The Development of Context Use and Three Way Bindings in Episodic Memory

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Abstract

To address the mechanism underlying the development of episodic memory, the current study used a modified list learning paradigm for children (i.e. ABCD, ABAC, ABABr) and compared the performance of 4 year-olds, 7 year-olds, and adults. The results show that only the ABABr condition, which involves a 3-way binding structure, differed across age. Additionally, a proposed computational model (multinomial process tree model) decomposed the binding strengths involved in the given tasks and made it possible to compare the changes in these binding strengths. The model shows that though all groups have similar item binding strength, the overall context (list) binding and 3-way binding strengths develops throughout development. Aside to the general context binding strength, however, 7 year olds showed a lower context binding strength than 4 year olds. The results are discussed by the interaction between context strength and attentional mechanism.

Keywords: episodic memory, memory development, computational modeling, binding, three-way binding, context

Introduction

Episodic memory refers to the stored information about events and their spatial-temporal relations (Tulving, 1972). This specific kind of memory about what happened when and where is crucial to human being since it is ubiquitous in our everyday life. Suppose that you visited your friend's house and parked your car somewhere. To remember the parking spot, you should at least store one of the two bindings: either between the car and the parking spot or between the context (visiting a friend's house) and the parking spot. A more complicated scenario is when you park your car two days in a row at two different spots. To accurately remember where you parked today, you would have to distinguish this memory from other memories such as yesterday's parking event. At the very minimum, the number of bindings necessary to remember doubles compared to the previous example. An even more complicated situation arises if you own two cars that could be parked in two different locations. Now you need to remember which car was driven today and where it was parked. This time, to distinguish between today's memory and yesterday's memory, one needs to form and store a three-way binding (i.e., [Time]-[Parking spot]-[Car]).

Beyond the complexity and variety of episodic memory, however, it is also well known that the ability to properly form episodic memory is not perfect at birth. Laboratory researches show that children experience more difficulty with episodic memory tasks compared to semantic tasks, (Drummey & Newcombe, 2002; Ghetti & Lee, 2010; Kail, 1990). Studies on children's memory in forensic context (Pipe & Salmon, 2009) and children's autobiographical memory (Bauer, 2007) show that episodic memory is vulnerable during childhood.

One of the possible explanations for the development of episodic memory could be the ability to properly use binding structures (c.f. Doumas, Hummel, & Sandhofer, 2008; Halford, Wilson, & Phillips, 1998). As described above, different episodic events require different binding structures and as the events get more complex a more complex binding structure is required. The current study attempts to explain the development of episodic memory by using a list learning paradigm modified for children along with a computational model (multinomial process tree model, MPT) that could decompose the underlying binding structures of episodic memory.

In the list learning paradigm, one studies two lists of word pairs, where each list is followed by a retention interval. At test, after the studying the lists, questions about the first and second list are asked. One of the advantages of the list learning paradigm is that they could be easily manipulated into various conditions which represent various episodic events. For example, the episodic events that were mentioned in the car parking examples could all be transformed into a list learning paradigm. The first example where one had to remember a single parking event could be transformed into a condition called ABCD. The first two letters 'AB' refer to the item pairs in the first list and 'CD' refers to the item pairs in the second list. As the letters in 'AB' and 'CD' do not overlap, the items in the first and second list of the ABCD condition do not overlap (see Figure 1). Therefore when asked to recall the event given a cue like "Where did you park your car when you visited your friend?" one only needs a binding between the car and the parking space or the context (visiting the friend) and the parking space. This kind of binding is called a two-way binding since the binding involves two items.

The episode of distinguishing two parking events (i.e., parking the car in different locations on different days) could be transformed into an ABAC condition (Barnes & Underwood, 1959; Postman, 1962). In the ABAC condition, as denoted by the letters, only the first items are overlapped in the two lists (see Figure 1). Therefore, to recall the event correctly when asked "Where did you park your car today?" one not only needs the binding between the car and the parking space but also the binding between the parking space and today. Thus, to succeed in the ABAC condition one needs at least 2 two-way bindings.

The last example of two cars and two parking locations can be transformed in a list learning paradigm called the ABABr condition (Porter & Duncan, 1953; Postman, 1964). In the ABABr condition items in the first and second list are the identical but their pairings differ. To perfectly recall the events in this condition it is known that at least a three-way binding between the car, the location and the context is required (Humphreys, Bain, & Pike, 1989).

The three conditions sufficiently represent various episodic events while providing the minimum requirements to properly recall a certain event. Also the complexity of the minimally required binding increases from the ABCD condition to the ABABr condition. Additionally, using a multinomial process tree (MPT) model based on the responses in each condition, it is possible to decompose the strength of different bindings (Batchelder & Riefer, 1999; Riefer & Batchelder, 1988). Moreover, the model could show how theses binding strength change during development.

Therefore, the current paper will first address the modified list learning paradigm and the experiment results from different ages. Second, a MPT model will be proposed that could decompose the binding strength in different ages and discuss the developmental factors of episodic memory.

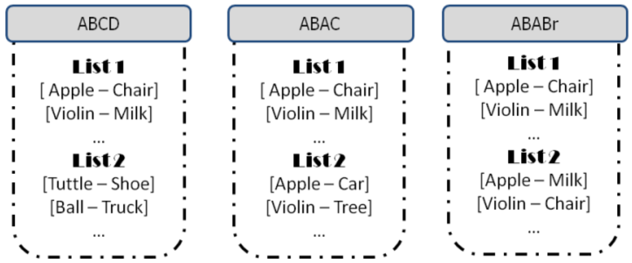

Figure 1: An illustration of the presented stimuli and each experiment conditions.

Experiment

Method

Participants Three age groups participated in the experiment. There were forty five 4 year old children (23 girls, *M* = 4.70 years, *SD* = 0.24 years, 16 for the ABCD condition, 14 for the ABAC condition and 15 for the ABABr condition), forty six 7 year old children (22 girls, *M* = 7.30 years, *SD* = 0.27 years, 15 for the ABCD condition, 17 for the ABAC condition and 14 for the ABABr condition), and fifty nine adults (23 females, *M* = 20.07 years, *SD* = 2.88 years) participated in the experiment. There were 20 for the ABCD condition, 18 for the ABAC condition and 21 for the ABABr condition). There were an additional nine 4 year olds who were excluded from the analysis where six lost interest in the experiment and three did not learn the study items after 10 presentations. Children participants were recruited from upper middle class suburbs of Columbus, Ohio and the adults were undergraduate students at The Ohio State University participating for course credit.

Stimuli There were three conditions in the experiment that resembled the traditional list learning paradigm. For the study stimuli, each condition had two lists and each list had six pairs of visual object which were shown one at a time. Along with each item pair a child friendly cartoon character for each list was constantly presented next to the pairs serving as a list context (see Figure 2). The difference between each condition was the structure of the list. In the ABCD condition there were different items in each list making 24 unique items in total. In the ABAC condition the two lists had the same cues (1st item) where the targets (2nd item) differed. In the ABABr condition the items for each list were the same but the pairing was different between the two lists. The test stimuli were identical to the study stimuli except that the target was not shown (see Figure 3, Test). Half of the test stimuli were from 1st list and the other half was from the 2nd list. All stimuli were pseudo randomized and were presented using Microsoft Power Point.

Figure 2: An illustration of the presented stimuli for each study trial. - Examples show two lists each with its own character on the left side with two items presented on the right.

Procedure The experiment consists of two study phases where participants studied six pairs of items respectively. A 3 to 4 minute retention interval followed each study phase, which involved participants to play a simple and engaging video game. Sequentially there were 6 cued recall tests. The procedures were same for all groups except that the two children group participated in their schools while adults participated in the laboratory.

A practice phase preceded the experiment to explain the procedure to the participants. The procedure was identical to the experiment except that the items were reduced to one pair a list and did not have a retention interval. After the practice phase, each participant was randomly assigned to one of the experiment conditions.

After participants understood the procedure through the practice phase, they were told that they are going to visit a cartoon character's house. They were first introduced to the character and then to the objects in the character's house. (see Figure 3, first slide of each list) They were also told that the character likes to hide things under these objects and that they are going to find out what the hidden objects are. Then the object pairs were presented by first showing an item (cue at test) with the character, which was constant throughout the each list. Thereafter, the cue item moved to unveil the target item (see Figure 3). The instructions were as follows: *"Let's see what is under Sponge Bob's airplane. (The airplane moves upward and unveils the strawberry) What is it? Yes it is a strawberry. So Sponge Bob (pointing at Sponge Bob) has a strawberry (pointing at the strawberry) under his airplane (pointing at the airplane). Now let's see what Sponge Bob has under his turtle. …."* When all three objects appeared on the screen, the experimenter rephrased each items and the character while pointing at them one at a time. This procedure helped the children to look and attend to each of the objects and the characters.

After presenting all six pairs in a list, a cued recall test was done for all pairs in a random order to ensure that the participants learned all pairs. The participants saw a character and a cue item and the correct answer was shown as a feedback after their response. The procedure repeated asking the whole list pairs until the participants perfectly answered all six pairs. The number of repetitions was analyzed as the amount of learning to criterion. Related instructions were as follows: *"Do you remember what Sponge Bob had under his airplane? (1) Yes! You are right. Very good! (2) Oh! It was a strawberry. So, Sponge Bob (pointing) hid the strawberry (pointing) under the airplane (pointing)."* After studying the first list, a 3-4 minute retention interval followed where children played simple video games. The studying procedure for the second list was same as the first list. The test had six cued recall test, three from each of the lists without feedback. The participants had to accurately recall what was under the cue. The responses were recorded on a response sheet.

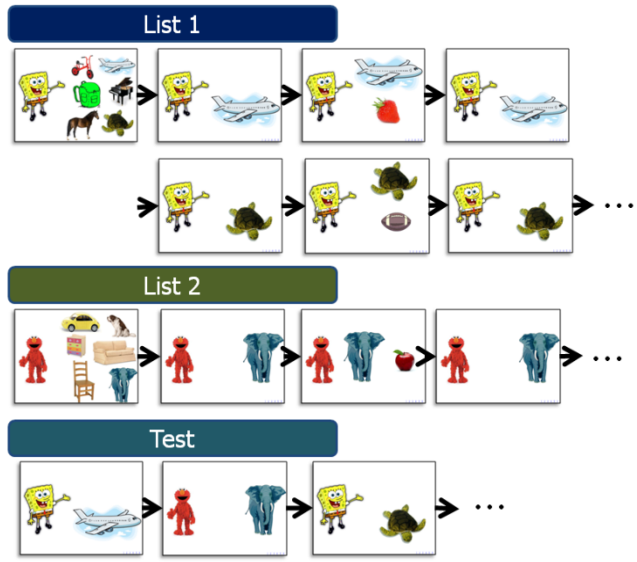

Figure 3: An illustration of the study lists and test.

Results

Accuracy at test was analyzed using a 3 X 3 (Age X Condition) between-subjects ANOVA. Results showed a main effect for Age, F (2, 141) = 4.65, $p < 0.05$, and a main effect for Condition, F (2, 141) = 19.13, $p < .001$, and a marginal interaction, F (4, 141) = 2.07, $p = .089$ (see Figure 4). Conducting a Tukey's HSD post-hoc test for Age, the adult group differed from the 4 year-old group, $p < .05$, and marginally from the 7 year-old group, $p = .085$. However, the two children groups did not differ. For Condition, the ABCD condition differed from the ABABr condition, $p < .001$, and the ABAC condition, $p < .001$, but there was no significant difference between the ABABr condition and the ABAC condition.

A one-way ANOVA for each condition only showed significant difference for the ABABr condition, F (2, 47) = 2.07, $p < .005$. From a Tukey's HSD post-hoc test, adults significantly differed from 4 year olds, $p < .001$, marginally differed from 7 year olds, $p = .056$, whereas the 4 and 7 year olds did not have significant difference.

The amount of learning to criterion was also analyzed. For each participant the amount of repetition needed to learn the 2^{nd} list was subtracted from that of the 1^{st} list. The subtracted value implies the amount of interference from the

1st list when learning the 2nd list (see Firgure 5). Using a 3 X 3 (Age X Condition) between-subjects ANOVA showed a main effect for Age, F (2, 136) = 4.23, $p < .05$, a marginal main effect for Condition, F (2, 136) = 2.91, $p = .058$, but no Age X Condition interaction. A one-way ANOVA for each of the conditions only showed significant difference for the ABABr condition, F (2, 45) = 4.20, $p < .05$. Moreover, a Tukey's HSD post-hoc test only showed a significant difference between adults and 4 year olds, $p < .05$.

From the accuracy data, only the ABABr condition, which requires a 3-way binding, showed a developmental change. On the other hand, performance on the ABCD or the ABAC conditions did not show an age difference. The results suggest that the only developmental change is the ability to form a 3-way binding. However, the results from the learning to criterion data does not fully support that the only developmental change is in the 3-way-binding abilities. Although the amount of interference in the ABABr condition reflects the developmental change in the test accuracy, it does not account the test accuracy data in the ABCD or ABAC condition. If the performance at test in the ABCD or ABAC condition is resulting from the same mechanism among difference age groups, the amount of interference should be the same or at least should show a developmental trend as in the ABABr condition. In the ABCD condition, 7 year olds have a positive interference whereas other age groups are having a negative interference. Also in the ABAC condition, 7 year olds are having more interference than adults, whereas 4 year olds are having lesser interference than adults. Therefore, merely comparing the correct recalls would not truly reveal the underlying mechanism of episodic memory development.

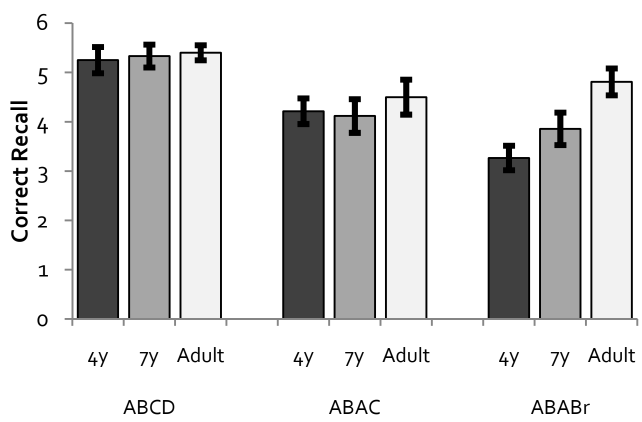

Figure 4: Mean correct response for the Experiment. Error bars refer to +/- one standard error.

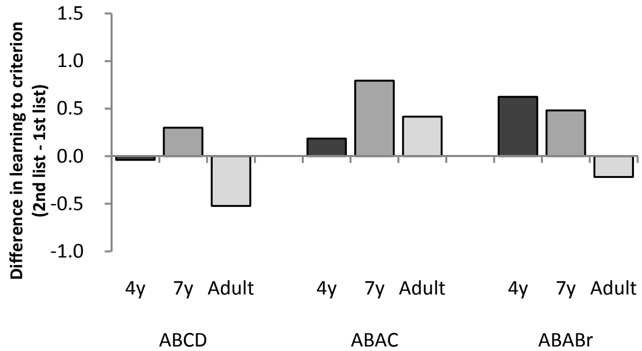

Figure 5: Amount of interference by calculating the difference of learning to criterion between the two lists (2nd list minus 1st list). Values indicate the average divided by the standard deviation.

Computational Model

It could be inferred from the results of the experiments that the development of accurately using the three-way binding increases during development. However, the results merely show the difference of the overall accuracy performance and could not show what kind of binding is related and how it is changing during development. The proposed multinomial process tree (MPT) model not only uses the correct responses but also incorporates the classified errors to estimate the binding strengths. The estimated binding strength makes it possible to compare the binding strength within an age group as well as among age groups.

Model description

A multinomial process tree model (MPT) is a simple probability model that is used to discompose the underlying cognitive process (Batchelder & Riefer, 1999). The model categories all responses based on the assumed underlying mechanism involved. Thereafter, the parameters of the underlying mechanisms are estimated by the frequency of each response category.

The current MPT model assumes 4 probability parameters for the underlying process – experiment (E), list (L), item (I), and 3-way binding (B). For example, in the ABAC condition when a cued recall test with "list1" and "A" is given the correct response would be "B" (see Figure 6). To make a correct response like this, one should remember that the correct response was in the experiment context (E), and also that it was presented in list1 (L), and that it was presented with item "A" (I). If one did not respond anything or something outside of the experiment, it would mean that they do not have the appropriate information about the experiment (1-E). If one responded as "N", it could be inferred that they remember the experiment context (E), the cued item "A" (I), but confused about which list it was in (1-L) since "N" is also paired with "A" except that it was presented in list2. All respond categories could be inferred in this manner and the parameters could be estimated.

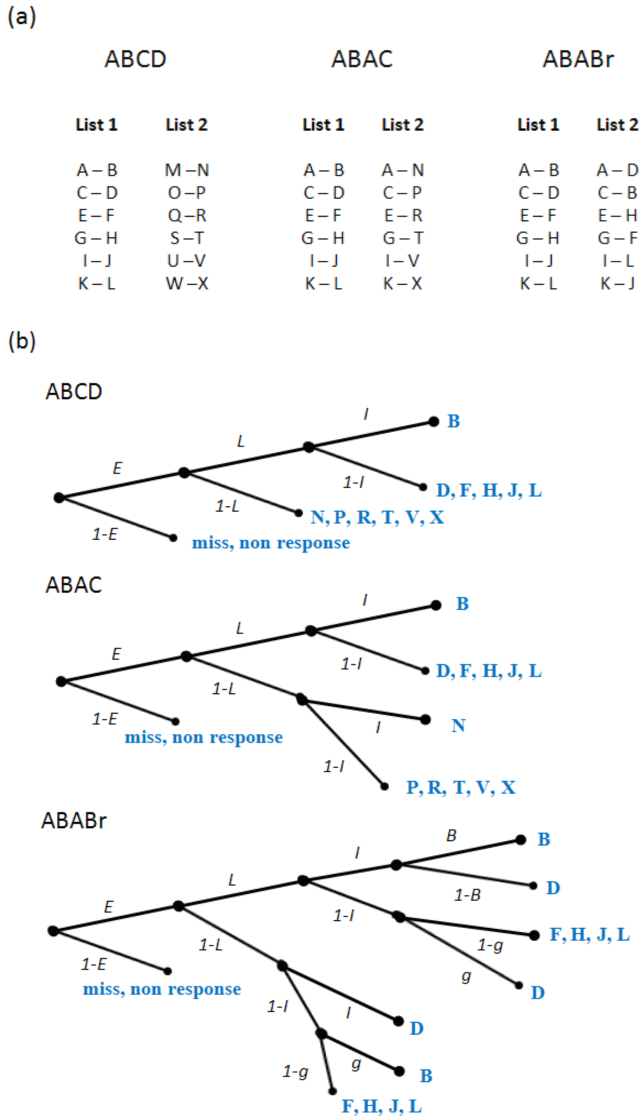

Figure 6: An illustration of the proposed MPT model. (a) Examples of different conditions. (b) Related processes for each respond category in each condition. The blue letters denote the possible responds when the cue "list1" and "A" is given at test. The g parameter is a guessing parameter fixed to 0.2.

Estimated model parameter

The estimated binding parameters are shown in Figure 7. The E (experiment) parameter and the B (3-way binding) parameter showed an increasing pattern with development. The trend is consistent with the accuracy results where the overall misses are reduced and accuracy in the ABABr condition increased. The I (item) parameter did not show a significant difference among age groups which is also consistent with the accuracy results in the ABCD condition that involves an item binding ability. However, the L (list) parameter showed a 'U shape' pattern where the 7 year olds had the lowest value. A low L parameter is mainly from list intrusion where the participants confuse which list the item came from. The pattern is not predictable from the accuracy results. However, taking account the high interference in the 7 year old data, it is possible that 7 year olds are worse than 4 year olds in distinguishing lists.

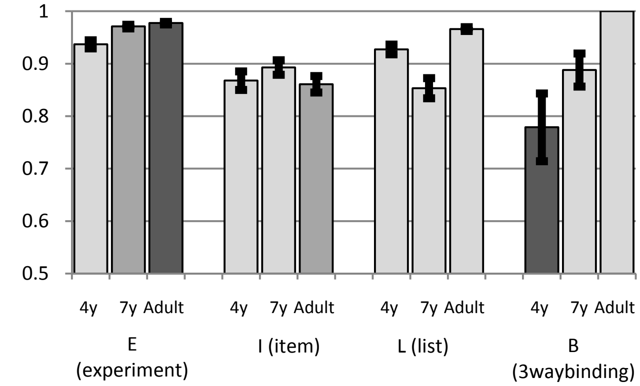

Figure 7: The estimated parameters of the MPT model. Error bars refer to 95% confidence interval.

General Discussions

The current research used a modified list learning paradigm for children and a multinomial process tree model (MPT) that could decompose the binding structures that are involved in episodic memory. Experimental results show that the use of complex binding structures such as using a 3-way binding increases throughout development. The MPT model also shows similar results where the B (3-way binding) parameter increased with age. Moreover, it was both shown from the experimental results and the MPT model that item binding did not differ among the age group. Both results support the current literature where the item binding is a simple two way binding and could be compared to the relatively early development of semantic memory. The development of the 3-way binding could be related to the fact that more complex binding structure develop throughout development (Doumas et al., 2008; Halford et al., 1998).

However, the L (list) parameter, which is affected by confusing which item came from which list, of the 7 year olds shows interesting patterns. Unlike other parameters, the L parameter does not show a developmental trend nor is constant due to the 7 year old data. Additionally the interference data in 7 year olds is higher in the ABCD and ABAC condition. Two mechanisms could be involved in this U-shape pattern of the L parameter. One would be the amount (or strength) of list context that one could use. Taking account the formation of context that was proposed by Howard and Kahana (2002), context is formed by a drifting context. Therefore, whenever an item and its study context are encountered, the previous item and context becomes a part of context while attenuating its strength, and by this process the context is evolving where recent context (including items) have a stronger strength and older ones have a weaker strength. If we apply this to the current data in the ABAC condition, when one learns the 2nd list the currently formed context, which includes cues in the 1st list, would have many overlapping elements with the 2nd list, especially the cues of the 2nd list. Moreover, because of the overlap, confusability would increase and the items in the 1st list could override the items in the 2nd list (Sederberg, Gershman, Polyn, & Norman, 2011). If the formed (or evolved) context is developmentally more salient and less attenuated for 7 year olds than 4 year olds, 7 year olds would have a stronger context that could be used, and would have more items overriding from the 1st list.

However, the increase in the amount of context strength does not fully explain the adult data. If context strength is increasing and therefore making the list information confusing, adults should have the lowest L parameter, which is not true in the data. The second mechanism could explain the anomaly of the adult data which is the attentional mechanism. It is well known that due to the immature prefrontal cortex, young children often have difficulty performing tasks that depend on these brain areas (Zelazo, Carlson, & Kesek, 2008). Therefore, though the amount of context strength does increase throughout development, adults would have a stronger attentional mechanism that could inhibit irrelevant information. Studies with prefrontal lobe damaged patients would support this idea where a similar list learning paradigm (e.g. ABAC, ABABr) was conducted (Shimamura, Jurica, Mangels, Gershberg, & Knight, 1995). The results show that patients had more interference learning the 2nd list than the control group when there were more overlapping items between the study lists. It was argued that the interference results from the inability to inhibit irrelevant information when forming memory.

In sum, it was found that the ability to use a 3-way binding increases across age while suggesting that the simple item binding abilities would have been developed before the age of 4. The developmental mechanism for context (list) use was discussed by two mechanisms – context strength from a perspective that context evolves and attentional mechanisms. Future research could be suggested to compare these two mechanisms directly by manipulate the saliency of the context, which would change the amount of context strength.

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