Increasing relational memory in childhood with unitization strategies

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Abstract

Young children often experience relational memory failures, which are often thought to result from immature recollection processes that are presumed to be required for these tasks. However, research in adults has suggested that relational memory tasks can be accomplished with familiarity, a processes thought to be mature at the end of early childhood. The goal of the present study was to determine if relational memory performance could be improved in childhood by teaching young children memory strategies shown to increase the contribution of familiarity in adults (i.e., unitization). Six- and 8-year-old children were taught to use visualization strategies that either unitized or did not unitize pictures and color borders. Estimates of familiarity were extracted by fitting dual-process models of recognition receiver operator characteristic curves (Yonelinas, 1994; 1997). Bayesian analysis revealed that strategies involving unitization improved memory performance and increased the contribution of familiarity in both age groups.

Relational memory in early childhood: Does unitization help?

The ability to bind one piece of information to another piece of information and remember it across a delay (i.e., relational memory) is present in the first few years of life (e.g., Bemis & Leichtman, 2013). For example, young children are often tasked with remembering the route from their house to the bus stop or curriculum material such as learning relations between animals and their habitats. Although young children are expected to complete tasks such as these successfully, they often fail. One possible explanation for these failures is they occur due to the immaturity of basic relational memory abilities (Sluzenski, Newcombe, & Kovacs, 2006).

Historically, relational memory abilities have been thought to rely on recollection, one of the two cognitive processes argued to underlie recognition memory (Yonelinas, 2002). During childhood, recollection has been shown to follow a protracted developmental trajectory into the adolescent years (Ghetti & Bauer, 2012). However, it has recently been suggested in the adult literature that if two pieces of to-be-remembered information are bound in a unitized fashion (i.e., "fused" into a single item), the contribution of another cognitive process, familiarity, is significantly increased (Yonelinas, Kroll, Dobbins, & Soltani, 1999). This is a particularly exciting possibility from a developmental perspective as familiarity is thought to reach maturity before recollection. Specifically, if children unitize to-be-remembered pieces of information, they may be less prone to errors and forgetting as a result of increased reliance on relatively 'mature' familiarity processes.

The goal of the present study was to take what is known about manipulations that increase the contribution of familiarity to relational memory processes in adults and determine if the same memory strategies would improve children's performance on a relational memory task.

Because this study relies heavily on a dual-process theory of memory, we will first review this approach. Then the concept of unitization will be discussed followed by a review of stimuli manipulations that make use of unitization phenomena and how unitization may be used as a strategy through visual imagery. Finally, a brief review of memory development will be used to shed light on why a visual unitization strategy may improve relational memory performance during early childhood.

A Dual Process Theory of Memory

Yonelinas (2002), proposed that recognition memory is a dual process system, composed of two, independent cognitive processes: familiarity and recollection. Familiarity is reflected as a global feeling of knowing, whereas recollection requires the remembering of specific contextual details surrounding an event. Many differences are known to exist between these processes (see Yonelinas, 2002 for review), with one of the most apparent being their ability to support the learning of novel relations, as in relational memory tasks (Diana, Reder, Arndt, & Park, 2006).

It was originally thought that familiarity could support performance on tasks requiring recognition of a single item (i.e., item memory tasks), but that recollection was required when memory for two items was required (i.e., relational memory tasks). However, recent work has shown that familiarity is able to support relational memory if to-be-remembered information is encoded in a coherent gestalt fashion (i.e., if it is unitized Yonelinas et al., 1999). For example, Yonelinas et al. (1999) presented participants with faces either right-side up or up-side down and found that up-right faces, which are processed holistically, could be recognized through the use of familiarity, whereas up-side-down faces, which are processed as separate, individual features and therefore require binding, could not be retrieved with familiarity alone. Thus, whether or not familiarity can support memory for relations between items is dependent on the way items are initially processed (Diana, Yonelinas, & Ranganath, 2008).

The process of encoding separate items together as a single unit, is referred to as unitization. Recent theories consider unitization to be a continuum with differing levels of unitization (LOU) ranging from high unitization (i.e., multiple pieces of information completely combined) to low unitization (i.e., multiple pieces of information completely separated; Park & Yonelinas, 2015). Unitization allows for better recognition because it increases the contribution of familiarity, however evidence is mixed regarding whether unitization has any impact on recollection (Diana, Ven den Boom, Yonelinas, 2011; Park & Yonelinas, 2015).

Unitization Increases the Contribution of Familiarity

Many methods have been used to show that the contribution of familiarity is increased when items are unitized relative to situations when items are not unitized (Ecker, Maybery, & Zimmer, 2013; Giovanello, Keane, & Verfaellie, 2006; Kan, et al., 2011; Kuo & Van Petten, 2008; Mitchell, Johnson, Raye, & Green, 2004; Quamme, Yonelinas, & Norman, 2007; Rhodes & Donaldson, 2007; Rhodes & Donaldson, 2008; Wilton, 1989). Improvements in memory due to unitization can occur through both stimuli manipulations (Ecker, et al., 2013; Kan et al., 2011; Kuo & Van Petten, 2008; Mitchell, et al., 2004; Wilton, 1989) and manipulations of task encoding instructions, (Giovanello, et al., 2006; Quamme, et al., 2007; Rhodes & Donaldson, 2007; Tibon, Gronau, Scheuplein, Mecklinger & Levy, 2014). As manipulations involving task instructions are most relevant to the present study, they are elaborated upon below.

Semantic Binding with Unitization. Most relevant to the present study, holistic processing of to-be-remembered information occur with semantic binding, such as manipulations to the processing of word pairs (Giovanello et al., 2006; Quamme et al., 2007; Rhodes &

Donaldson, 2007). Giovanello et al., (2006), found that when word pairs were presented as either compound word pairs (e.g., RAIN – BOW) or unrelated pairs (e.g., RAIN – FORK), participants were better able to remember the compound word pairs. Holistic processing of novel words pairs can also be induced under certain manipulations (Quamme et. al., 2007). When presented with novel word pairs such as CLOUD – LAWN, subjects were given sentences that either promoted holistic processing (e.g., a cloud lawn is a grassy area used for sky gazing) or that kept the words separate (e.g., while the boy laid in the lawn, he looked up at the clouds). When the word pairs were encouraged to be encoded holistically, the contribution of familiarity increased during recognition, however memory performance was equal across conditions.

Unitization as a Strategy

Familiarity can also be heightened through unitization in the form of participant initiated strategies (Bastin et al., 2013; Diana et al., 2008; Rhodes & Donaldson, 2008). It has been shown, in adults, that visual imagery is a useful memory strategy that improves memory performance on relational memory tasks more than overt strategies such as rehearsal (Bower, 1970; McGee, 1980). Visual imagery has been used to promote unitization and in doing so, increase familiarity in non-unitized stimuli. It should be noted that visualization strategies that promotes unitization makes use of LOU and specifically target familiarity and associative memory, as opposed to elaborative encoding strategies which are known to improve item memory (see Levels of Processing, Craik, 2002; Park & Yonelinas, 2015). Two primary visualization strategies have been used to show an increase in the contribution of familiarity through strategies that promote high unitization: 1) imagining a stimulus as a certain color and 2) imaging two stimuli interacting with each other. First, Diana, et al. (2008) tasked participants with remembering a word and the background color on which it was presented. Participants in the unitized condition were instructed to visualize a situation in which the item would be the color of the background. In contrast, participants in the non-unitized condition were instructed to visualize the item associated with another item the color of the background (e.g., a stop sign if the background was red and a dollar bill if the background was green). Results showed that although no statistical difference was observed in the ability to discriminate old from new items or the background color of the items between conditions, participants in the unitized condition showed a significant increase the contribution of familiarity to recognition, as shown by ROC curves (see also Bastin et al., 2013). Similarly, Rhodes and Donaldson (2008), tasked participants with remembering both associated and unassociated word pairs. Within their unitization condition, participants were told to use an interactive imagery strategy, whereas in their non-unitized condition participants were told to visualize both words separately. Different from Diana et al., (2008) Rhodes and Donaldson (2008) found that not only was familiarity increased for participants in the unitized condition relative to the non-unitized condition, they also performed better on the recognition memory task.

Memory Development

Previous research has shown that performance on relational memory tasks improves throughout childhood (Bemis & Leichtman, 2013; Drummey & Newcombe, 2002; Fandakova, Shing, & Lindenberger, 2013; Lloyd, Doydum, & Newcombe, 2009; Lorsbach & Reimer, 2005; Riggins, 2014; Scarf, Gross, Colombo, & Hayne, 2013; Yim, Dennis, & Sloutsky, 2013). For example, when tasked with remembering items, backgrounds, and item + background combinations, 4-, 6-, and 8-year-old children showed no differences in their abilities to remember items or backgrounds. However, the ability to remember item + background pairs, improved with age (Sluzenski et. al., 2006). Likewise, when similar aged children were tested on a novel fact paradigm that required remembering new facts along with who taught the facts, no age-related differences were observed in memory for the facts, but age-related improvements were observed in memory for who taught the facts (Drummey & Newcombe, 2002). In fact, a subsequent longitudinal study examining change between 4 and 10 years, pinpointed the period between 5- to 7-years of age as showing the most dramatic improvements in relational memory (Riggins, 2014). Gradual improvements continue into adolescence, particularly on difficult relational memory problems such as binding multiple items to locations on a grid (Lorsbach & Reimer, 2005).

The results of the above studies exploring the development of relational memory are consistent with studies exploring the development of familiarity and recollection, which suggest earlier maturation of the former compared to the latter. Billingsley, Smith, & McAndrews (2002), used a remember/know paradigm and observed changes in recollection from childhood (8-10 years of age) to adulthood, but no changes in familiarity. Likewise, in two conjoint-recognition studies exploring the development of familiarity and recollection, it was found that from early childhood to late childhood (5- to 11-years of age) recollection improved, where familiarity did not change (Brainerd, Holliday, & Reyna, 2004). When testing 6-, 8-, 10-, 12- and 14-year-old children using ROCs, Ghetti and Angelini (2008) observed that recollection improved throughout all age groups, whereas familiarity did not (when sufficient processing time was given, see Ghetti & Angelini; 2008 for details). This supports the notion that familiarity is relatively mature by early childhood (i.e., 6 years of age), however, recollection continues to develop into adolescence (Brainerd et al., 2004; Ghetti & Angelini, 2008).

Together, the studies above suggest a protracted development of recollection between middle childhood and adolescence, but relative maturity of familiarity during this time. It is possible that if a mechanism was used to increase reliance on familiarity during this period, it may improve children's relational memory by increasing the contribution of this relatively more mature processes. One proposed mechanism is unitization through visual imagery. Below, it will be discussed how unitization has been used to improve relational memory performance in populations similar to children.

Increasing Memory Performance in Special Populations

It is reasonable to suggest that unitization may boost relational memory performance (by increasing the contribution of familiarity) in young children who do not have fully developed recollection, as these strategies have been shown to improve performance in populations in which recollection has been compromised. First, multiple studies have shown that unitization can increase relational memory performance in patients with brain damage due to various causes (Ryan, Moses, Barense, & Rosenbaum, 2013;Quamme et al,2007) however it should be noted that these manipulation only worked if brain areas responsible for familiarity remained intact (Quamme et al., 2007). Additionally, it is well documented that elderly adults experience declines in episodic memory specially tasks requiring binding (for review see Naveh-Benjamin, 2000)and elderly adults have also been shown to benefit from unitization strategies (Bastin et al., 2013; Zheng, Li, Xiao, Broster, & Jiang, 2015; Zheng, Li, Xiao, Ren, & He, 2016).

Unitization in Childhood

Based on research in older adults showing improvements in relational memory performance, younger children may also benefit from a unitization strategy on relational memory tasks. Specifically, the hypothesis is that because familiarity has been shown to reach maturity earlier in development, unitization strategies may improve children's relational memory as it will increase reliance on relatively mature familiarity abilities. The direct question has not been empirically tested, however, there is some evidence that provides indirect support for this hypothesis. For example, bottom-up perceptual unitization has been observed in children as young as 5 years old (Hale & Piper, 1973; Spiker & Cantor, 1980). Although memory strategies show significant development from preschool to elementary school years, there is also support for the notion that children as young as 4 years of age can utilize memory strategies after training (for review see Schneider & Sodian, 1997). For visual imagery strategies specifically, children as young as 5 years of age have been shown to be capable of using visual imagery strategies after training and having them improve memory performance (Ryan, Ledger, & Weed, 1987).

Current Study

The goal of the present study was to determine if using a visual unitization strategy would improve performance on an associative memory task in children. Although unitization strategies have been used to boost relational memory performance in adult populations, this effect has not yet been tested in children. Two groups of children, 6-year olds and 8-year olds, were brought to the lab. These age groups were chosen because familiarity process are thought to be mature; however they differ in that recollection is thought to be more mature in 8 compared to 6-year olds (Ghetti & Angelini, 2008). Children were presented with pictures of common animals and items printed in black and white surrounded by either a red or yellow border. The encoding strategy was manipulated between-groups in order to limit carry-over effects from one strategy to the other. Two groups were trained in visual unitization strategies (*Unitization* group and *Interactive* group, following Diana et al., 2008, 2011 & Rhodes and Donaldson, 2008) and a third group was trained on a separate visualization strategy (*Non-Unitization* group). The Non-Unitization condition promoted elaborative encoding of the stimuli, but did not promote integration to the stimuli and color, so it was expect that this condition would rely heavily? on recollection. During retrieval, children were shown only the black & white images. They were asked to remember if the image's border was red or yellow and to make a confidence judgment on that decision. Confidence judgments were used to construct ROC curves and determine the relative contribution of familiarity and recollection for each group. Children have been shown to make accurate self-memory judgments by 5 years of age and ROCs curves have been constructed to observe the relative contribution of familiarity and recollection for children as young as 6 years of age (Ghetti & Angelini, 2008; Roebers, Gelhaar, & Schneider, 2004). It was predicted that relational memory would be improved by the visual unitization strategies (*Unitization* and *Interactive* conditions) due to the increased contribution of familiarity, which was thought to be mature in both groups.

Method

Participants

A total of 127, 6- and 8-year old children recruited from the University Infant and Child Studies Database. Children were assigned to one of the three experimental conditions (See Table 1). This sample size was determined from a power analysis with parameter estimates based on the results of Diana et al. (2008). Data from 8 children were excluded due to computer errors (n = 3), non-compliance (n = 2), failing the practice (n = 2) and not using the confidence scale (n=1). It should be noted that collection for the *Non-Unitization* condition began after collection to the *Unitized* and *Interactive* Conditions.

To ensure all children were capable of understanding the task instructions and completing the task, participants with known developmental disorders, who were colorblind, or who heard English less than 50% of the time were excluded from participation. Parents provided informed consent for all participants and 8-year-old children also provided written assent. All children received a small gift for participating.

Table 1: Participant Demographics

	Mean Age in Years (*SD*)	Total N (% Male)
6-year olds		
Unitized	6.59 (0.37)	19 (57.9%)
Interactive	6.41 (0.28)	21 (42.9%)
Non-Unitized	6.29 (0.24)	19 (36.8%)
8-year olds		
Unitized	8.28 (0.20)	21 (61.9%)
Interactive	8.38 (0.33)	19 (36.8%)
Non-Unitized	8.36 (0.29)	20 (35.0%)

Materials

Training stimuli. Four black and white images from the Snodgrass & Vanderwart (1980) line drawings were used for the training portion of the study. These images are standardized, contain common objects and animals, and had been frequently used with children of similar ages to the present study (e.g., Cycowicz, Friedman, & Duff, 2003; Lloyd, et al., 2009). The images were printed on standard stock paper. Two of the images were surrounded by a red border and two were surrounded by a yellow border. Colored images of a red apple and a yellow school bus were laid on the desk within all children's view. Red and yellow crayons were provided to ensure the children understood the task.

Encoding stimuli. An additional 120 black and white images from the Snodgrass and Vanderwart (1980) line drawings were used for the encoding portion of the task. All images were presented on a computer monitor to keep exposure as consistent as possible between subjects. Half of the images were surrounded by a red border and half by a yellow border. All images were adjusted to be similar in size and as centered as possible within the border. The image-color pairings were counterbalanced between subjects and presented in random order. Stimulus presentation and randomization was programmed with E-Prime® 2.0 (Psychology Software tools).

Retrieval. During the retrieval portion the same Snodgrass & Vanderwart (1980) images displayed during encoding were shown again except without the colored borders. A 3-point smiley face confidence scale was presented at the bottom of the screen to aid children in their confidence decision. Similar scales have been used in previous research with children of this age and have been shown to aid in helping children make accurate memory judgments (Roebers, et al., 2004). To ensure consistency across participants, all verbal responses were recorded by the experimenter with a standard keyboard.

Procedure

This study took place in 1 session that lasted approximately an hour and a half. The session consists of three portions: (1) training to ensure participants understood the task (2) encoding, and (3) retrieval. The procedure was modified from the methods of Diana et al. (2008) to be appropriate for use with children. Between the encoding and retrieval portions participants received a 10 minute snack break. The study was explained to the participants as a story-telling exercise or fact-telling exercise. The University Institutional Review Board approved all of the following methods.

Training. To ensure participants fully understood the directions of the task, they participated in a brief training session. First, participants were trained in how to visualize.

Participants were instructed to close their eyes and picture in their mind a red apple. They were told basic features of an apple to aid the visualization process and then opened their eyes and a printed image of an apple was revealed. Participants were asked to confirm that what they pictured in their minds looked similar to the image. This process was repeated with a yellow school bus.

Once successful visualization of the red apple and yellow school bus were established, participants were trained on the specific visualization instructions for their randomly assigned condition. All subjects were presented with 4 training stimuli, an elephant with a red border, a shirt with a yellow border, a yoyo with a red border, and a butterfly with a yellow border. Participants in the U*nitized* condition were instructed to: "Come up with a story for why the picture would be the color of the border (i.e., red/yellow)." They were informed that their stories did not need to be realistic and they could be as creative as they wanted. Children who struggled during the practice were provided with example stories to use as a guide. After the children had provided their story, they were told to visualize the story in the same manner in which they visualized the apple and school bus. Participants were asked what color the item they were picturing was. Then, participants were given the red and yellow crayon, and asked to color the printed stimuli the way they pictured it. Participants passed the practice trial if they completed coloring in the image with the correct color. Participants were given feedback if they did not fully color in the image. This process was repeated for all 4 training items. If by the end of the 4 trials participants had not correctly colored any of the stimuli, they were excluded from analysis.

Participants in the *Interactive* group completed the same training as those in the *Unitized* group, with the exception that they were instructed to "come up with a story for why the pictured item would be interacting with another item the color of the border." The specific items for the red and yellow border were always a red apple and a yellow school bus. After the child gave their story, they were told to visualize their story like they did with the apple and school bus during training. Participants were then given a red and yellow crayon to color the printed stimuli the way they pictured it (i.e., they were expect to draw either the apple or school bus next to the stimuli). Participants were corrected if they did not draw the correct interacting item near the stimuli. As in the *Unitized* condition, this process was repeated for all 4 training items and if by the end of the 4 trials participants had not drawn the correct item near the stimuli, they were excluded from analysis.

Participants in the *Non-Unitization* group had similar training to those in the unitization groups, with the exception that they did not complete a story-telling task. Instead, participant in the *Non-Unitization* group were instructed to generate facts about the picture on the screen. All participants told either one or two facts. For example, for the target image of an elephant, children gave facts such as, “Elephants are big and have big ears” or “They can squirt water at you.” After the children told their facts, they were told to close their eye and visual first the picture and then either an apple or a school bus depending on the color of the border. This condition was designed to keep encoding time, verbal generation, and visualization of both the picture and color as similar as possible to the other conditions with the exception that the picture and color were not integrated. During the coloring phase the children in this condition were instructed to draw what they visualized after the picture. Children were corrected if they did not draw either the apple or the school bus. These tasks kept the *Non-Unitization* condition as similar as possible in verbal generation, focus on the pictured item, and visualization, they just did not complete any tasks that would cause unitization between the picture and the color. Again, this process was repeated for all 4 training items and no children failed the training task in the *Non-Unitization* condition.

Encoding. After the training portion, participants began the encoding portion of the experiment. Participants were presented with stimuli from the same image set as those viewed during the training portion. The images remained on the screen for the length of time it took the participants to come up with their story or give their facts, in order to reduce the cognitive load during encoding (see Ghetti & Angelini, 2008 for rationale). Similar to the training, participants were instructed to come up with either a story or facts based on their condition, and then complete their specific visualization task. Once the story and visualization were complete, the experiment moved on to the next stimulus. If children provided stories that were not appropriate for their given condition, they were corrected by the experimenter and asked to try again[1]. This process continued for 120 stimuli.

Retrieval. The retrieval portion began approximately 10 minutes after the encoding portion had ended. Participants again viewed the images they saw during encoding, but during retrieval all images were presented with no border. Participants were first instructed to respond whether the image was originally presented with a red or yellow border. Once the color judgment had been made, participants rated their confidence of that judgment on a 3-point scale. A smiley face scale was be provided to aid the children in their judgments. A happy face represented a 3, very confident, a neutral face represented a 2, a little confident, and a confused face represented a 1, not confident or guessing. Participants were encouraged to use the entire scale in their judgments.

Data Analytic Approach & Results

[1] Children rarely needed to be corrected. Fewer than 10 children were ever corrected, and the two children who consistently gave incorrect stories were removed from analyses and labeled as non-compliant.

All analyses consisted of a model comparison approach utilizing Bayes Factors within the ANOVA framework (Rouder, Morey, Speckman, & Province, 2012). This approach provides benefits beyond NHST approaches, because opposed to a dichotomous decision, BFs provide an index of how well the data support one of two competing hypotheses, allowing for claims to be made regarding both effects and lack of effects, which only the former claim able to be made using NHST. Bayes Factors fall along a continuum with values greater than 1 represent greater support for the more complex (i.e., alternative) hypothesis, whereas Bayes Factors less than 1 represent greater support for the more simple (i.e., null) hypothesis. The approach does not included thresholds for decision making and instead values further away from 1 are thought to represent greater support for that particular hypothesis. However, it is generally accepted that Bayes Factor less between .33 or 3 (representing 3/1) do not provide enough evidence for either hypothesis to make a strong claim (Jeffreys, 1961). For the results of null hypothesis significance testing go to https://osf.io/fb7vk/.

All analyses were run using the BayesFactor package in R and used the default prior, which this package defines as a distribution of prior probabilities of effect sizes using the Cauchy distribution centered at 0, originally suggested by Jeffrey's (1961). This prior represents the belief that potential observed effect sizes are more likely to be small than large. For comparison utilizing a null effect, it was defined as a point null = 0.0. Additional sensitivity analyses were run to determine the impact of widening the priors on outcomes, however no outcomes changed and therefore only results with the default priors are presented.

Differences in memory performance. A measure of children's ability to discriminate the correct from incorrect color (d'), regardless of confidence rating, served as the dependent variable for the comparison between groups. For all analyses, d' was calculated with red as the target color. Main effects of Age and Condition were compared against a null model and their interaction was compared against a model with both main effects.

There was decisive support for a main effect of Condition (BF_{10} = 8.41 x 10^{18}). Follow-up analyses revealed support for memory performance being greater for both the *Unitized* and *Interactive* conditions compared to the *Non-Unitization* condition (BFs_{10} = 7.65 x 10^{15}, 2.30 x 10^{15}). Results, however, were inconclusive regarding differences between the *Unitized* and *Interactive* Conditions (BF_{10} = 1.72). There was weak support for no differences in Age (BF_{10} = 0.36) and no Age X Condition interaction (BF_{10} = 0.61).

Due to suggestions from past developmental work (Lloyd, et al., 2009), the proportion of items with the color correct and color incorrect were also analyzed separately. Results were largely the same, with the exception that there was now substantial evidence for no main effect of Age (BF_{10} = 0.26) or an Age x Condition interaction (BF_{10} = 0.20) rather than the week evidence found with d'. The number of color correct items, color incorrect items, and d' for each group are presented in Table 2.

Table 2: Percent correct and d' for both age groups, M(*SD*)

	Color Correct (%)	d'
6-year olds		
Unitized	0.75 (0.10)	1.44 (0.65)
Interactive	0.78 (0.11)	1.60 (0.72)
Non-Unitization	0.52 (0.06)	0.10 (0.29)
8-year olds		
Unitized	0.77 (0.10)	1.57 (0.65)

Interactive	0.83 (0.13)	2.19 (0.97)
Non-Unitization	0.52 (0.08)	0.13 (0.42)

Exploration of encoding time differences between groups. In the present study, encoding time was not held constant between participants; instead the encoding period lasted as long as it took the children to generate their stories. Exploratory analyses were conducted to determine if encoding times differed between the different conditions and age groups. Mean encoding times across all stimuli for each age group and condition are summarized in Table 3. Results were inconclusive regarding differences in encoding times between Condition (BF_{10} = 0.97), between Age groups (BF_{10} = 0.45), and for a Condition x Age interaction (BF_{10} = 0.18). Encoding time was not related to retrieval accuracy (BF_{10} = 0.27), and when encoding time was added as a covariate in the main analyses, all results related to differences in retrieval accuracy remained the same.

Table 3: Encoding Times for all groups in minutes, M(sd)

	Encoding Times
6-year olds	
Unitized	36.48 (7.69)
Interactive	33.00 (11.82)
Separate	28.29 (8.23)
8-year olds	
Unitized	37.22 (10.28)
Interactive	32.85 (7.62)
Separate	34.98 (9.43)

Contribution of familiarity & recollection. To determine if the conditions differed in the contribution of familiarity Receiver Operating Characteristics (ROCs) were constructed for individual subjects and then averaged across condition and age groups (see Figure 1). For a review of ROC analyses see Yonelinas & Parks (2007). ROCs compare the proportion of color correct to color incorrect responses at different levels of confidence. Participants' 3-point confidence judgments within each color were combined to create a 6-point scale ranging from Very confident yellow (1) to Very confident red (6). Analyses were run testing for differences in the proportion of confidence responses given at each level between age groups. No differences were found, all $BF_{10} < 0.28$. The proportion red and yellow responses were taken cumulatively for each confidence level starting at 6 through confidence level 2, for a total of 5 points. In this way, the cumulative proportion of yellow responses were plotted on the x-axis and cumulative proportion of red responses are plotted on the y-axis similar to proportions of false alarms and hits plotted in traditional ROCs of recognition memory. Confidence levels of 1 are not plotted because they always result in a proportion of 1.0 for both cumulative red and yellow responses.

Linearity Analysis. Once individual's plot were made, linearity analyses were performed. First, polynomial trend lines were fit to each individual's ROCs. The 2^{nd} order coefficient values were recorded for each polynomial trend line (*Unitized* M(sd)= -2.65 (2.95), *Interactive* M(sd) = -4.00 (4.28), *Non-Unitization* M(sd) = -0.25 (1.14)). Based on the assumption that increasing the contribution of familiarity increases the curvature of the fit-line, the mean 2^{nd} order coefficient served as an index of the level of familiarity contributing to retrieval[2]. Model comparisons were

[2] As stated in Yonelinas & Park (2007), "as overall recognition performance becomes very poor, the ROC approaches the chance diagonal, at which point it will necessarily have a slope of 1.0". Ratcliff et al (1992) cautions against linearity ROC analyses for d' less than 0.5, which was clearly violated in our Non-Unitized condition. These findings beg to question the legitimacy of the curvilinearity analysis for the Non-Unitized condition.

run comparing a model with a main effect of condition to a null model to examine differences in the second-order polynomial term from the linearity analysis. The overall Bayesian ANOVA supported difference between conditions (BF_{10} = 9231.22). Follow-up analysis showed decisive support for both the *Unitized* and *Interactive* conditions having greater curvature to their best fit lines compared to the *Non-Unitization* Condition (BFs_{10} = 1749.15, 11,578.57). However differences between the *Unitized* and *Interactive* Conditions were inconclusive.

Parameter Estimates. To complement the above linearity analysis, estimates of familiarity and recollection were derived by fitting a dual-process model of memory to the individual ROCs (Yonelinas, 1994; 1997). Under the dual process model, the probability of getting a source correct response can be defined as the probability an item is recollected as the target color plus the probability that it is not recollected as the target color, but is familiar enough to fall above the threshold level.

$$P(\text{Source Correct}) = R_t + (1-R_t)\varphi(d'/2-c_i)$$

In the above equation, R_t represents the recollection estimate of the target color (for the purposes of this paper, red), d' represents the familiarity estimate, c represents a specific criterion level (e.g., confidence level), and φ is a function representing the cumulative proportion of responses exceeding a response criterion. The probability of a false alarm, however, is represented as the probability that an item is recollected as the lure color (for the purpose of this paper, yellow), but is familiar enough to fall above the threshold level.

$$P(\text{Source Incorrect}) = (1-R_l)\,\varphi(-d'/2c_i)$$

These two equations can then be combined to give an overall representation of relational memory performance.

$$P(\text{Source Correct}) - P(\text{Source Incorrect}) = R_t + (1-R_t)\varphi(d'/2c_i) - (1-R_l)\varphi(-d'/2c_i)$$

Using a sum of squares search algorithm, this model was fit to each individual's ROC points. The algorithm finds the best fit of the model by finding the parameters that result in the smallest sum of squares error assuming variance in both hits and false alarms. Specifically, the algorithm finds the parameter estimates for the three free parameters (R_t, R_I, and d') that minimize the distance between the observed known parameters (Source correct rate, Source Incorrect rate, and criterion levels) and those predicted by the model. This results in probability recollection terms for each color that can vary from 0 to 1, and a d' familiarity term that typically varies from 0 to 4[3]. The recollection and familiarity terms were compared between age groups and conditions using model comparisons and Bayes Factors (see Table 3).

For the estimates of familiarity, effects of Age, Condition were compared against a null model, and their interaction was compared against a model with both main effects. There was decisive support for differences in the contribution of familiarity between conditions (BF_{10} = 645633924), with support for differences between the two groups involving unitization and the *Non-Unitization* group (BFs_{10} = 79298546, 867792759), however results were inconclusive regarding differences between Unitized and Interactive Groups (BF_{10} = 1.25). Results were uninformative regarding the main effect of Age (BF_{10} = .52 and the Age x Condition interaction (BF_{10} = 2.05).

For the estimates of recollection, effects of Age and Condition and their interaction were compared against a model including only color and set as covariates. As with familiarity, there was support for a main effect of Condition (BF_{10} = 297897968). Follow-up analysis showed support for no differences between the Unitized and Interactive groups (BF_{10} = 0.18), however

[3] Although the curvilinearity analysis may be untrustworthy for lower performance condition, such concerns do not apply to the parameter estimation analyses. This type of method is known to be problematic when performance is very high, but we are unaware of similar cautions when performance is low (Yonelinas, 1999).

both of these groups showed a greater contribution of recollection than the *Non-Unitization* group (BFs_{10} = 595235715, 297897968). There was substantial support for the no differences between age groups (BF_{10} = .15) and no Age X Condition interaction (BF_{10} = 0.20).
Because the contributions of both familiarity and recollection were found to be higher for both of the unitized groups (i.e., Unitized and Interactive) than the Non-Unitized group, additional exploratory analysis was run to determine which memory component was responsible for the increase in memory performance.

For all three conditions dominance analysis was run to determine the contribution of familiarity, recollection for red items, and recollection for yellow items to memory performance (d'). Dominance analysis provides a qualitative assessment of the relative importance of all predictors in a multiple regression. The results provide a dominance score for each predictor indicating its relative importance compared to the other predictors. The sum of the dominance scores sum is equivalent to the R^2 of the model with all predictors included. One of the biggest strengths of this methods is it allows for the comparison of the relative importance of multiple predictors in a regression framework (Azen & Budescu, 2003) removing issues related to multicollinearity. Table 5 shows the overall R^2 for each regression broken down into the portion that can be explained by each predictor. Larger values represent greater importance of that particular predictor in explaining memory performance. For all three conditions familiarity was a more important predictor of memory performance than recollection for either color, and the importance of familiarity was greater for the two Unitized conditions (Unitized and Interactive). This suggests that familiarity may be playing a larger role in memory performance than recollection, thus the increase in memory performance with unitization can be primarily attributed to familiarity.

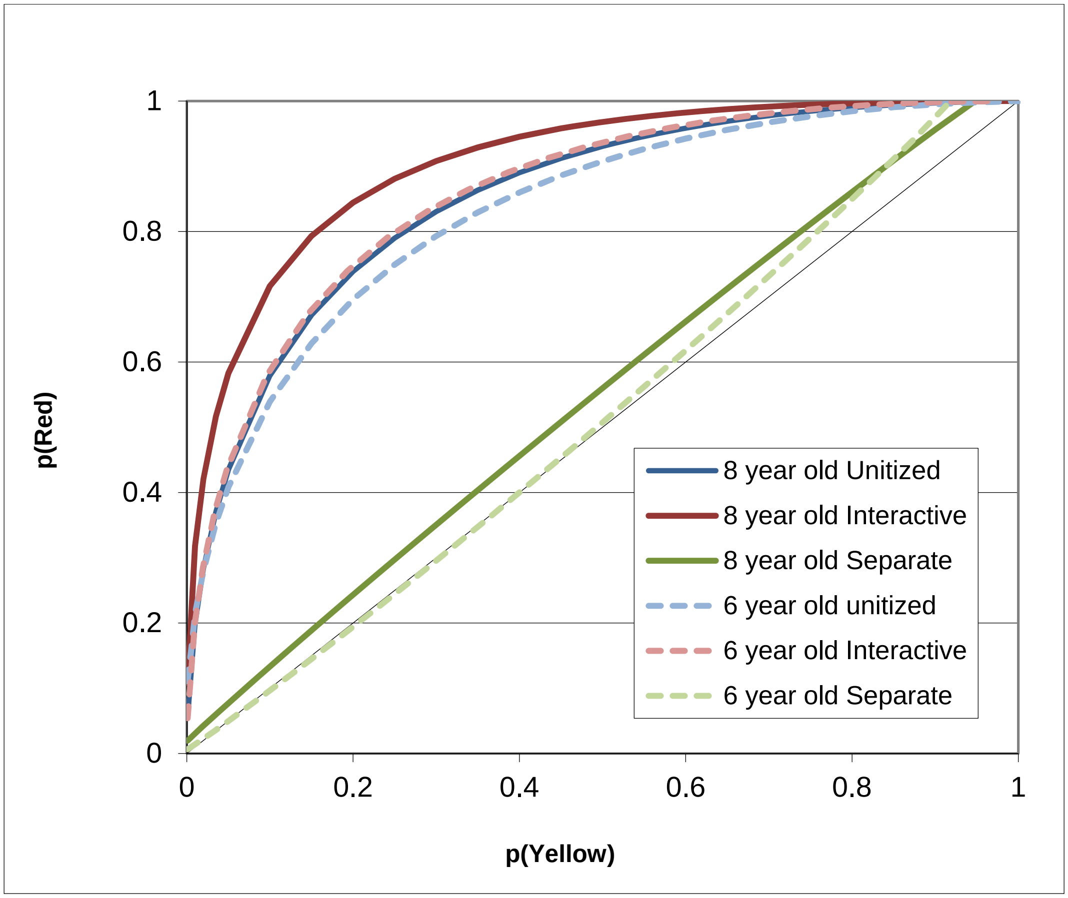

Figure 1. ROC curves for each of the six conditions.

Table 4. Estimates of Familiarity and Recollection, with Recollection estimates collapsed across color, M(sd)

	Familiarity	Recollection
6-year-olds		
Unitized	0.97 (0.74)	0.21 (0.20)
Interactive	1.00 (0.75)	0.27 (0.25)
Non-Unitized	0.07 (0.15)	0.03 (0.05)
8-year-olds		

Unitized	0.98 (0.66)	0.26 (0.24)
Interactive	1.76 (1.08)	0.23 (0.25)
Non-Unitized	0.12 (0.18)	0.05 (0.10)

Table 5. Results of Dominance Analysis showing the relative importance of Familiarity and Recollection to memory performance with Recollection added across colors.

	Familiarity	Recollection
Unitized	0.70	0.24
Interactive	0.77	0.13
Separate	0.45	0.38

Table 6. Estimates of Familiarity and Recollection, M(sd)

	Familiarity	Recollection (red)	Recollection (Yellow)
6-year-olds			
Unitized	0.93 (.82)	0.26 (.24)	0.18 (.19)
Non-Unitized	0.95 (.84)	0.28 (.26)	0.28 (.24)
8-year-olds			
Unitized	0.98 (.69)	0.26 (.27)	0.26 (.23)
Non-Unitized	1.66 (1.28)	0.33 (.28)	0.15 (.23)

Discussion

The goal of the present study was to determine if using visual unitization strategies would improve children's performance on a relational memory task through the increased contribution of familiarity. The results of the present study showed that, in fact, children who used visual unitization strategies (i.e. the Unitized and Interactive groups) performed better on the relation memory task and had higher contributions of familiarity than the children who used the *Non-Unitization* visualization strategy. Additionally, along with greater contributions of familiarity, children who used unitization strategies also showed greater contributions of recollection at retrieval. However, dominance analysis suggested familiarity contributed to the increase in memory relatively more so than recollection.

Previous studies in adults have also found significant differences in the contribution of familiarity for unitized and non-unitized conditions (Diana et al., 2008; Diana, et al., 2011; Bastin, et al., 2013; Rhodes and Donaldson, 2008), however the comparisons used in past adult work differ slightly from the comparisons used in the present study. For example, Rhodes and Donaldson (2008) used conditions similar to our *Interactive* and *Non-Unitization* conditions, whereas Diana et al (2008, 2011) and Bastin et al (2013) compared the *Unitized* condition used in the present study with a condition where participants visualized a word and color associated with each other. To our knowledge this is the first study to directly compare the Unitized and Interactive conditions in this manner, and while both were found to improve memory performance relative to a non-unitized condition, results were inconclusive regarding if one type of unitization is more effective than the other. Future research is needed to determine differences in levels of unitization between these and other conditions to determine which manipulations lead to the greatest contribution of familiarity.

In contrast to most findings in adult studies, in addition to an increase in the contribution of familiarity with visual unitization, we also observed an increase in the contribution of recollection (cf. Parks & Yonelinas, 2015). The proportional contribution of recollection however was much higher in the Non-Unitized condition, as would be expected. The three conditions were kept as similar a possible regarding total time spent at encoding, length of verbal response from the child, and the number of items visualized, however one primary difference between the two unitized conditions and the separate condition was the generation of novel ideas versus the recitation of semantic knowledge. One potential concern of the present study however, is the remarkably poor performance in the Non-Unitized condition. There are several potential explanations for this findings. First, the children in this study may not have had mature enough recollection process to succeed on this task, as adults have been shown to perform above chance on similar conditions (i.e., Rhodes & Donaldson, 2008). Second, generating stories for both of the unitized conditions was likely a more engaging and salient task leading to more opportunities for deeper connections and relations to be formed increasing the contribution of recollection. Even though performance in this condition was low, it does not contradict the original hypothesis and instead emphasizes how beneficial unitization strategies during early childhood can be. It should be noted however, that due to the poor performance in this condition the linearity analyses may not be reliable (Yonelinas & Park, 2007) and therefore future studies should aim to compare additional conditions where the contribution of recollection is more comparable to the unitized conditions.

An additional surprising finding about recollection in the present study was the lack of difference in the contribution of recollection between the two age groups. Previous studies have suggested recollection abilities increase between 6 and 8 years of age (e.g., Ghetti & Angelini, 2008; Sluzenski et al., 2006), however no age related differences were found in the present study. There are several potential explanations for why differences in recollection were not observed in the present study. One potential explanation is the age difference between the groups was not large enough. The present sample had an average age difference of slightly less than two years. While existing literature is consistent in the notion that familiarity develops before recollection, the precise age points at which the developmental trajectories deviate is unclear. A larger distance between the age groups may have revealed differences in recollection emerging, however it would have led to other methodological issues (e.g., greater differences in story telling capabilities, confidence scale use, etc…). Another possible explanation for the lack of differences in recollection between the two groups is the task that was used in the present study. Many previous studies exploring the development of recollection have used easier tasks (e.g., having children remember more distinct pairing such as animals and unique background (Sluzenski, Newcombe, & Kovacs, 2006) or toys and locations (Riggins, Rollins, & Graham, 2013), rather than black and white pictures with arbitrary colored borders). Aside from being asked to visualize either the apple or the school bus, children in the separate condition did not have their attention drawn to the border and therefore there was little episodic context to recollect.

This study serves as an example as to how empirical work in adults can be used to address applied questions within developmental research. We have taken current memory theory and methods commonly used in adults and used them to improve memory performance in children. There were however difficulties in applying these adult paradigms to a developmental sample. First, tasks instruction had to be adjusted to match a 6-year old's vocabulary potentially losing some of the nuanced differences between conditions when used with adults. For example, previous adult work has compared our *Unitization* condition to an *Associated* condition (Diana et al., 2007; 2008). We however, were unable to come up with task instructions to explain the associated condition to children of this age and therefore just the *Interactive* condition as used.

Additionally, as children are known to be overconfident in their memory abilities (Roebers, 2002), there was difficulty in getting the younger children to use the entire confidence scale making the ROCs and parameter estimates less reliable that they would be with adults.

Additionally this was the first study to directly compare pure unitization and interactive imagery as visual unitization strategies. However, differences between them were unclear and therefor more research is need to determine what is necessary for unitization to occur and benefits to be observed. Potential methods for tapping into these subtle differences involve comparing conditions in adult populations that can understand minute differences in task instructions and exploring the neural substrates. Additionally, future studies should more closely examine specific details of the generated stories such as distinctiveness, vividness, or meaningfulness, and how thought factor related to memory performance in potential increases in familiarity.

Overall the results of this study show that relational memory performance can be improved in early childhood through the use of visual unitization strategies and that these strategies improve performance even more than separate visualization strategies. Moreover, unitization increased the contribution of familiarity as well as recollection, however improvements in performance were predominantly attributable to increases in familiarity. This finding is particularly exciting as it shows we can teach children strategies that make use of their earlier developing familiarity processes (Billingsley et al., 2002; Brainerd et al., 2004; Ghetti & Angelini, 2008). As stated in the introduction early childhood is a period of rapid development of relational memory abilities (Bemis & Leichtman, 2013; Drummey & Newcombe, 2002; Fandakova et al., 2013; Lloyd et al., 2009; Lorsbach & Reimer, 2005; Riggins, 2014; Scarf et al., 2013; Yim et al., 2013) however with the use of unitization strategies such as those used in this study, we can help children succeed on these tasks, while development is still occurring.

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