Gain-loss framing enhances mnemonic discrimination in preschoolers

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Abstract

Episodic memory relies on discriminating among similar elements of episodes. Mnemonic discrimination is relatively poor at age 4, and then improves markedly. We investigated whether motivation to encode items with fine grain resolution would change this picture of development, using an engaging computer-administered memory task in which a bird ate items that made the bird healthier (gain frame), sicker (loss frame), or led to no change (control condition). Using gain-loss framing led to enhanced mnemonic discrimination in 4- and 5-year-olds, but did not affect older children or adults. Despite this differential improvement, age-related differences persisted. An additional finding was that loss-framing led to greater mnemonic discrimination than gain-framing across age groups. Motivation only partially accounts for development in mnemonic discrimination.

*Keywords:* mnemonic discrimination, motivation, pattern separation, memory development.
1.1. Mnemonic Discrimination Development

Memories for everyday events share a great deal of overlap, as our experiences often take place in similar places and involve similar objects and people with similar characteristics. Therefore, episodic memory requires successful mnemonic discrimination of people, places and objects, and the ability to encode and store past events with high specificity. Mnemonic discrimination may involve a process called pattern separation, a hippocampal computation that reduces the degree of overlap between similar inputs to circumvent catastrophic interference (Complementary Learning Systems theory: O’Reilly & McClelland, 1994; Norman & O’Reilly, 2003). Recent findings indicate that mnemonic discrimination is quite poor during preschool ages, and improves markedly throughout early and middle childhood (Canada, Ngo, Newcombe, Geng, & Riggins, 2018; Ngo, Newcombe, & Olson, 2017; Rollins & Cloude, 2018), coinciding with the developmental window in which episodic memory shows the most robust gains (reviewed in Ghetti & Bunge, 2012; Olson & Newcombe, 2014). The development of mnemonic discrimination may play an important role in the lifting of childhood amnesia (Canada et al., 2018; Ngo et al., 2017; Keresztes et al., 2017).

One paradigm designed to test mnemonic discrimination is the Mnemonic Similarity Task (MST), in which studied objects must be discriminated from perceptually similar objects at test (reviewed in Yassa & Stark, 2011). Four-year-old children consistently showed poorer mnemonic discrimination than 6-year-olds and young adults, whereas only subtle differences were detected between 6-year-olds and young adults in a child-friendly version of the MST (Ngo et al., 2017) and in a 4AFC task (Ngo, Lin, Newcombe, & Olson, 2018).
These findings raise the question: why do young children perform poorly on mnemonic discrimination tasks? One reason may be neurobiological - before the age of 6, late-developing subfields of the hippocampus (i.e., dentate gyrus), limit optimal pattern separation, resulting in poor mnemonic discrimination. Canada and colleagues (2018) found that (1) performance on the MST improved from ages 4 to 8, (2) C2-4/DG gray matter volume waxed and then waned in this age range (i.e., showed a quadratic relation to age), and (3) crucially, in younger children, greater volume was related to better discrimination, whereas in older children, the opposite was true. Discrimination performance on the MST also correlated linearly with age in a sample of children aged 6 to 14, and discrimination was associated with hippocampal maturation characterized by the multivariate patterns of age-related differences in hippocampal subfields’ gray matter volumes (Keresztes et al., 2017).

When young children perform poorly on a task, it is always important to ensure that they comprehended it. Previous studies implemented pre-test practice sessions to facilitate children’s understanding of the task (Canada et al., 2018; Ngo et al., 2017; Rollins & Cloude, 2018). Even the youngest group of children (age 4) showed effects of the level of similarity between lures and targets, demonstrating an understanding of the task procedure (Ngo et al., 2017). However, children’s abilities to spontaneously form memories with high resolution may not reflect what they can do when motivated to encode and retrieve the specific details of the studied objects. In fact, signals from extra-hippocampal structures that carry information about behavioral significance—emotional, motivational, or attentional signals—can influence pattern separation (reviewed in Kassab & Alexandra, 2018). Several studies have demonstrated that arousal evoked at encoding
may enhance subsequent mnemonic discrimination in young adults (Balderston et al., 2017; Segal, Stark, Kattan, Stark, & Yassa, 2012). However, there have been no studies investigating the role of motivation on mnemonic discrimination in children.

This study sought to investigate the malleability of the age-related changes in mnemonic discrimination during early and middle childhood. We asked whether motivating children to encode items with high specificity through a gain-loss framing would affect subsequent mnemonic discrimination. In an adaptive memory system, experienced episodes should be prioritized in memory based on their significance. If we think an event may be important for guiding future behaviors, there is a strong incentive to remember it. For example, if you go mushroom picking and eat a mushroom that makes you violently ill, it is important to be able to remember and later discriminate the sickness-inducing mushroom from the good mushrooms. In instances in which the outcomes of consuming two types of mushrooms are undifferentiated, mnemonic discrimination between these similar experiences is behaviorally unimportant.

1.2. Current Study

Here we tested the hypothesis that poor mnemonic discrimination in young children is due to low motivation to encode and/or retrieve past experiences with sufficiently high resolution. Thus when encoding motivation increased, young children should perform comparably to older children. An alternative hypothesis is that age-related differences between young and older children may be due to immaturity of the neural circuits supporting pattern separation.

To test the motivation hypothesis, we manipulated gain-loss framing and examined its effects on mnemonic discrimination. Gain-loss frame was employed such
that items were either portrayed as positive or negative arbitrarily. To do this, we created an engaging game-like computerized task in which children learned that certain food items made the main character sick or healthy in the experimental condition. We included a control condition in which the items were learned in the same cover story, but devoid of the sick/healthy element. We reasoned that children would care about the health of the main character, and this would motivate them to pay attention to the discriminating details of the food items. Given that the age range between 4 and 6 years is a window in which gains in episodic memory are most robust (Peterson et al., 2011), with relatively less drastic changes occurring from age 6 onward (Olson & Newcombe, 2014), we tested younger children (preschoolers—ages 4-5), older children (ages 6-8), and young adults.

**Methods**

2.1. Participants

A total of 45 4- and 5-year-old children and 52 6- to 8-year-old children recruited from the Philadelphia suburban areas participated in the study at the Temple Ambler Infant and Child Laboratory. All children were free of neurological damage and had no history of developmental disorders as reported by a parent. Two additional children (1 5-year-old and 1 7-year-old) were tested but did not complete the task. All children received a small toy for their participation. The adult sample consisted of 44 undergraduate students from Temple University who participated for partial course credit (see Table 1 for age-related descriptive reports of all age groups). All participants gave informed consent and reported to have normal or corrected-to-normal vision. This experiment was approved by the Institutional Review Board committee at Temple University.

2.2. Memory Task
Materials.

An animation sequence of a forest scene was created in Adobe Photoshop CS6. One GIF image of a cartoon bird was obtained to serve as the character of the cover story for the memory task. Ninety-six animate object images (32 triplets of object exemplars) were selected from a pool of 183 object images sampled from Google image search engine. The encoding and test instructions were given by pre-recorded voice audio. Testing materials have been made publically available (https://osf.io/p7jvf/).

Procedure.

Participants were randomly assigned to either the experimental or control condition, and to one of the three animation versions. All participants were tested individually. The task procedure was presented on a 13” laptop screen, and entailed two encoding—test blocks, with 16 encoding and 16 test trials within each block. In the experimental condition, the female voice recording introduced the cover story at the beginning of the encoding phase “Meet my friend Birdie. She’s taking the trip to the forest. In this forest, there will be some food she would like to eat. Some foods make her healthy, and some foods make her sick”. Two example trials were introduced, “when she eats a food that makes her healthy, her health bar goes up, like this” – demonstrated in an increase in the health bar. In the next example trial, the voice recording stated “when she eats a food that makes her sick, her health bar goes down, like this” – demonstrated in a decrease in the health bar. The encoding instruction continued with “Birdie will eat a lot of food, watch out for the things that make her sick or healthy, ok? Are you ready?”

Throughout the encoding phase, Birdie was seen flying through the forest, encountered a green diamond at a fixed interval (see Figure 1A). The appearance of the green diamond
indicated that there’s food that she would like to eat. The screen zoomed into the
diamond, initiating one trial of encoding phase. In each trial, the image of the object
appeared on the screen for 2s. The health bar then appeared below the object image for 1s,
followed by either an increase or decrease of the health bar for 2.5s for the healthy or sick
items, respectively. The increase or decrease in the health bar was always accompanied
with a tone similar to that typically found in video games. A voice recording stating “Oh
look, it made her healthier.” or “Oh no, it made her sick.” for the healthy and sick items,
respectively. After each trial, the animation proceeded with Birdie continuing on her
journey until she encountered another green diamond. The inter-trial interval (8s) was
constant across all 32 trials. The degrees of increase and decrease in the health bar were
equated. The order of sick and healthy items was pseudo-randomized such that Birdie’s
health bar never depleted or completely filled. In the control condition, everything was the
same as the experimental condition with the exception that encoding instruction did not
mention anything about the healthy/unhealthy characteristic of the foods or the
implementation of the health bar. The duration presentation of the items was the same
between the experimental and control conditions. We implemented a neutral tone at the
matched timing window as the experimental condition, to ensure that the two conditions
differed minimally except for the gain/loss framing of the studied items (see Figure 1B).

Immediately after the encoding phase of each block, participants were given a
self-paced three-alternative-forced-choice test phase consisting of 16 trials. The three
options included a target, i.e., a studied item, and two lures: perceptually similar
exemplars of the corresponding target. Children were asked to choose the exact food item
that Birdie ate during her journey by pointing at one of the three options (see Figure 1C).
The experimenter recorded children’s responses on paper. The order of test trials was randomized. The positions of the targets were counterbalanced across test trials. All items were counterbalanced such that they were assigned as targets or lures an equal number of times across participants. Each exemplar within a triplet was assigned as the target, whereas the other two exemplars assigned as the lures, resulted in three task versions. Each of the versions was duplicated for the experimental versus control conditions, totaling to 6 task versions. The entire experimental procedure lasted approximately 35-40 minutes. All participants were tested individually.

To avoid potential ceiling effects in adults, the procedures differed between children and adults such that the level of difficulty increased for adults. For the children, the experiment was divided into two encoding-test blocks (16 encoding trials followed by 16 test trials per block). For the adults, the experiment consisted of one encoding and one test phase (32 trials).

2.3. Verbal Intelligence

All children were administered the Kaufman’s Brief Intelligence Test, 2nd edition (KBIT-2: Kaufman & Kaufman, 1990) to assess general verbal intelligence. Children were instructed to choose one of the six images simultaneously shown on a page that was the best match for a word or phrase (e.g., what is something that floats and you can ride in — a boat), and to respond with a one-word answer to verbal riddles (e.g., what is something that wags its tail and barks? — dog). The test, with increasing level of difficulty in each section, was terminated when a child provided 4 incorrect responses consecutively. Standard score was calculated for each child based on his/her age.
Adults were administered the 45-item American National Adult Reading Test (AMNART; Grober & Sliwinski, 1991—an American version of the National Adult Reading Test; Nelson, 1982). This test measures the ability to read aloud irregular words. Pronunciation errors were tallied and AMNART-estimated IQ score was calculated using Grober and Sliwinski’s formula, which accounts for years of education.

**Results**

The proportion of correct trials out of 32 total test trials was calculated for each participant. We conducted several preliminary analyses. There were no sex differences in memory performance for any of the three age groups, all *p’s > .22*. KBIT scores did not differ between the two conditions in either group of children, all *p’s > .63*, and the AMNART scores did not differ between the two conditions in young adults, *p = .66*. Memory performance did not differ among the three animation versions, *p = .17*, suggesting that there were no unintended differences in difficulty across task versions.

3.1. **The effects of age and conditions on mnemonic discrimination**

Next, we examined the effects of age and condition on mnemonic discrimination performance using between-subjects factorial ANOVA. We found a significant main effect of Age, *F*(2, 135) = 38.81, *p < .001, MSE = 0.59, ηp² = .37, a nonsignificant main effect of Condition, *F*(1, 135) = 2.94, *p = .09, MSE = 0.05, ηp² = .02, and a significant Age*Condition interaction, *F*(2, 135) = 3.48, *p = .03, MSE = 0.05, ηp² = .05. Younger children, performed better on the experimental condition compared to the control condition (*M = 0.62, SE = 0.04 vs. M = 0.73, SE = 0.03, t(43) = -2.39, *p = .02*. In contrast, older children (*M = 0.85, SE = 0.02 vs. M = 0.85, SE = 0.02, t(50) = 0.14, *p =
.89) and adults (M = 0.89, SE = .02 vs. M = 0.88, SE = 0.02, t(42) = 0.10, p = .92),
performed similarly in the two conditions (see Figure 2).

Importantly, although gain-loss framing enhanced mnemonic discrimination in
younger children, their performance was still lower than older children in the control
group, t(41) = -3.42, p = .001, suggesting that age-related differences are not abolished by
gain-loss framing.

3.2. The effects of gain vs. loss framing on mnemonic discrimination

Next we asked whether sick and healthy items were remembered differently across
three age groups within the experimental condition. A 3(age groups) x 2 (item type: sick,
healthy) mixed ANOVA showed a non-significant Age*Item type interaction, F(2, 68) =
0.46, p = .64, MSE = 0.003, ηp² = 0.01. There was a significant main effects of Age, F(2,
68) = 9.51, p < .001 MSE = 0.28, ηp² = 0.22, such that younger children performed more
poorly than their older counterparts, all p’s < .003, whereas older children and young
adults did not differ, p = .56. Interestingly, there was also a main effect of Item type, F(1,
68) = 11.94, p = .001, MSE = 0.09, ηp² = 0.15, such that mnemonic discrimination was
better for sick items than healthy items (see Figure 3).

3.3. Data Availability

Data from this experiment have been made publically available through the Open
Science Framework at https://osf.io/8k43j/.

4. Discussion

Preschool-aged children have consistently displayed deficits in fine-grained
mnemonic discrimination, showing a proclivity for mistaking similar objects for studied
items (Canada et al., 2018; Ngo et al., 2017; Rollins & Cloude, 2018). However, how
non-mnemonic top-down factors such as motivational state influence children’s abilities to discriminate similar memories has not been studied. The current study, to our knowledge, is the first to investigate the influence of motivation through gain-loss framing on mnemonic discrimination in children. Two main findings were revealed.

4.1. The influence of gain-loss framing on mnemonic discrimination

First, we showed that framing items as either positive or negative boosted youngest children in their subsequent fine-grain discrimination for learned items from similar exemplars. That is, young children who viewed objects in a gain-loss framing outperformed those who viewed objects in a traditional task variant of the MST. Importantly, this improvement did not bring the younger children’s mnemonic discrimination performance on par with older children or young adults in the control condition. Thus, although there is a degree of plasticity in mnemonic discrimination depending on the learning condition, the general age trend persists. These results demonstrate that the previously reported age effects on mnemonic discrimination using various tasks were not primarily due to factors such as the lack of motivation or task age-appropriateness. Instead, the age-related improvements in mnemonic discrimination are likely linked to neurobiological changes in intra- and extrahippocampal regions important for the increase in pattern separation during childhood (Keresztes, Ngo, Lindenberger, Werkle-Bergner, & Newcombe, 2018).

Our results on the enhancement of gain-loss framing on mnemonic discrimination in children converge with previous findings from the adult memory literature demonstrating that mnemonic discrimination can be influenced by arousal. For example, anxiety evoked by threat of shock at encoding enhanced mnemonic discrimination, but
threat of shock at retrieval impaired mnemonic discrimination in the MST (Balderston et al., 2017). In another study, arousal evoked by emotional stimuli (e.g., poisonous snake) prior to encoding neural stimuli enhanced subsequent mnemonic discrimination, and that the degree of arousal measured by a change in salivary alpha amylase correlated with memory performance in young adults (Segal, Stark, Kattan, Stark, & Yassa, 2012). The author suggested that this facilitation in pattern separation for items encoded during threat might be mediated by noradrenergic activity during encoding. In agreement with this view, a model proposed by Kassab and Alexandre (2018) predicts that neuro-modulatory signals may act in concert with cortical inputs to inform the dentate gyrus about the changing demands on pattern separation under different conditions. According to this model, the hilus of the dentate gyrus may serve as a convergent zone whereby bottom-up factors (i.e., pattern similarity) interact with top-down factors (i.e., motivation), which jointly determine the engagement of pattern separation.

In the current study, we did not detect an enhancement effect of the gain-loss framing in older children or young adults. One possibility is that older children and young adults are able to spontaneously encode and retrieve memories with high specificity, such that they might not “need” the motivational aid. Another possibility is that these effects would have been observed in a more difficult task, although it is worth noting that only 3.85% and 11.36% among the older children and young adults performed at ceiling level in our paradigm. The third possibility is that older children and especially young adults may be more susceptible to other means of motivation, such as monetary rewards (reviewed in Murty & Adcock, 2014), compared to the gain-loss framing employed in the current work.
4.2. Asymmetric effects of gain vs. loss frame on mnemonic discrimination

Second, we found asymmetric framing effects across all age groups such that negative framing yielded higher mnemonic discrimination accuracy than positive framing. It is likely that in addition to serving as a motivational aid, gain-loss framing also provokes emotional valence by inducing appetitive and aversive experiences at encoding. These results align with previous findings that young adults, and older adults in some cases, show better memory for the details of negative items compared to that of neutral (Kensinger, Garoff-Eaton, & Schacter, 2006, 2007a) and positive items (Kensinger, Garoff-Eaton, & Schacter, 2007b). Similarly, threat of receiving a painful thermal probe increased memory for individual items devoid of any contextual representations, but worsen recollection-based memory, which contains details about the relationships among features of an episode (Bauch, Rausch, & Bunzeck, 2014). Together, this study and others suggest that memory for negatively framed items—those that might evoke an aversive valence—yields superior mnemonic discrimination compared to those positively framed.

4.3. Future Direction

Other approaches for assessing the role of motivational and emotional state on mnemonic discrimination in children are worth considering for future studies. First, in our design, items on the study list were arbitrarily assigned to a positive or negative valiance, as opposed to being intrinsically perceived as positive or negative. It would also be interesting to examine whether emotional stimuli (e.g., fire vs. a calming meadow, see Leal et al., 2014) would result in enhanced discrimination in younger children. Furthermore, future investigators may wish to measure physical arousal by pupillary
response or galvanic skin response, thereby directly assessing whether arousal drives the enhancing effects of motivation on mnemonic discrimination in children.

Second, motivation was not implemented via a behavior-contingent-outcomes paradigm in the current work. That is, whether or not Birdie’s health improved or declined was not contingent on any aspects of participants’ behavior, unlike studies in adults (see work by Wittman et al., 2005 and Murty, DuBrow, & Davachi, 2005).

Finally, it has been shown that children display malleability in their memory performance after receiving explicit instruction to utilize a specific strategy (Brehmer, Li, Muller, von Oertzen, & Lindenberger, 2007). Here, we did not employ an explicit memory instruction to test the malleability of mnemonic discrimination in children. Instead, we utilized the gain-loss framing to model a learning condition that amplifies the need to make fine-grained discrimination, similar to circumstances encountered in real life. Future work should consider examining whether instructing children to pay attention to distinctiveness of the studied items would yield the same (or even more robust) enhancement effects on mnemonic discrimination, similarly to what has been done in the aging population (Koutstaal, Schacter, Galluccio, & Stofer, 1999). Related to this idea, future investigations of whether young children could perform fine-grained mnemonic discrimination would potentially benefit from other methods employing the testing-the-limits paradigm such as combining instruction and extensive training (e.g., Brehmer et al., 2007).

4.4. Conclusions

In acknowledging the adaptive nature of human memory systems, it remains critical to delineate the influence of motivation on the core properties of episodic memory.
In fact, it has been suggested that children may prioritize extracting schematic knowledge at the expense of encoding and recollecting past events with high specificity in the first few years of life. This precedence of learning the general rules of the environment over remembering the specifics of past events may be advantageous, allowing infants and toddlers to build a strong semantic knowledge of world (Newcombe, Lloyd, & Ratcliff, 2007; Keresztes et al., 2018). An important question arising from this view is whether young children could prioritize encoding items with high specificity in circumstances in which the details of past experience would be advantageous for subsequent remembering. Evidence from this research suggests a degree of malleability in mnemonic discrimination in preschoolers, such that motivation boosts mnemonic discrimination. However, it did not abolish the robust age-related differences between preschoolers and their older counterparts.
References


FRAMING ENHANCES MNEMONIC DISCRIMINATION


Table 1. Sample sizes, age-related descriptive statistics, and verbal IQ assessed by the KBIT of each age group.

<table>
<thead>
<tr>
<th></th>
<th>Younger children</th>
<th>Older children</th>
<th>Young adults</th>
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<td>Experimental</td>
<td>Control</td>
<td>Experimental</td>
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<td><strong>N</strong></td>
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<td>25</td>
<td>29</td>
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<tr>
<td><strong>Sex</strong></td>
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<td>11M</td>
<td>10F</td>
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<tr>
<td><strong>Age/Month Mean (SD)</strong></td>
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<td>62.27 (8.84)</td>
<td>85.28 (9.40)</td>
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<tr>
<td><strong>Age/Month Range</strong></td>
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<td>46.01-71.95</td>
<td>71.46-101.72</td>
</tr>
<tr>
<td><strong>Verbal IQ</strong></td>
<td>99.80 (15.23)</td>
<td>104.24 (12.71)</td>
<td>101.55 (18.67)</td>
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</table>
Figure 1. (A) A screenshot of the forest cartoon with Birdie and a green diamond indicated a location with a food that Birdie wants to eat. (B) An example of an encoding trial in the experimental and control conditions. In the experimental condition, the object image was presented for 2s, followed by an appearance of the “health bar” – the horizontal turquoise bar - for 1s. Then there was either an increase or a decrease in the
health bar accompanied by a tone for the healthy and sick trials, respectively. Note that the red arrows are only for visual illustration. In the control condition, an image was presented on its own for a matched duration. (C) Examples of the self-paced 3AFC test phase and was identical between the two conditions.
Figure 2. Accuracy distribution of the control and experimental conditions across three age groups. Black horizontal bars indicate the group medians.
Figure 3. Accuracy distribution of the sick and healthy items in the experimental condition across three age groups. Black horizontal bars indicate the group medians.