered increased throughout early childhood, once they successfully identified a character there were no age-related differences in their ability to remember decisions they made and age-related differences in feedback memory were only trending towards significance.

Thus, the ability to form explicit, detailed memories for social interactions develops relatively early in childhood; however, there are

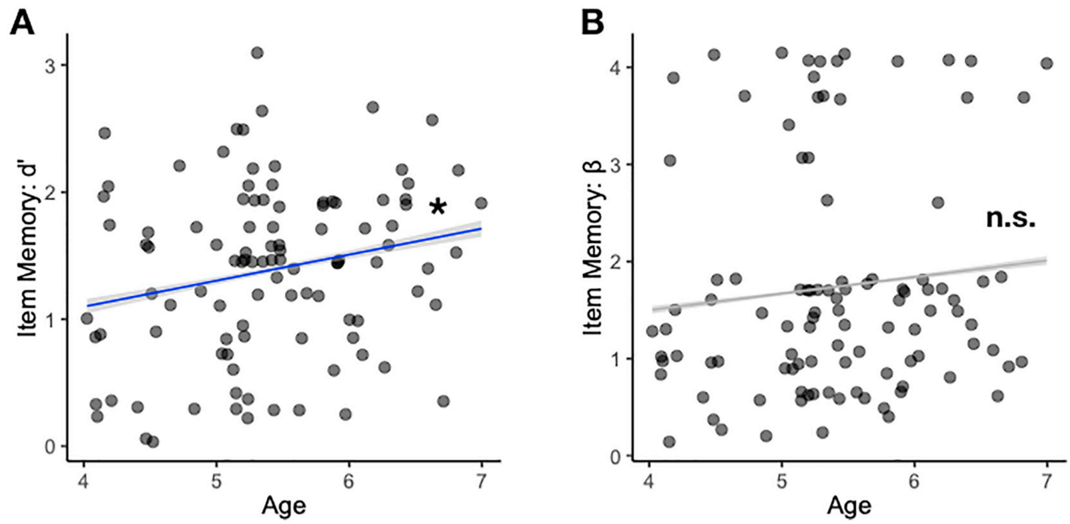

Fig. 2. *Item Memory.* A. There were age-related differences such that d' for item memory increased between 4 and 6 years of age. B. There were no significant differences in ß between 4 and 6 years of age. *p < 00.05, n.s. indicates p > 0.10.

Table 2
Mean hit rate and false alarm rates for characters.*

Age group	Mean hit rate (SE)	Mean false alarm rate (SE)
4-year-olds	0.71 (0.04)	0.28 (0.06)
5-year-olds	0.69 (0.03)	0.19 (0.03)
6-year-olds	0.73 (0.04)	0.16 (0.04)

* SE indicates standard error of the mean.

age-related refinements in aspects of these memories, which we discuss in detail below.

Regarding item memory, our findings showed age-related increases in the ability for children to discriminate between previously encountered and new characters. Prior research has shown that there is a refinement in memory discriminability throughout 4 to 6 years of age (Geng et al., 2018, 2019; Koski et al., 2013; Lloyd et al., 2009; Ngo et al., 2018; Ngo, Lin, et al., 2019; Riggins, 2014; Riggins et al., 2015; Sluzenski et al., 2006). Here, we extend this literature to show that this same pattern of item memory generalizes to identifying individual characters encountered in a social-like interaction. However, previous research has shown that item memory deficits in young children could be sensitive to the nature of the memory test and that memory performance may be worse in young age groups in signal-detection tasks like ours. Therefore, we implemented an analysis approach that quantified d', which should correct for any age-related differences in response thresholds or biases. Our analysis approach also allowed us to directly look at response thresholds as a function of age, and there were no significant age-related differences in our measures of response biases. Thus, our item memory findings demonstrate that while 4-year-olds can significantly encode characters they previously encountered in our task, there are age-related increases in the number of successfully encoded characters across early childhood.

Regarding our associative memory tests, we found that once a character was successfully identified, there were no significant age-related relationships with decision memory. Decision memory in our task referred to children's ability to remember which specific cake they selected for a specific character. Although it was not associated with age, decision memory was positively related to the amount of time it took for a child to select a cake. These findings suggest that across all age groups, children may have better memory for more challenging decisions that require greater evaluation. Interestingly, these findings conflict with much of the prior literature, which shows developmental refinements in associative memory across 4 to 6 years of age (Geng et al., 2018, 2019; Koski et al., 2013; Lloyd et al., 2009; Ngo et al., 2018, 2019; Riggins, 2014; Riggins et al., 2015; Sluzenski et al., 2006), which we discuss below.

Notably, our current paradigm differs from this previous work in two important ways. First, our encoding session had a social element in which children were interacting with characters. These interactions may have been more salient than associative memoranda used in previous paradigms. Prior research in adults has shown that there is better associative learning of salient features of an event in emotionally arousing situations (Mather et al., 2016), in particular, for motivationally-relevant events (Clewett & Murty, 2019). Critically, placing children in the position of selecting a cake could make the decision intrinsically emotional, and thus facilitate associative memory. In line with this interpretation, a prior study showed that using emotional cues to trigger memory resulted in the recall of more associations and greater details when compared to memories triggered by neutral cues during early childhood (Liwag & Stein, 1995). Unfortunately, our current study did not have a baseline neutral condition, which would be necessary to determine if the emotional consequence of the outcome was driving better associative learning for characters and the decisions children made.

Second, our paradigm differs from previous associative memory paradigms because it involves active manipulation of the environment during encoding. In much of the prior work on associative learning, children are learning about arbitrary relationships between items or between items and backgrounds. In our study, however, children were actively making decisions in response to trial-unique characters and thus, believed they were making causal interactions with their environments. Critically, this type of causal learning could have enhanced associative memory in our youngest children. In line with this interpretation, research in adults has shown that making causal decisions enhances declarative memory and engagement of the hippocampus (Murty, DuBrow, & Davachi, 2015, 2018), a neural structure known to support associative learning (Davachi, 2006; Ranganath, 2010). Further, developmental research has shown that children show rich representations of causal relationships by 4 years-of-age (Gopnik, Sobel, Schulz, & Glymour, 2001; Sobel, Tenenbaum, & Gopnik, 2004). Critically, if it is causality that is supporting better associative memory in 4-year-olds, our decision memory findings would likely generalize to non-social contexts that involve action and feedback. Thus, future research needs to independently manipulate the extent to which learning contexts are social and children's ability to actively make decisions, in order to clarify which factors underlie the age-invariant memory

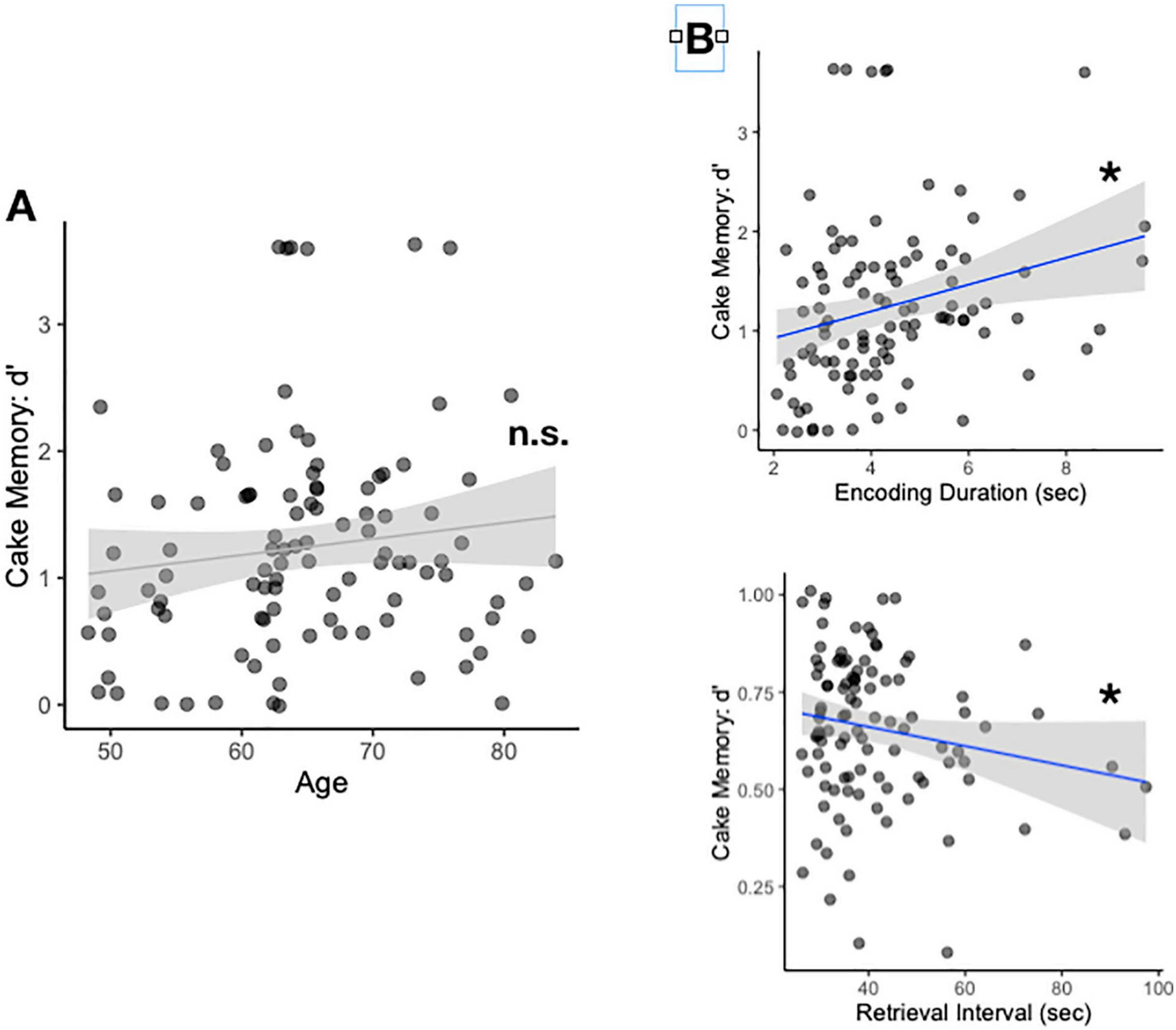

Fig. 3. *Decision Memory.* A) There were no age-related differences in d' for decision memory, such that there was stable memory for which cake was selected. B) There was a significant age-invariant positive relationship between encoding duration and decision memory (Top) and a negative relationship between retention interval and decision memory (Bottom). ***Indicates $p < 0.001$, *$p < 0.05$, n.s. indicates $p > 0.10$.

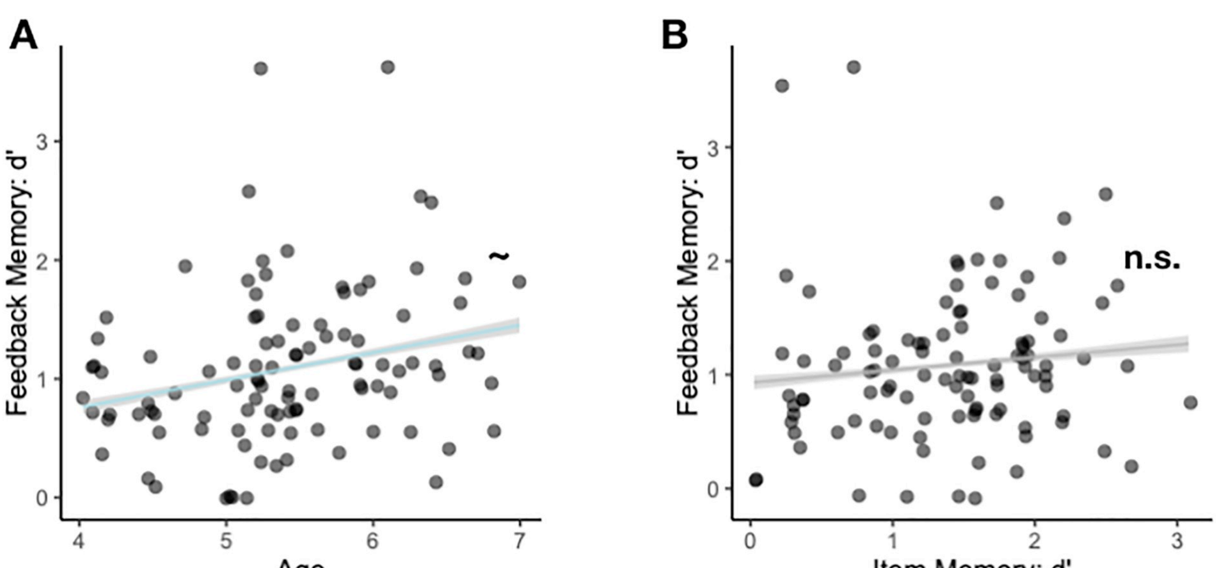

Fig. 4. *Feedback Memory.* There was a trend towards a significant relationship between feedback memory and age between 4 and 6 years of age (Left). Feedback memory was not predicted by individual differences in item memory (i.e., corrected recognition; Right). ~ indicates $p < 0.10$, n.s indicates $p > 0.10$.

trajectories we see in decision-memory.

In addition to decision memory, we also characterized age-related differences in children's ability to remember a character's feedback in response to their selection (i.e., did the character like the cake). Although each age group had significant memory for feedback, we found a trend towards age-related increases in feedback memory such that memory improved across development. Although this was only trending to significance, Bayesian analysis suggested that there was moderate evidence for this effect, suggesting that with a larger sample size or less variance in our population this effect would be significant. Thus, our preliminary evidence suggests that there are age-related improvements in feedback memory. One potential reason our age-related effects on feedback memory may be more tenuous than our other memory measures is that there may be more individual differences in other cognitive processes that contribute to successful feedback memory. A growing body of research in the adult literature has begun to characterize factors that determine whether an individual is able to remember feedback and have shown that factors like perceived agency, environmental uncertainty, and surprise magnitude can all influence these memory processes (Jang, Nassar, Dillon, & Frank, 2019; Rouhani, Norman, & Niv, 2018; Stanek, Dickerson, Chiew, Clement, & Adcock, 2019). Although our current data cannot strongly support age-related increases in feedback memory across childhood, we believe it sets the foundation to explore how different processes that influence feedback sensitivity and memory develop across early childhood.

While the current study only probed memory for social encounters, prior research suggests that these findings could have broad implications for the development of children's social behaviors. Recently, two studies in adults showed that the ability to make adaptive choices in a social environment relied on intact associative memories of prior social encounters (Murty et al., 2016; Schaper et al., 2019). These data in adults highlight the importance of associative forms of memory in guiding adaptive behavior in social environments. Here, we show that rich associative representations of interactions with individuals are intact as early as 4 years of age, such that children have the ability to remember associations between characters, decisions, and the outcomes of those decisions. However, there is variability in the development of associative memory for these features, such that children may show a more protracted development of memory for feedback versus memory for the decisions they made. By incorporating our findings with the prior literature, we propose that memory may play an important role in guiding complex social development in early childhood, and it will be necessary to first unpack the complex interplay between memory and decision-making during this critical period of social development.

Our findings provide a novel characterization of children's ability to encode and retrieve memories of dynamic social interactions. Although a growing body of literature has characterized children's ability to perceive social feedback, this field has yet to extend these findings to the ability for children to explicitly retrieve these episodes. Here, we provide evidence that the ability to form memories of multi-dimensional social encounters is intact as early as 4 years of age. However, the developmental trajectories of memory for the feedback of social encounters may be more protracted than the development of memory for the decisions children have made.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2020.104324.

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