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The Cost of Learning: Interference Effects in Memory Development

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Learning often affects future learning and memory for previously learned information by exerting either facilitation or interference effects. Several theoretical accounts of interference effects have been proposed, each making different developmental predictions. This research examines interference effects across development, with the goal of better understanding mechanisms of interference and of memory development. Preschool-aged children and adults participated in a 3-phased associative learning paradigm containing stimuli that were either unique or repeated across phases. Both age groups demonstrated interference effects, but only for repeated items. Whereas proactive interference effects were comparable across age groups, retroactive interference reached catastrophic-like levels in children. Additionally, retroactive interference increased in adults when contextual differences between phases were minimized (Experiment 2), and decreased in adults who were more successful at encoding repeated pairs of stimuli during a training phase (Experiment 3). These results are discussed with respect to theories of memory and memory development.

Keywords: learning, memory development, cognitive development

There is much work suggesting that learning and memory interact, in that previously acquired knowledge affects acquisition of new knowledge (Krascum & Andrews, 1998; Murphy & Allopenna, 1994), and newly acquired knowledge affects memory for established knowledge (Roediger & Marsh, 2005). In some cases this interaction is facilitative. For example, expertise in a particular domain often benefits memory for information within that domain (Chi, Glaser, & Rees, 1982; Guida, Gobet, Tardieu, & Nicolas, 2012). Previous knowledge may also assist category learning (Murphy & Allopenna, 1994) and learning of causal relations (Griffiths, Sobel, Tenenbaum, & Gopnik, 2011). Similarly, seminal work by Ebbinghaus demonstrated savings effects, in which unconscious memory for previous learning facilitates later learning of the same information (Nelson, 1985).

At the same time, interactions between learning and memory can also produce interference effects: Under some conditions, memory for previously learned information attenuates learning of new information (i.e., proactive interference; PI), whereas under other conditions, learning of new information attenuates memory for previously learned information (i.e., retroactive interference; RI). For example, a professor may experience PI when finding it difficult to learn students' names at the beginning of each semester, as he or she has taught many students previously. At the same time, RI may affect the professor's ability to recall the name of a particular student from a previous semester, as he or she has since learned the names of other students. Interference effects can be relatively benign, as in this example, but can also be very disruptive for learning and memory. As discussed in the section on Mechanisms of Interference resistance to PI and RI and developmental changes in these effects may provide important information about mechanisms of interference and about memory development. The current research examines developmental differences in interference with the goal of better understanding mechanisms of PI and RI effects and of memory development.

Researchers have studied interference effects experimentally for over a century, producing a wealth of theories and insights into the mechanisms of learning and memory (see Anderson & Neely, 1996; Wixted, 2004, for reviews). Traditionally, susceptibility to PI has been related to the integrity of executive function, in that executive control processes help to minimize PI effects (see Anderson & Neely, 1996; Jonides & Nee, 2006, for reviews). Some researchers have suggested that susceptibility to RI is also a function of executive control, in that executive processes create RI by inhibiting memories during retrieval that are not currently relevant (Anderson, 2003; Bjork, 1989). Other work, however, suggests that susceptibility to RI may be modulated by the integrity of memory traces subserved by encoding and consolidation processes (Humphreys, Bain, & Pike, 1989; McClelland, McNaughton, & O'Reilly, 1995). Studying interference effects in different developmental populations in which processes of executive control and memory formation are known to differ can shed light on the mechanistic underpinnings of interference, as well as inform our understanding of memory development. We will return to this issue in the section on interference and memory development.

A standard way of experimentally examining PI and RI effects would be to present a learning Task X (e.g., Study List 1) followed by a learning Task Y (e.g., Study List 2). PI is typically defined as attenuation of learning on List 2 that is not attributable to fatigue or other nonmemory factors (see Anderson & Neely, 1996; Jonides & Nee, 2006; Kail, 2002, for reviews). Similarly, RI is typically

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defined as attenuation of memory for information presented in List 1 following learning of List 2 (assuming that attenuation is not attributable to fatigue or other nonmemory factors; see Wixted, 2004, for a review). Comparison of learning in List 1 before and after learning in List 2 also provides information about savings effects, which may be defined as improved performance when relearning List 1. The presence of savings effects indicates that some memory is preserved even in the face of RI, whereas the absence of savings effects (or even *negative savings*—attenuation of learning when the same material is learned the second time) may indicate severe RI, after which little or no memory is preserved or accessible. As we discuss later in this section, such interference is similar to catastrophic interference observed in some connectionist systems.

A model paradigm used to investigate interference is the paired-associates learning task, in which participants study lists of arbitrarily paired items, such as *bag-tree* (which can be presented either as words or as pictures). Researchers often refer to these lists in abstract notation, such as "AB," indicating a paired association between a cue from Set A and a target from Set B. After learning the AB list, participants learn a second list of pairs before memory for both lists is tested. The second list can include completely new cues and targets (CD), cues from the first list paired with novel targets (AC), or cues and targets from the first list that are paired differently. The paradigms associated with these list structures are denoted AB-CD, AB-AC, and AB-ABr, respectively.

During testing, participants are typically presented with a cue from a particular pairing and are asked to identify the associated target. PI is identified as attenuated memory for targets from the second list, and RI is identified as attenuated memory for targets from the first list following learning of the second list. Memory performance is compared with baseline conditions in which participants learn the first list but not the second (controlling for RI), or learn the second list but not the first (controlling for PI). In general, AB-AC and AB-ABr paradigms generate the greatest amount of interference and are commonly used to study these effects (see Wickelgren, 1973, for a review).

Although early studies of interference effects greatly contributed to our understanding of memory, this work has been often criticized for focusing on list memory and thus representing a narrow set of memory phenomena (see Dempster & Corkill, 1999, for a review). Later research has indicated the ubiquity of interference effects in learning and memory, which have transpired across a wide range of populations and tasks. For example, PI and RI have been documented in early development using a variety of tasks used with infants and preschoolers (Fagan, 1977; Howe, 1995; Lee & Bussey, 2001; Mareschal, Quinn, & French, 2002; Rossi-George & Rovee-Collier, 1999; Tyrrell, Snowman, Beier, & Blanck, 1990).

Finally, interference effects have contributed to our understanding of learning and memory in some unexpected ways. For example, although people typically experience only partial forgetting of information resulting from interference, early connectionist models exhibited catastrophic RI, in which new learning produced almost complete forgetting of previously learned information (McCloskey & Cohen, 1989; Ratcliff, 1990). Such dramatic (and unexpected) memory failures of the early connectionist systems resulted in proposals of complementary learning systems, one subserved by the hippocampus and one by the neocortex (McClelland et al., 1995). Implementing this complementary learning systems approach in connectionist models resulted in substantially attenuated interference effects (McClelland et al., 1995; Norman & O'Reilly, 2003). Overall, interference effects have profoundly affected our understanding of learning, memory, and (as we argue in the section on interference and memory development) of cognitive development. In what follows, we review the proposed mechanisms of both kinds of interference and major findings generated by these proposals.

Mechanisms of Interference

Proactive Interference (PI)

PI has been traditionally linked to executive functions, including attention, working memory, and cognitive flexibility, and thus to the integrity of the prefrontal cortex (see Jonides & Nee, 2006, for a review). For example, Engle and colleagues (Engle, 2002; Kane & Engle, 2000) demonstrated that resistance to PI depends on working memory span, with participants with low spans exhibiting greater interference effects than participants with higher spans.

There is also a large body of developmental research linking PI with cognitive flexibility. In these tasks, infants and young children learn to respond to a set of stimuli in a particular way. Later, these contingencies change, such that success in the task requires flexible switching. Many infants and children continue to respond to the stimuli according to the first set of contingencies. Infants, for example, demonstrate perseveration in the A-not-B task by continuing to search for an attractive object where it had been hidden previously, despite watching the experimenter hide the object in a new location (Diamond, 1985; Piaget, 1963). Older children also demonstrate perseveration in the Dimensional Change Card Sort test (Zelazo, 2006), by failing to follow instructions to switch to a new dimension (e.g., shape) and continuing to sort objects according to a previously relevant dimension (e.g., color). Many children perseverate even when aware of the new sorting dimension (Munakata & Yerys, 2001; Zelazo, Frye, & Rapus, 1996). Although perseveration effects are typically discussed as measuring such processes as executive control and working memory, whereas PI effects are often discussed as a phenomenon of long-term memory, the similarities between these phenomena are striking, in that both involve difficulty learning new information as a result of learning prior information (for discussions, see Diamond, 1985, 1988; Zelazo et al., 2003).

Given that PI is often linked to mechanisms of working memory and may be compared with children's errors of perseveration, there is little surprise that one of the most prominent theories of the cognitive mechanisms of interference (Anderson, 2003; Anderson, Bjork, & Bjork, 1994) links PI to an important aspect of executive function—inhibitory processes. Consider the AB-AC paradigm: When cue A_i is presented during learning of the second list, it activates a previously learned, prepotent association with B_i, thus requiring the learner to actively inhibit this response in favor of C_i. Successful inhibition of B_i results in correct performance, whereas failure to inhibit B_i results in PI. However, inhibition is not cost-free: Success at inhibiting B_i allows learning of association A_iC_i, but may result in forgetting of association A_iB_i, thus potentially giving rise to RI.

RI

One way of explaining RI is through inhibitory processes. The idea is that if cues in two lists overlap (as in AB-AC lists), then learning of the A_iC_i pairing in the second list requires inhibiting the learned response B_i. This inhibition results in RI—forgetting of the original A_iB_i pairing. In contrast, failure to inhibit B_i results in PI, with little or no RI.

Evidence for this framework has been found in adults using the retrieval practice paradigm (Anderson et al., 1994). In this paradigm, participants studied a list of exemplars from a given category (e.g., Fruit: Orange, Banana, Apple, etc.). Participants were then primed to retrieve only a subset of these items before being tested on all items. The primary finding was that practice resulted in higher memory accuracy for practiced items, but lower accuracy for unpracticed items from the practiced category, relative to items from categories that were not practiced at all. These findings suggest that retrieval of the practiced items inhibited memory for unpracticed items from the same category, thus making it more difficult to recall these items even when a nonpracticed retrieval cue was used (Anderson, 2003).

Several unique predictions can be derived from this account. First, proactive and RI share the same mechanism and these types of interference should be inversely related: weaker PI stems from more efficient inhibition, which leads to stronger RI. And second, participants with less capacity to inhibit (i.e., young children, low-working-memory-span adults, or patients with prefrontal lesions) should exhibit stronger proactive and weaker RI than typical adults.

Whereas the inhibition-based theory attributes interference effects to aspects of retrieval, an alternative theory suggests that aspects of encoding and storage may help determine the extent of RI effects (Humphreys et al., 1989; O'Reilly & Rudy, 2001; Sutherland & Rudy, 1989). According to this account, memories are protected from interference when they are encoded into a complex configural structure. The idea of configural structure (or configural associations) goes back to the literature on negative patterning discrimination (see Sutherland & Rudy, 1989, for a review). In these experiments, an animal is reinforced (+) in the presence of individual cues (i.e., A+/B+), but not reinforced (−) in the presence of the compound (i.e., AB−). It has been argued that the animal could not solve this problem without forming a configural association ($<AB> \rightarrow \text{Response}_1$), in addition to simple associations ($A \rightarrow \text{Response}_2$ and $B \rightarrow \text{Response}_2$).

The idea of configural structure has been extended to human memory research. For example, Humphreys et al. (1989) argued that in learning multiple lists of paired associates with overlapping elements (such as in AB-AC or AB-ABr paradigms), forming a configural code involving a cue, target, and context (i.e., $<A_i\text{-}B_i\text{-}\text{Context}_i>$) would protect memory from cross-list (either proactive or retroactive) interference. The encoding of more complex structures may be effective at preventing interference because it introduces unique information that reduces the amount of overlap between learning sets (Humphreys et al., 1989). The following example illustrates the argument. Consider two lists of items—P, I, T (List 1) and T, I, P (List 2)—which are given to a participant sequentially. After learning List 2, the participants could be asked: "What follows 'I' in List 1?" If the participant encoded individual items "P," "I," and "T," the task is difficult and interference is likely. However, if a participant formed a configuration, such as words <PIT> and <TIP>, the task is much easier and interference is less likely.

Developmental work has suggested that young children have difficulty forming such complex structures (Rudy, Keith, & Georgen, 1993). One recent study (Yim, Dennis, & Sloutsky, 2013) investigated the development of episodic memory with a modified paired-associates task in which objects were paired together as a cue and target in different contexts. Crucially, the structure of the stimulus pairings was manipulated, such that high performance required differing levels of associative complexity across conditions. For example, in one condition, successful learning could be achieved by merely encoding a single two-way (cue–target) association for each pair, whereas in other conditions, successful learning required multiple two-way associations or a three-way (cue–target–context) association. In addition to providing behavioral data, Yim et al. (2013) applied a multinomial processing tree model to the results and concluded that the ability to form more complex associative structures increases between 5 years of age and adulthood.

Although it is possible that a configural code could prevent both PI and RI, people may not form such a code unless the task at hand requires it. For example, even in AB-AC or in AB-ABr paradigms, it may not be necessary to form a configural code to learn information in List 1, because each pair item is unique. However, when information presented in Phase 2 overlaps with information from Phase 1, as in AB-AC or AB-ABr paradigms, a configural code may be necessary to prevent RI and participants may form such a code when learning List 2. In such cases, mechanisms of preventing PI and RI could be independent: PI could be prevented by inhibition, whereas RI could be prevented by a configural code. Thus, the configural encoding account makes two critical predictions: It implicates configural encoding in preventing RI (in contrast to the inhibition account), suggesting that RI should be greater in children and individuals who are less proficient at configural encoding.

In sum, the inhibition account suggests that the same inhibitory mechanisms underlie PI and RI, with these types of interference being inversely related. In contrast, the configural code account suggests that the mechanisms of PI and RI could be relatively independent, with RI stemming from failures to encode and store information configurally. Given that the two accounts make different developmental predictions, developmental data may help distinguish between these accounts. In addition, examining developmental change in the ability to resist interference may elucidate important issues in memory development. We will return to these issues in the next section.

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Interference and Memory Development

The processes by which learning and memory interact are especially important for understanding memory development. Intuitively, learning and memory interact in many essential aspects of cognitive development, including categorization, reading, and language learning. These processes have the potential to produce substantial interference effects, as children learn that the same objects can be categorized in different ways, that the same letters can be read in different words, and that the same concepts can be mapped onto different labels.

The current work aims to use interference to better understand the development of episodic memory. Many believe that episodic memory exhibits a relatively late onset and undergoes protracted development, especially compared with the rapid development of semantic memory (Drummey & Newcombe, 2002; but see Bauer, Wenner, Dropik, & Wewerka, 2000). However, even those who argue for an early onset acknowledge that, throughout the preschool years, many aspects of episodic memory are fragile. Although sometimes young children exhibit excellent memory for individual items (Sloutsky & Fisher, 2004), they have difficulty remembering what happened where and when (Bauer, 2007). Children's testimonies in forensic contexts are often unreliable (Pipe & Salmon, 2009), and laboratory recall and recognition tasks demonstrate that episodic memory continues to improve through adolescence (Brainerd, Reyna, & Ceci, 2008; Ghetti & Lee, 2011). If episodic memory does undergo protracted development (Sluzenski, Newcombe, & Kovacs, 2006; Sluzenski, Newcombe, & Ottinger, 2004), what causes this change?

Work reported here uses developmental evidence to differentiate between theoretical accounts claiming that interference arises as a result of inhibitory control (Anderson, 2003) and failures of configural encoding (Humphreys et al., 1989; Yim et al., 2013). The second goal was to use an interference paradigm to investigate sources of developmental change in episodic memory.

To achieve the first goal, predictions derived from each account can be compared. If interference is a function of *inhibition at retrieval* (Anderson, 2003), then (a) adults should demonstrate weaker PI and stronger RI effects than children, as the ability to inhibit prepotent responses increases with age (Brocki & Bohlin, 2004); and (b) the magnitudes of PI and RI should be negatively correlated, as stronger inhibition should result in reduced PI and increased RI. In contrast, if interference stems from *failures of configural encoding*, then (a) children (who are less able to form complex memory structures) should exhibit stronger RI than adults, and (b) the ability to encode items and context configurally should predict the magnitude of interference effects.

To test these predictions, we developed a new experimental paradigm designed to measure effects of both PI and RI in learning and memory. This design allowed us to compare interference effects between elements that were unique across different phases of the task (and thus did not require configural encoding) and those that overlapped across different phases (and thus required configural encoding). Comparing the magnitudes of PI and RI between ages and stimulus types may provide insight into the mechanisms of interference, as well as how these mechanisms develop.

The predictions were tested in three experiments. As shown in Figure 1, each experiment contained three main experimental phases, in which participants were presented with sets of contingencies that varied by phase. In Experiment 1, stimuli were presented within a visual context that varied across phases. In Experiment 2, the visual context did not vary across phases, allowing us to estimate effects of potential encoding of contextual information on interference effects. In Experiment 3, we tested the effect of configural encoding by including a training phase designed to encourage participants to encode stimuli configurally.

Experiment 1

In Experiment 1, we examined developmental differences in the magnitudes of PI and RI effects. Previous literature suggests that the magnitude of RI may remain stable between the ages of 4 and 7 years (Howe, 1995; Lee & Bussey, 2001). However, these studies did not include an adult comparison group, so it is unclear whether the mechanisms responsible for this effect are fully de-

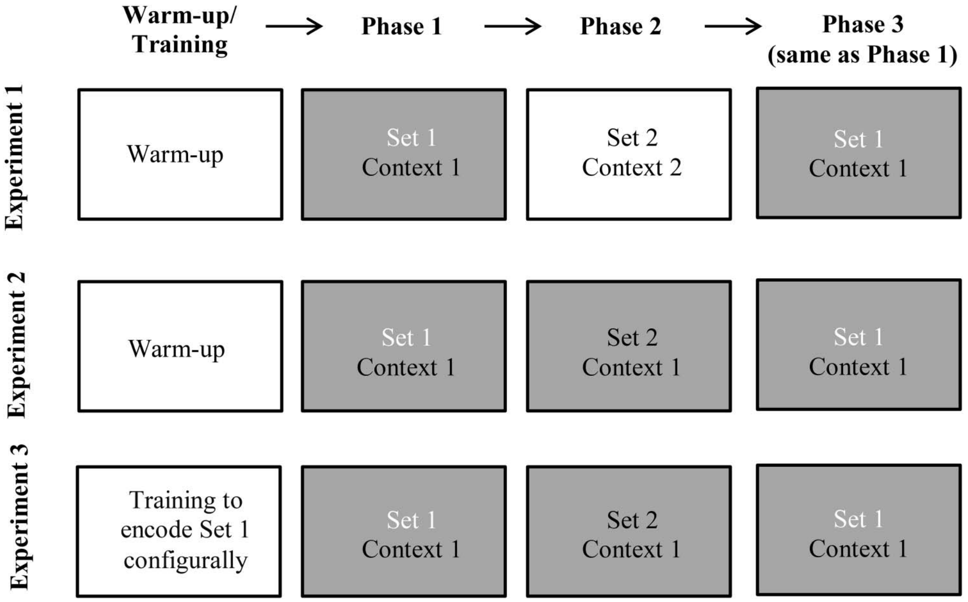


Figure 1. Design of Experiments 1 to 3. A warm-up or training phase was followed by three main experimental phases in which participants learned different stimulus sets in specified contexts. Same shading indicates same context in which items were presented.

veloped by this age range. Unlike RI effects, some work suggests that PI effects decrease between childhood and adulthood (Kail, 2002; Yim et al., 2013). To increase the probability of capturing developmental differences in PI and RI, we included 4- to 5-year-olds and adults.

Method

Participants. Thirty-four preschool-age children (M = 5.31 years, SD = 0.24 years, range = 4.8 to 5.8 years; 18 females) and 28 college undergraduates (nine females) participated in this experiment. Children were tested in local preschools located primarily in middle-class neighborhoods of Columbus, Ohio. They were recruited on the basis of returned permission slips and received stickers for participating. Adults were recruited from introductory psychology classes and received partial course credit.

Stimuli. Experimental stimuli consisted of illustrations of familiar objects from each of four categories—animals, vehicles, clothing, and furniture—for a total of 12 objects (see Table 1). The objects presented in the table were paired randomly, with a constraint that none of the pairs included objects from the same group (i.e., none of the pairs included two animals). On each trial, a pair of objects was presented to the participant, along with two characters familiar to children—Winnie the Pooh (referred to as "Pooh Bear") and Mickey Mouse—as well as a visual occluder (see Figure 2). The two characters functioned as responses, such that each pair was associated with one character in a particular phase.

The entire experiment contained eight object pairs, which were divided into two sets of four pairs. Within each set, two object pairs were associated with each character. The two pairs associated with each character were selected from the four categories presented in Table 1, one object from each category. The visual occluder was included to make the task more engaging to children and to emphasize the association between pairs of objects and a character, as objects could rise into the occluder and "pop out" by one character.

Across three experimental phases, participants learned to associate pairs of objects with one of the two characters; the overall task structure is presented in Table 2. Phase 1 and Phase 3 contained the same items and the same set of contingencies, whereas a different set was learned in Phase 2. Each set of stimuli contained two types of pairs: overlapping and unique, with items randomly assigned to the pair types. Overlapping pairs consisted of the same objects presented in different combinations and associated with different characters across sets. For example, using abstract notation for objects (A, B, C, and D) and characters (X and Y), if the overlapping pairs in Phase 1 were AB → X and CD → X, in Phase 2 the new pairings might be AC → Y and BD → Y. Note that in Phase 2, overlapping pairs were novel combinations of previously presented elements. Conversely, unique pairs consisted of different elements across sets. Each set contained four pairs in total: two overlapping and two unique. Participants could successfully learn (and remember) contingencies for unique pairs by associating a single object with the outcome (e.g., E → Y). For overlapping pairs, participants could successfully learn in Phase 1 in the same way, that is, associating individual objects to outcomes (e.g., A → X). However, because individual objects in overlapping pairs were associated with different outcomes across phases, this strategy would result in interference effects in Phases 2 and 3. We assume that associating *pairs* of objects with outcomes (e.g., <AB> → X) would greatly reduce interference, because overlapping pairs are comprised of recombined objects across phases.

Table 1
Object Stimuli Presented in Experiment 1

Animals	Clothing	Vehicles	Furniture
Turtle	Baseball cap	Boat	Lamp
Bunny	T-shirt	Plane	Table
Butterfly	Boot	Train	Chair

On each trial, participants were presented with a pair of (two) objects, along with a visual occluder and two characters (see Figure 2). The spatial locations of the characters remained constant throughout the experiment. In contrast, the context (i.e., colors of the background and the occluder) remained constant within the phase, but varied across the phases. Specifically, pairs were presented either on a light gray background with a black occluder or on a dark gray background with a white occluder. These contexts were assigned to phases, such that Phases 1 and 3 had the same context and Phase 2 had a different context, with the assignment counterbalanced across participants.

Procedure. Children were tested in a quiet room in their preschools, and adults were tested in the lab on campus. The task was presented to children on a touchscreen monitor and to adults on a standard computer monitor. The main experiment consisted of three experimental phases in which participants learned to associate pairs of objects with different characters. In Phases 1 and 3, the same set of contingencies was learned in a single context, whereas in Phase 2, a different set was learned in a different context. Between each phase participants were given a 1-min break, in which adults were asked to sit quietly and children received a sticker. Each phase included five blocks of eight trials, for a total of 120 trials across the experiment (see Figure 3 for an overview of the task structure). On each trial, participants were shown one pair of two objects. Each pair of objects was seen twice per block, with trial order randomized for each block and each participant, for a total of 10 repetitions of each pair per phase. The spatial position of objects in each pair (top or bottom) was counterbalanced within each block. The entire experiment took approximately 25 min for children and 20 min for adults.

Prior to the experiment, participants were shown a pair of objects and told that these objects would disappear into this tube (experimenter pointed to the occluder) and pop out by one character, either Pooh Bear or Mickey Mouse (experimenter pointed to the characters). The participants' task was to predict where the objects would reappear. Child participants responded on each trial by touching the appropriate character on the touchscreen, whereas adults responded by pressing the left or right arrow keys corresponding to their choice. After a response was made, the bottom object in the pair moved upward and collided with the top object, before both items moved into the occluder and reappeared approximately 2 s later by the appropriate character (see Figure 2). At the end of the trial, participants received explicit feedback about the accuracy of their prediction: They heard a high tone following correct responses or a low tone following incorrect responses. Children also received additional verbal feedback by the experi-

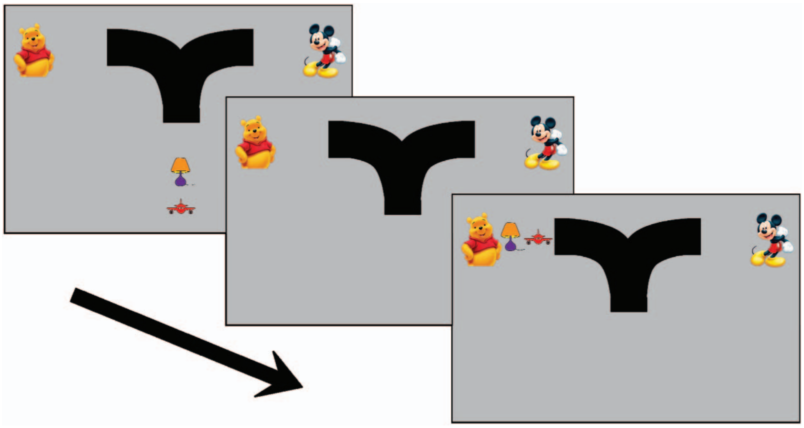


Figure 2. On each trial, participants saw a pair of objects that were stationary until response, then rose into the visual occluder and reappeared by the associated character. These stimuli were presented to participants in color. See the online article for the color version of this figure.

menter, for example, “Great job, those do go to Pooh Bear” or “Uh oh, those actually go to Mickey Mouse.”

The main experimental task was preceded by a warm-up phase, in which participants received instructions using age-appropriate language and the opportunity to become familiar with the task through practice trials. Stimuli for these practice trials consisted of four simple shapes and colors (e.g., blue circle) combined into two pairs. One pair was associated with Pooh Bear and one with Mickey Mouse. These pairs were presented with a blue occluder on a white background. Warm-up trials were presented in a random order until participants correctly predicted the outcome on five consecutive trials. All participants completed the warm-up phase and proceeded to the experiment proper.

Results and Discussion

Six children were not included in analyses because of failure to complete the task ($n = 2$), failure to follow task instructions ($n = 1$), or computer failure ($n = 3$). Additionally, because the purpose of the experiment was to understand interference of learned information, we excluded participants who failed to exceed 70% accuracy across the final four blocks of the first phase for either overlapping or unique pair types. Three additional children and four adults were excluded as a result of this criterion. The final sample included 25 preschoolers ($M = 5.31$ years, $SD = 0.26$ years, range = 4.8 to 5.8 years; 12 females) and 24 adults (eight females).

Table 2
Overview of Contingencies Presented in the Experiment

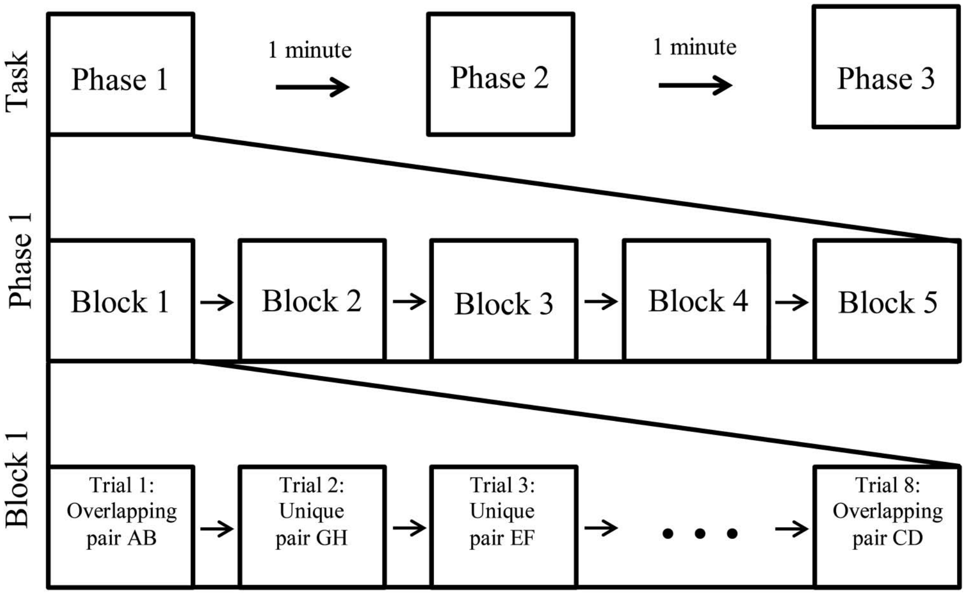
	Phase 1 (set 1)	Phase 2 (set 2)	Phase 3 (set 1)
Overlapping pairs	AB → X	AC → Y	AB → X
	CD → X	BD → Y	CD → X
Unique pairs	EF → Y	IJ → X	EF → Y
	GH → Y	KL → X	GH → Y

Note. A through L are the objects (presented in pairs), whereas X and Y are the characters (Pooh Bear and Mickey Mouse).

Recall that prior to the experiment proper, participants were presented with a warm-up phase that introduced a simplified version of the task. Children and adults learned quickly in this phase of the experiment: The average number of trials required to reach the criterion of five consecutive correct trials was 5.21 for children ($SD = 0.51$, min = 5, max = 7), and 5.5 for adults ($SD = 1.25$, min = 5, max = 9).

To reiterate, Phases 1 and 3 of the experiment proper were identical, whereas Phase 2 was different in that (a) overlapping items were paired differently, (b) unique items were new, (c) the context was different, and (d) item-outcome contingencies were different (see Table 2). To measure PI and RI effects, we compared accuracies in the first and subsequent phases. Accuracy in Phase 1 is considered baseline as it measures initial learning. Learning in Phase 2, in contrast, may be influenced by what was already learned in Phase 1. Similarly, information learned in Phase 2 may affect memory for what was learned in Phase 1, leading to changes in accuracy in Phase 3. The analysis, however, is not straightforward, as simply comparing accuracies across phases leads to ambiguity regarding the cause of any differences. For example, attenuation of accuracy could result from simple memory decay or other task effects (Wixted, 2004), with interference playing no significant role. In addition, including all blocks in the analysis would be highly conservative, as the comparison would assume effects of interference to last across the entire phase.

We approach both problems by comparing accuracies for each pair type (i.e., overlapping and unique) averaged within specific blocks. Specifically, PI can be estimated by comparing accuracy for overlapping and unique pairs in the first block of Phase 1 and the first block of Phase 2. PI is inferred from attenuated learning of overlapping (but not unique) pairs in the beginning of Phase 2 compared with the beginning of Phase 1. RI can be estimated by comparing accuracy of overlapping and unique pairs in the last block of Phase 1 and the first block of Phase 3. RI is inferred from attenuated learning of overlapping (but not unique) pairs in the beginning of Phase 3 compared with the end of Phase 1. Therefore, a significant interaction between phase and pair type provides unambiguous evidence of interference, as a pair type comparison



On each trial, items were presented in pairs (e.g. Lamp-Plane; AB).
Each pair was presented twice per block, which resulted in 10 presentations per phase.

Figure 3. Structure of the experimental design, showing a typical (randomized) order of overlapping and unique pairs in the hierarchical task-phase-block-trial design.

controls for memory decay and task effects. The design also allows us to estimate savings—faster learning of the same material when it is presented again in Phase 3. Savings effects provide important evidence that some memory is preserved even in the face of RI. Savings can be estimated by comparing accuracy in Block 1 of Phase 1 and Block 1 of Phase 3 for overlapping and unique pairs. Greater accuracy in Phase 3 for both pair types is evidence of savings, whereas lower accuracy for overlapping pairs, or *negative savings*, could be construed as evidence of catastrophic-like interference.

Table 3 shows children's and adults' average accuracy across all blocks in each phase, separated by pair type. To reiterate, we measure PI effects by comparing accuracies in the first block only of Phases 1 and 2 (see Figure 4); an interaction between phase and pair type provides unambiguous evidence of interference unaffected by fatigue or other task effects.

To analyze PI (see the left-most column in Figures 4A and 4B), we performed a three-way mixed ANOVA with Phase (Phase 1 vs. Phase 2) and pair type (overlapping vs. unique) as within-subject factors, and age (children vs. adults) as a between-subjects factor. There was a significant phase by pair type interaction, $F(1, 47) = 9.29$, $p = .004$, $\eta_p^2 = .17$, but no three-way interaction, $p = .26$, suggesting that the magnitude of PI did not differ between children and adults.[1] Planned comparisons indicated that attenuation of accuracy was marginally significant in children for overlapping pairs, $t(24) = 1.90$, $p = .07$, Cohen's $d = 0.38$, but not for unique pairs, $p = .48$. Similar effects were found in adults: attenuation was significant for overlapping pairs, $t(23) = 4.29$, $p < .001$, $d = 0.88$, but not for unique pairs, $p = .23$. Overall, children and adults exhibited evidence of PI when beginning to learn overlapping pairs in Phase 2.

We measured RI effects by comparing accuracy during the last block of Phase 1 and the first block of Phase 3 (see the middle column in Figures 4A and 4B). The logic of this comparison is that, in the absence of RI or memory decay, there should be no difference in accuracy between these blocks, as the pairs presented in each were identical. A three-way mixed ANOVA with Phase (Phase 1 vs. Phase 3) and pair type (overlapping vs. unique) as within-subject factors, and age (children vs. adults) as a between-subjects factor, revealed a significant three-way interaction, $F(1, 47) = 18.56$, $p < .001$, $\eta_p^2 = .28$, indicating that the magnitude of RI varied across age groups.

To better understand this interaction we performed separate Phase × Pair type ANOVAs for children and adults. The interaction between phase and pair type was significant in children, $F(1, 24) = 32.87$, $p < .001$, $\eta_p^2 = .58$, but not in adults, $p = .62$. Planned comparisons suggest that children's accuracy was significantly attenuated for overlapping pairs, $t(25) = 7.49$, $p < .001$, $d = 1.79$, but not for unique pairs, $p = 1$. In adults, accuracy attenuated somewhat for both overlapping, $t(23) = 2.63$, $p = .015$, $d = 0.59$, and unique, $t(23) = 3.19$, $p = .004$, $d = 0.99$, pairs. Whereas children clearly exhibited strong RI, results in adults were somewhat ambiguous: It is not clear whether RI affected both pair types, or if participants experienced simple memory decay for both pair types.

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[1] The statistics reported in this article were performed on raw accuracy proportions. We also performed logit transformations of all the data and reran the analyses with the transformed data. The transformed data resulted in the same pattern of findings, with only minimal changes to individual effects (see Footnote 3).

Table 3
Mean (SD) Accuracy for All Phases and Blocks for Children and Adults in Experiment 1

	Pair type	Block 1	Block 2	Block 3	Block 4	Block 5	Phase average
Children							
Phase 1	Overlapping	.76 (.22)	.90 (.16)	.91 (.12)	.96 (.11)	.96 (.12)	.90 (.08)
Phase 1	Unique	.77 (.22)	.91 (.18)	.96 (.09)	.97 (.08)	.93 (.14)	.91 (.09)
Phase 2	Overlapping	.61 (.28)	.75 (.35)	.82 (.26)	.87 (.16)	.85 (.26)	.78 (.18)
Phase 2	Unique	.73 (.24)	.94 (.13)	.94 (.13)	.94 (.11)	.93 (.11)	.90 (.09)
Phase 3	Overlapping	.62 (.26)	.82 (.23)	.79 (.28)	.87 (.21)	.87 (.24)	.79 (.15)
Phase 3	Unique	.93 (.17)	.9 (.20)	.92 (.12)	.95 (.13)	.97 (.08)	.93 (.06)
Adults							
Phase 1	Overlapping	.73 (.18)	.92 (.16)	.94 (.11)	.96 (.10)	.96 (.10)	.90 (.07)
Phase 1	Unique	.71 (.20)	.91 (.12)	.98 (.07)	.97 (.08)	.97 (.08)	.91 (.06)
Phase 2	Overlapping	.56 (.17)	.92 (.14)	.92 (.14)	.95 (.10)	.97 (.08)	.86 (.06)
Phase 2	Unique	.78 (.17)	.94 (.11)	.97 (.11)	.99 (.05)	.99 (.05)	.93 (.06)
Phase 3	Overlapping	.85 (.19)	.90 (.19)	.97 (.08)	.98 (.08)	.95 (.13)	.93 (.08)
Phase 3	Unique	.83 (.19)	.94 (.15)	.97 (.08)	.99 (.05)	.99 (.05)	.94 (.07)

Note. Results are separated by pair type (overlapping and unique).

To gain more insight into whether the extent memory is preserved (even when RI effects were observed), we calculated savings effects by comparing performance in the first block of Phase 1 and the corresponding block of Phase 3 (see the right-most column in Figures 4A and 4B). We performed a three-way mixed ANOVA with phase and pair type as within-subject factors, and age as a between-subjects factor, and found a significant three-way interaction, $F(1, 47) = 7.27$, $p = .01$, $\eta_p^2 = .13$, suggesting that the magnitude of savings effects varied as a function of pair type and age. To examine these relationships more closely, we performed separate Phase × Pair type ANOVAs in children and adults. A significant interaction was found between these factors in children, $F(1, 24) = 12.71$, $p = .002$, $\eta_p^2 = .35$. Paired-samples t tests revealed that accuracy for unique pairs increased, $t(24) = 2.70$, $p = .013$, $d = 0.54$, thus suggesting savings, whereas accuracy for overlapping pairs attenuated, $t(24) = 2.06$, $p = .05$, $d = 0.41$, thus suggesting negative savings. Remarkably, negative savings indicate that children's learning of overlapping pairs was actually *worse* in Block 1 of Phase 3 than in Block 1 of Phase 1: There were no savings, and learning of the same information the second time (i.e., in Phase 3) was more difficult than the first time (i.e., in Phase 1). Taken together, the magnitude of RI in children coupled with negative savings point to catastrophic-like RI.

In contrast, the Phase × Pair type ANOVA for adults revealed no significant interaction between these factors, $p = 1$, although a main effect of Phase was found, $F(1, 23) = 8.90$, $p = .007$, $\eta_p^2 = .28$, indicating that, for both pair types, adults were more accurate in Phase 3 than in Phase 1. These findings indicate significant savings in adults as accuracy in Block 1 improved from Phase 1 to Phase 3.

In sum, the results of Experiment 1 indicate that (a) attenuation transpired primarily for overlapping pairs; (b) severe RI effects transpired in children, but not in adults; and (c) comparable PI effects were found in children and adults. These results indicate that children were prone to marked RI for overlapping, but not unique pairs. And more importantly, this interference was bordering catastrophic: Remarkably, children's accuracy for overlapping pairs was worse in Phase the beginning of Phase 3 than when learning the same pairs for the first time in Phase 1. In contrast, adults exhibited little evidence of RI.

However, these findings alone cannot distinguish between two possible mechanisms. First, in accordance with the inhibition account, it is possible that when presented with items in Phase 2, adults and children inhibited information learned in Phase 1, which prevented strong PI. However, in Phase 3, only adults, but not children, were released from this inhibition. As a result of this differential release, only children, but not adults, exhibited RI. This possibility can also readily account for negative savings found in children.

Alternatively, in accordance with the configural account, it is possible that adults formed a configural code (either <A-B> → X or <A-Context 1> → X), which prevented them from exhibiting strong interference effects, whereas children did not, which resulted in stronger RI in children than in adults. This possibility can also account for negative savings. In particular, children (who do not encode stimuli configurally) may experience PI from Phase 1 in Phase 2, and from Phase 2 in Phase 3.

To distinguish between these possibilities, we calculated the correlations between RI and PI effects in children and adults.[2] According to the inhibition account, effective inhibition in Phase 2 should result in weaker PI and stronger RI. Therefore, PI and RI should be negatively correlated. According to a variant of the inhibition account assuming differential release from inhibition in children and adults, this negative correlation should transpire only in children, as children continue to be subject to inhibition without release in Phase 3. Contrary to this hypothesis, the correlations between PI and RI were negligible in children, $r(24) = .15$, $p = .48$, and in adults, $r(23) = -.21$, $p = .32$, suggesting that the inhibition account was not the case.

Although this experiment has not supported the ideas that RI is caused by active inhibition or by differential release from inhibition, by undermining this account, it provided only indi-

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[2] To calculate PI effects, we measured the change in accuracy between the first block of Phases 1 and 2 for overlapping and unique pairs, and calculated the difference of these changes for each participant. Similarly, to measure RI, we took the difference of the change in accuracy between the last block of Phase 1 and the first of Phase 3 for each pair type. We took the same approach to measure interference effects for individual subjects throughout the study.

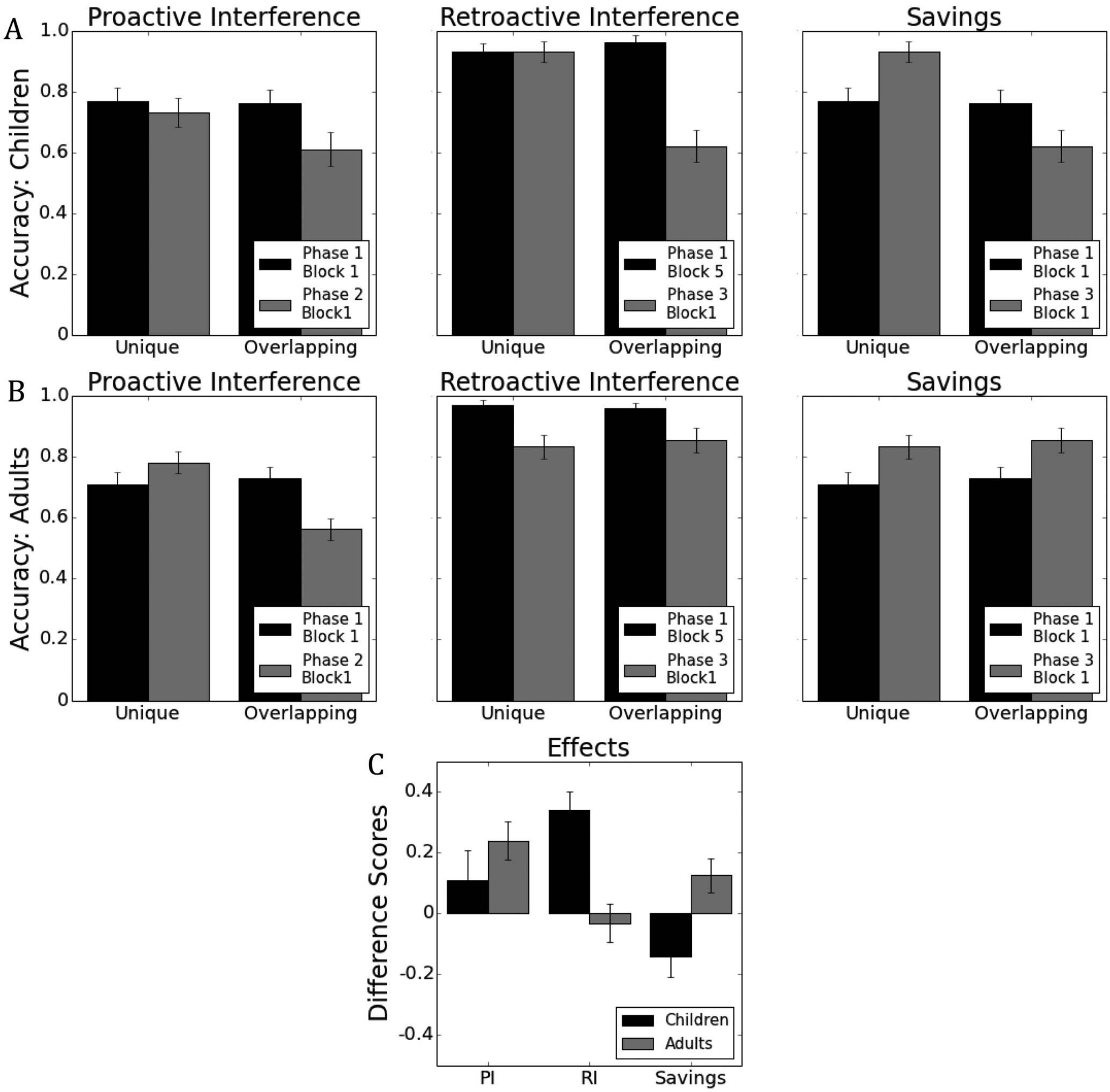

Figure 4. Accuracy results for analyzed blocks in Experiment 1, for children (A) and adults (B). Results are separated by pair type (unique and overlapping). Also shown are the difference scores depicting PI, RI, and savings effects (C). Please refer to the text for further details.

rect evidence for the configural encoding account. To provide more direct evidence for the configural encoding account, we deemed it necessary to make configural encoding more difficult, thus inducing RI effects in adults. Recall that for the configural code to prevent RI, participants, at the very minimum, had to either encode items configurally (i.e., <A-B> → X) or encode an item and the context configurally (i.e., <A-Context 1> → X). Previous work suggests that adults are more likely to bind context and item information than young children (Sluzenski et al., 2006; Yim et al., 2013), so it seems likely that context was part of the configural code. If this is the case, then reducing contextual differences among the phases would result in increased RI effects in adults. If children do not encode contextual information in the first place, this manipulation should have only minimal effects on children's performance.

To examine these issues and to provide a more direct test of the configural encoding account, we conducted Experiment 2. In Experiment 2, we eliminated the differences in visual context, such that the context was identical in all three phases. If adults spontaneously encoded the visual context in any phase during Experiment 1, interference should increase in Experiment 2.

Experiment 2

Method

Participants. A total of 37 preschool-age children participated in this experiment, with a mean age of 5.29 years (*SD* = 0.23, min = 4.93, max = 5.69, 15 females). As in Experiment 1, children were recruited from local day cares and preschools, and received stickers for participating. Thirty-five adults also participated (12 females), and received partial credit for an introductory psychology course as compensation.

Stimuli and procedure. All stimuli were identical to those of Experiment 1, except that the visual context did not vary across phases or training trials. In all trials of the main experiment and the practice phase, the visual context consisted of a light gray background with a black visual occluder. The structure of contingencies between pairs of objects and characters across phases was the same as in Experiment 1, as was the task procedure.

Results and Discussion

Ten children were excluded from the analysis after not completing the task because of failure to complete the experiment ($n = 5$), computer error ($n = 3$), or terminating the task for lunch or being picked up by a parent ($n = 2$). An additional child was excluded because of an undisclosed diagnosis of autism spectrum disorder. As in Experiment 1, we also excluded participants whose mean accuracy during Blocks 2 through 5 of Phase 1 was below 70% for either overlapping or unique pairs. We excluded an additional three children and two adults as a result of this criterion. The final sample, then, consisted of 23 children, with a mean age of 5.38 years (*SD* = 0.22, min = 5.04, max = 5.69; nine females), and 33 adults (12 females). Children reached the criterion of five consecutive practice trials after a mean of 5.26 trials (*SD* = 0.53, min = 5, max = 7), and adults after a mean 5.91 trials (*SD* = 2.75, min = 5, max = 17).

Table 4 shows children's and adults' accuracy for overlapping and unique pairs in each block and phase. As in Experiment 1, we calculated PI by comparing accuracy for each pair type in the first block of Phases 1 and 2 (see the left-most column in Figures 5A and 5B). A mixed three-way ANOVA with phase (Phase 1 vs. Phase 2) and pair type (overlapping vs. unique) as within-subject factors, and age (children vs. adults) as a between-subjects factor, indicated no significant three-way interaction, $p = .43$, indicating that attenuation in Phase 2 did not vary between children and adults, as in Experiment 1. The two-way interaction between block and pair type, however, did reach significance, $F(1, 54) = 12.02$, $p = .001$, $\eta_p^2 = .18$, suggesting the presence of PI in both age groups. Planned comparisons revealed that attenuation of children's accuracy was significant for overlapping pairs, $t(22) = 3.60$, $p = .002$, $d = 0.75$, but not for unique pairs, $p = .65$. In adults, accuracy for overlapping pairs was nonsignificantly attenuated, $p = .85$, whereas accuracy for unique pairs significantly increased, $t(32) = 2.97$, $p = .006$, $d = 0.45$.

RI was measured by comparing accuracies in the last block of Phase 1 with the first block of Phase 3 (see the middle column in Figures 5A and 5B). A three-way mixed ANOVA with phase (Phase 1 vs. Phase 3) and pair type (overlapping vs. unique) as within-subject factors, and age (children vs. adults) as a between-subjects factor, indicated a marginally significant three-way interaction, $F(1, 54) = 3.91$, $p = .053$, $\eta_p^2 = .068$. To examine the possible relationship between age and the magnitude of RI, we next completed separate Phase × Pair type ANOVAs for children and adults. The interaction between these factors was significant in children, $F(1, 22) = 18.68$, $p < .001$, $\eta_p^2 = .46$, as well as in adults, $F(1, 32) = 7.73$, $p = .009$, $\eta_p^2 = .20$. This in contrast to Experiment 1, in which the interaction was only significant in children. Attenuation of accuracy in children was significant for overlapping pairs, $t(22) = 6.42$, $p < .001$, $d = 1.78$, but not unique pairs, $p = .21$. For adults, there was substantial attenuation for overlapping pairs, $t(32) = 4.77$, $p < .001$, $d = 0.86$, as well as some attenuation for unique pairs, $t(32) = 2.26$, $p = .033$, $d = 0.40$.

Table 4
Mean (SD) Accuracy for All Phases and Blocks for Children and Adults in Experiment 2

	Pair type	Block 1	Block 2	Block 3	Block 4	Block 5	Phase average
Children							
Phase 1	Overlapping	.78 (.16)	.82 (.19)	.89 (.15)	.97 (.09)	.96 (.10)	.88 (.08)
Phase 1	Unique	.66 (.18)	.90 (.16)	.91 (.14)	.99 (.05)	.96 (.12)	.88 (.05)
Phase 2	Overlapping	.61 (.17)	.89 (.20)	.90 (.21)	.93 (.14)	.84 (.25)	.83 (.14)
Phase 2	Unique	.70 (.25)	.90 (.15)	.93 (.14)	.93 (.14)	.93 (.15)	.88 (.11)
Phase 3	Overlapping	.63 (.28)	.85 (.18)	.86 (.17)	.89 (.18)	.95 (.11)	.83 (.11)
Phase 3	Unique	.91 (.14)	.95 (.13)	.93 (.14)	.98 (.07)	.97 (.09)	.95 (.09)
Adults							
Phase 1	Overlapping	.65 (.19)	.89 (.15)	.93 (.11)	.99 (.04)	.96 (.11)	.89 (.06)
Phase 1	Unique	.65 (.21)	.87 (.20)	.94 (.13)	.98 (.09)	.97 (.07)	.88 (.08)
Phase 2	Overlapping	.64 (.19)	.89 (.23)	.89 (.20)	.95 (.14)	.93 (.19)	.86 (.15)
Phase 2	Unique	.77 (.19)	.97 (.08)	.98 (.10)	.95 (.13)	.95 (.18)	.93 (.10)
Phase 3	Overlapping	.78 (.20)	.95 (.12)	.95 (.14)	.96 (.11)	.97 (.10)	.92 (.10)
Phase 3	Unique	.92 (.12)	.95 (.15)	.95 (.20)	.98 (.10)	.98 (.10)	.96 (.10)

Note. Results are separated by pair type (overlapping and unique).

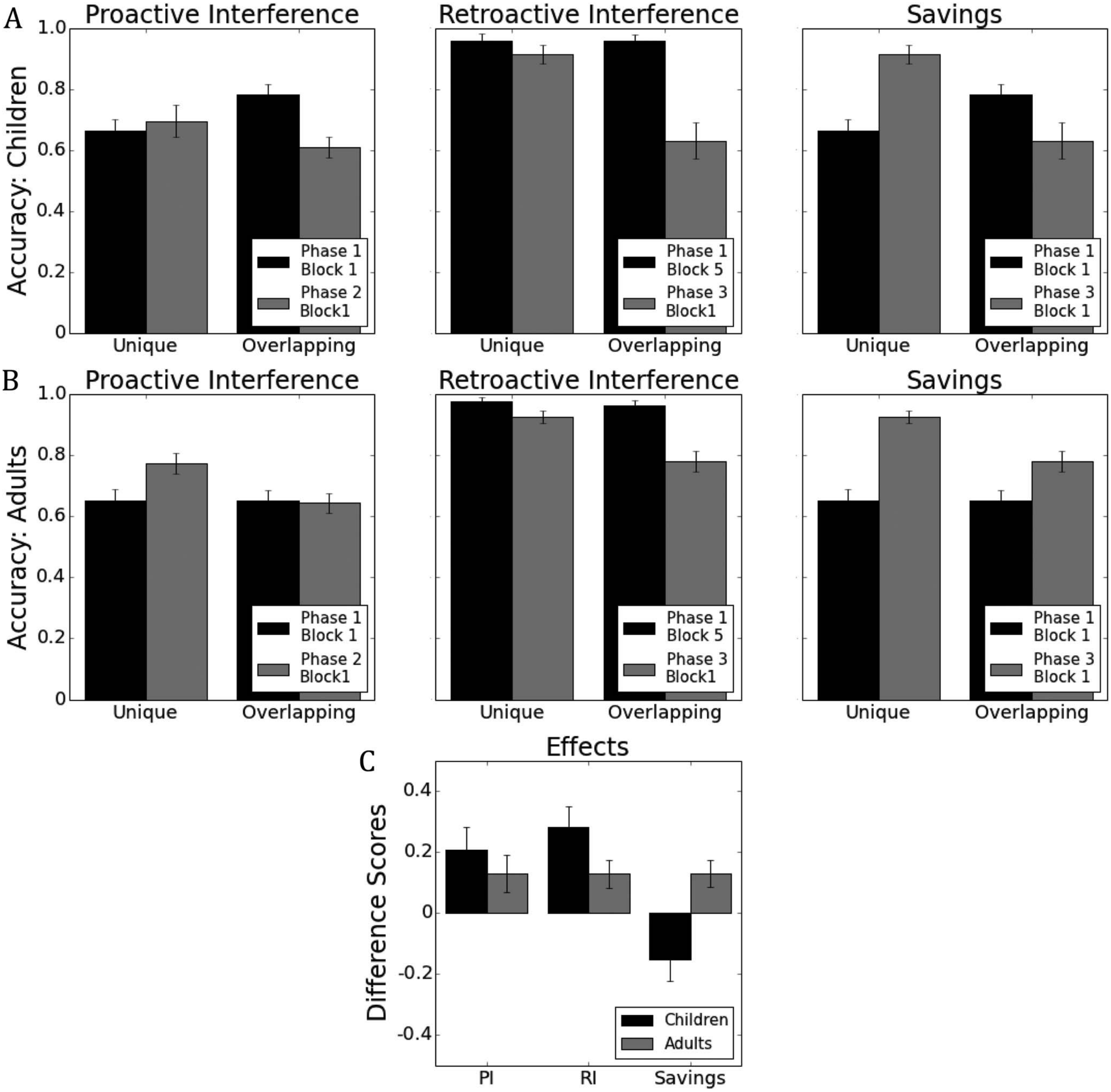

Figure 5. Accuracy results for analyzed blocks in Experiment 2, for children (A) and adults (B). Results are separated by pair type (unique and overlapping). Also shown are the differences scores depicting PI, RI, and savings effects (C).

As in Experiment 1, we also calculated savings effects (i.e., the benefit to performance in the beginning of Phase 3 as a result of having already learned the same information in Phase 1) by comparing performance in the first block of Phases 1 and 3 (see the right-most column in Figures 5A and 5B). A three-way ANOVA with phase and pair type as within-subject factors, and age as a between-subjects factor, revealed a significant three-way interaction, $F(1, 54) = 6.22$, $p = .016$, $\eta_p^2 = .10$, suggesting that savings depended on both the pair type and age group. To more clearly understand this relationship, we performed separate repeated-measures ANOVAs with block and pair type as factors for children and adults. The interaction was significant in children, $F(1, 22) = 20.63$, $p < .001$, $\eta_p^2 = .48$, and in adults, $F(1, 32) = 5.64$, $p = .024$, $\eta_p^2 = .15$. Planned comparisons revealed that children's accuracy improved from Phase 1 to Phase 3 for unique pairs, $t(22) = 4.59$, $p < .001$, $d = 0.96$, whereas it decreased for overlapping pairs, $t(1,22) = 2.13$, $p = .045$, $d = 0.66$, thus suggesting savings for unique pairs and negative savings for overlapping pairs. Conversely, in adults accuracy improved for both unique, $t(32) = 6.40$, $p < .001$, $d = 1.15$, and overlapping pairs, $t(32) = 2.96$, $p = .006$, $d = 0.51$, thus suggesting savings for both trial types. As in Experiment 1, then, RI affected children's performance to the extent that performance was actually *worse* for overlapping pairs when relearning information that had been introduced in Phase 1 (again suggesting catastrophic-like interference), whereas performance for unique pairs was better. In contrast, adults experienced savings effects for both pair types, suggesting that RI effects were not catastrophic in this age group. Additionally, we again calculated the correlations between the magnitudes of PI and RI, and, as in Experiment 1, found no correlation in children, $r(22) = .038$, $p = .86$, or in adults, $r(32) = .17$, $p = .34$.

The goal of Experiment 2 was to determine whether adults may have encoded visual contextual information (along with item-outcome information) to reduce RI in Experiment 1. To investigate this, we compared accuracies in the beginning of Phase 3 and the end of Phase 1 with mixed three-way ANOVAs with Phase (Phase 1 vs. Phase 3) and pair type (overlapping vs. unique) as within-subject factors, and experiment (Experiment 1 vs. Experiment 2) as a between-subjects factor, for children and adults. The three-way interaction between phase, pair type, and experiment was not significant for children, $p = .52$, but was significant for adults, $F(1, 55) = 4.42$, $p = .04$, $\eta_p^2 = .074$, suggesting that the magnitude of adults' RI effects was significantly greater when visual contextual cues were not provided in Experiment 2 ($M = .13$) than when these cues were provided in Experiment 1 ($M = -.03$). This result suggests that adults may have avoided RI effects in Experiment 1 by encoding contextual information along with item and outcome information (i.e., <A-Context 1> → X).

In sum, Experiment 2 replicated findings of Experiment 1 for children and extended findings of Experiment 1 for adults. Specifically, when contextual separation among the phases decreased in Experiment 2, adults exhibited evidence of RI. These findings, in conjunction with the lack of correlations between PI and RI, supported the configural account, but provided little evidence for the inhibition account.

If the ability to form configural associations prevents RI in adults, then training adults to form configural <Item-Item> → Outcome structures may attenuate interference effects even when contextual information is not provided. To examine this possibility, we conducted Experiment 3.

Experiment 3

The task implemented in Experiment 3 is similar to those in the first two experiments, but contained several key changes, which were made to encourage configural encoding. First, adults began the task by learning linguistic labels corresponding to *pairs* of objects (e.g., a panel containing a turtle and a t-shirt was referred to by a single label *dax*, and participants had to learn labels for each pair of objects). This label-learning phase of the task was designed to strongly encourage adults to attend to both objects in each pair, so that each pair of objects would become part of a complex associative structure. Crucially, adults only learned labels corresponding to pairs of objects that would later be learned in Phase 1 (and relearned in Phase 3). This design allowed us to determine the effects of learning labels corresponding to unique and overlapping pairs that were later associated with characters in the main experimental task.

The main experimental task was very similar to that of Experiments 1 and 2, with some minor modifications designed to further encourage adults to consider each pair of stimuli as a single associative unit. We hypothesized that adults who were more successful at configural encoding of overlapping pairs in the word-learning phase would be less susceptible to RI in the main experimental task. Although it would be desirable to perform the experiment with children as well, introduction of the training described in the following section substantially increased the length of the experiment, thus making it impractical to conduct this experiment with children.

Method

Participants. Sixty-eight adults (37 females) participated in this experiment, and received partial course credit for their participation.

Stimuli. Twelve illustrated objects were presented to participants in pairs identical to those used in the first two experiments. These pairs were divided into the same two sets seen in Experiments 1 and 2, and were again associated with familiar characters (Pooh Bear and Mickey Mouse) across three main experimental phases. As in Experiment 2, stimuli were seen on a light gray background throughout the entire experiment.

A central goal of this experiment was to introduce a training phase encouraging participants to encode the stimuli configurally. To this end, we introduced the training (i.e., label-learning) phase prior to the experiment proper. The experiment proper was similar to Experiments 1 and 2, with several minor changes to the stimuli, in which the goal was also to encourage configural encoding of stimuli. First, pairs of objects were enclosed in a dark gray border (see Figure 6). Additionally, each panel (containing both objects) was referred to participants as a single object using the learned label, and the spatial location of each object in the panel was consistent throughout the experiment. Finally, no visual occluder was presented and objects did not move around the screen, unlike in Experiments 1 and 2.

Procedure. This experiment included a training phase, as well as three main experimental phases (referred to as Phase 1, Phase 2, and Phase 3) that were very similar to the main task in Experiments 1 and 2. Instructions were given prior to the training phase as well as the first experimental phase. As the number of trials needed to reach criterion during the practice phase of Experiments 1 and 2 was generally very low, no warm-up trials were included in this experiment.

Training phase. During the training phase, participants learned to associate labels with the four pairs of objects that would later be associated with characters in Phases 1 and 3. Each pair of objects was presented as a single panel and associated with a label. For example, the panel containing a turtle and t-shirt was associated with the label *dax*. On each training trial, participants were presented with four object panels placed near the bottom of the screen and asked to identify which object panel should be denoted by a given label (see Figure 7). The spatial location of each panel was counterbalanced and presented in random order across the training phase.

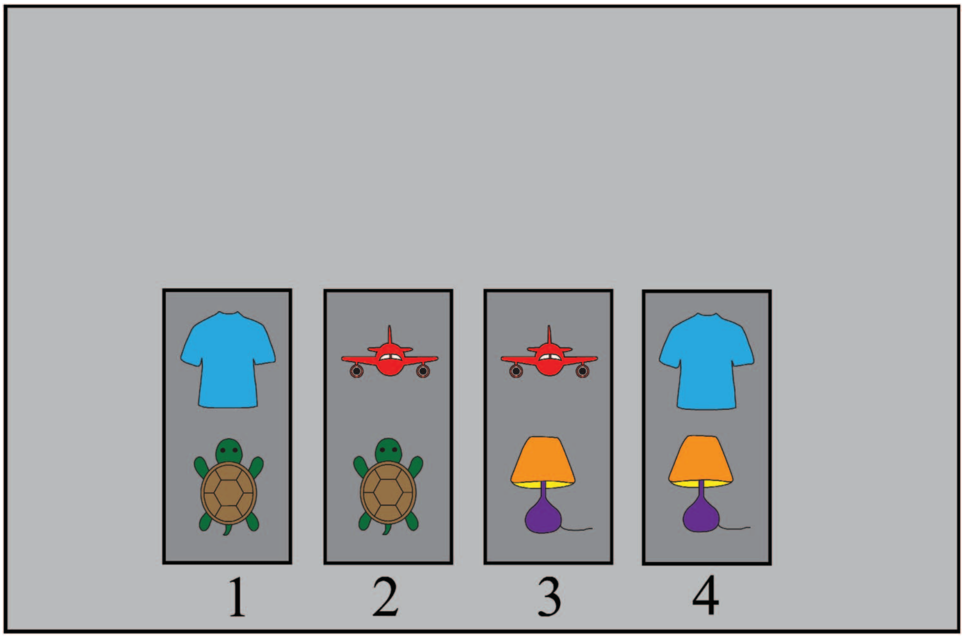

Figure 6. Sample trial during Phase 1 of Experiment 3. Please refer to the text for further details. These stimuli were presented to participants in color. See the online article for the color version of this figure.

The four choices of panels were constructed to encourage participants to configurally encode both objects within the panel. As shown in Figure 7, for each training trial, one panel was the correct choice, one panel was a foil that would be correct for a different label, and the remaining two panels were combinations of the target and foil panels. In this way, there were four different individual objects presented in different combinations across the four panels, and no single object could predict the correct answer choice. As such, a single two-way association between the label and a single object would be insufficient to identify the correct panel. Additionally, participants could not simply find one "correct" choice (i.e., recognize one panel that was the correct choice in a previous trial), as the foil panel was the correct choice for a different label, such that a single two-way association between the two objects in any given panel would also be insufficient for a correct response. Below each panel was a number (1 through 4). Participants were instructed to choose which of the four object panels was denoted by the given word by pressing the "1," "2," "3," or "4" button on the keyboard. Auditory feedback was given in the form of a high tone for correct responses or a low tone for incorrect responses. The length of this phase depended on participants' performance. Participants completed a minimum of 40 trials, and continued in the task until they responded with 90% or higher accuracy within a moving window of 40 trials, or until

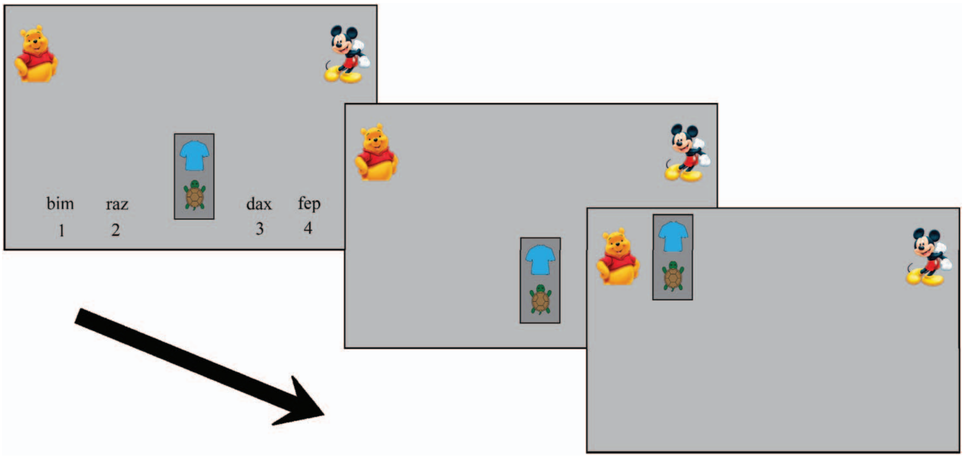

Figure 7. Sample stimulus configuration during a single trial of the training phase of Experiment 3. Participants were asked to identify the object panel denoted by a given label (in this case, *dax*). These stimuli were presented to participants in color. See the online article for the color version of this figure.

completion of a maximum of 120 trials. Participants then proceeded to the experiment proper that started with Phase 1.

Experiment proper. During Phase 1 of the main experimental task, participants were shown one panel of objects, along with four labels, and were asked to indicate which label denoted the given object panel by pressing the numbers 1, 2, 3, or 4 on the keyboard (see Figure 6). Auditory feedback was again given, with high tones accompanying correct responses and low tones accompanying incorrect responses. The purpose of this part of each trial was, again, to influence adults to consider the panel of objects as one configural whole when encoding the association between the panel and the appropriate character. After participants chose which label denoted the given object panel, participants were asked to indicate whether each panel belonged to Pooh Bear or Mickey Mouse by pressing the left- or right-arrow key. Following this choice, the panel of objects disappeared and reappeared by the correct character (regardless of the participant's choice). Note that the pair of objects did not slide into and out of a visual occluder as in the first two experiments. Auditory feedback was again given for correct and incorrect responses as in the first two experiments.

In contrast to Phase 1, Phases 2 and 3 did not include the label component, but simply required participants to indicate whether panels belonged to Pooh Bear or Mickey Mouse. Other than the changes noted previously, these phases did not differ from those in the first two experiments: Phase 2 included two unique pairs of objects not seen in the first phase (or in the training phase) and two overlapping pairs that were recombinations of objects seen in the previous phases. Phase 3 was again identical to the first phase, except that no word-learning component was included.

Results and Discussion

One participant was excluded from the analysis because of computer failure. Additionally, 14 participants were excluded as a result of low accuracy for either overlapping or unique pairs, according to a criterion of at least 70% for both pair types in Blocks 2 through 5 of Phase 1, as in Experiments 1 and 2. Finally, we excluded an additional 13 participants for failing to reach criterion during the training phase (i.e., reaching the maximum of 120 trials without reaching the training criterion of 90% correct within a moving window of 40 trials). These participants were excluded because it is unclear why they failed to reach criterion and whether this failure was a result of the inability to configurally encode or some other factor (e.g., confusion at the task or slow learning). Following this exclusion, the final sample consisted of 40 adults (22 females), all of whom exhibited evidence of successful label learning during the training phase and successful learning during Phase 1 of the experiment proper.

Table 5 summarizes performance in the training phase, in which adults learned to match a given label with the correct pair of objects. Recall that during each trial of Phase 1, participants performed a similar task in which they matched a given pair of objects with the correct label. Average accuracy during this label-learning portion of Phase 1 was 92.4% (SD = 13%) for overlapping pairs and 92.4% (SD = 10%) for unique pairs. This indicates that participants were able to successfully retrieve the mapping between the pair of objects and the associated label during Phase 1.

The purpose of this experiment was to determine whether configural encoding of overlapping elements (i.e., encoding them as a pair) would lead to a reduction of interference effects. To this end, we first analyze overall interference effects in the main experimental task (i.e., associating pairs of objects with characters), as in the first two experiments. Because we instantiated a number of changes to task structure, we do not directly compare interference effects with those of prior experiments. Rather, we examine whether variability in label learning explains variability in interference effects.

Table 6 shows the proportion of accuracy in each block and phase of the main experimental task. As in Experiments 1 and 2, PI was calculated by comparing accuracies in the first block of Phases 1 and 2 for each pair type (see the left-most column in Figure 8A). A repeated-measures ANOVA revealed a significant interaction between these factors, $F(1, 39) = 8.01$, $p = .007$, $\eta_p^2 = .17$. Accuracy for overlapping pairs was not significantly different between these blocks, $p = .90$, whereas accuracy for unique pairs was significantly higher in the beginning of Phase 2, $t(39) = 3.50$, $p = .001$, $d = 0.56$. This suggests that similar to Experiments 1 and 2, participants as a group exhibited PI.

We also measured RI by comparing accuracies in the last block of Phase 1 and the first block of Phase 3 for both pair types (see the middle column in Figure 8A). The interaction between these factors was significant, $F(1, 39) = 25.76$, $p < .001$, $\eta_p^2 = .40$, suggesting that adults were subject to RI, as there was attenuation for overlapping pairs, paired-sample $t(39) = 6.86$, $p < .001$, but not for nonoverlapping pairs, $p = .50$.

We also conducted an ANOVA comparing the first blocks of Phases 1 and 3 to measure savings effects (see the right-most column in Figure 8A). There was again a significant interaction in this comparison, $F(1, 39) = 14.43$, $p < .001$, $\eta_p^2 = .27$. Interestingly, paired-samples t tests revealed that accuracy for overlapping pairs did not differ between the first block of Phases 1 and 3, $p = .45$, whereas accuracy improved for unique pairs, $t(39) = 6.41$, $p < .001$, $d = 1.05$. As in the first two experiments, the magnitudes of PI and RI were not correlated, $r(39) = .053$, $p = .75$.

Table 5
Summary Statistics for Performance in the Training Phase of Experiment 3

	Mean	Median	*SD*	Min	Max
Number of trials to criterion	82.03	80	20.57	40	117
Percent correct for overlapping pairs	67.05	67.03	12.52	40.00	92.59
Percent correct for unique pairs	70.59	71.46	12.59	40.82	92.86

Note. All participants included in the analysis passed the criterion of achieving 90% correct responses within a moving window of 40 trials. Min = minimum; Max = maximum.

Table 6

Mean (SD) Accuracy for All Phases and Blocks in Experiment 3

Phase	Pair type	Block 1	Block 2	Block 3	Block 4	Block 5	Phase average
1	Overlapping	.69 (.26)	.87 (.18)	.92 (.13)	.96 (.09)	.97 (.08)	.88 (.08)
1	Unique	.66 (.24)	.89 (.15)	.89 (.16)	.92 (.13)	.94 (.12)	.86 (.09)
2	Overlapping	.70 (.21)	.91 (.14)	.94 (.12)	.96 (.12)	.96 (.11)	.90 (.08)
2	Unique	.84 (.22)	.98 (.08)	.98 (.07)	.98 (.07)	1 (0)	.96 (.05)
3	Overlapping	.73 (.21)	.92 (.14)	.94 (.12)	.95 (.10)	.97 (.08)	.90 (.06)
3	Unique	.93 (.15)	.98 (.08)	.96 (.11)	.97 (.08)	.96 (.09)	.96 (.05)

Note. Results are separated by pair type (overlapping and unique).

Taken together, these results indicate that adults overall demonstrated robust PI and RI effects. We next analyze effects of training on interference.

The primary purpose of this experiment was to determine whether training adults to configurally encode associative structures would reduce interference effects. We address this question with a series of simple linear regression analyses to determine the effect of overall accuracy for overlapping and unique pairs during training on the magnitudes of PI and RI. If configural encoding modulates the magnitude of interference in adults, then the ability to form configural associations between item pairs during the training phase should predict the magnitude of interference during the experimental task: Greater training accuracy should be accompanied by smaller interference.

To assess the relationship between an individual's ability to configurally encode information and the magnitude of interference, we performed a linear regression and found that individuals' accuracy in label learning for overlapping pairs during training predicted their susceptibility to RI, $\beta = -0.86$, $t(38) = -2.66$, $p = .011$, but not to PI, $p > .2$, and accounted for a reasonable amount of variance in RI, adj. $R^2 = .14$, $F(1, 38) = 7.06$, $p = .011$ (see Figure 9).[3] One possibility, however, is that better learners were just better, more engaged participants overall. If this is the case, then the same effects should transpire for the unique pairs. However, label learning for unique pairs during training did *not* predict the magnitude of RI, $p = .90$, $R^2 = .00$, suggesting that the effect of configural encoding is information-specific and does not stem from superior configural encoding *in general*.

To further investigate effects of training, we performed a median split of the sample based on accuracy for mapping novel words to overlapping pairs during the word-learning phase. We refer to participants with accuracies below the median split as "low learners" and those above the split as "high learners." Average accuracy for low learners was 57.44% ($SD = 7.81\%$), and average accuracy for high learners was 76.67% ($SD = 8.13\%$). Interference effects of low and high learners are presented in Figure 10. To determine whether low and high learners differed in their susceptibility to interference, we performed a series of three-way ANOVAs with learning level as a between-subjects factor.

When investigating PI effects by comparing accuracies of high learners and low learners in the first block of Phase 1 and the first block of Phase 2 (see the left-most column in Figure 10A and B), the three-way interaction between phase, pair type, and learner type was not significant, $p = .61$, suggesting that PI did not vary as a function of learning during the training phase. In contrast to PI, for which no effects of training were found, there was a marginally significant three-way interaction[4] when calculating RI by comparing the difference between the last block of Phase 1 and the first of Phase 3 in these groups (see the middle column in Figure 10A and B), $F(1, 38) = 3.81$, $p = .058$, $\eta_p^2 = .091$, suggesting that high learners ($M = .14$) experienced less RI when learning in Phase 3 than low learners ($M = .30$). We also used a mixed ANOVA to investigate the effect of training accuracy on savings effects by comparing accuracies in the first block of Phase 1 and the first block of Phase 3 (see the right-most column in Figure 10A and B). A marginally significant three-way interaction was found, $F(1, 38) = 3.00$, $p = .092$, $\eta_p^2 = .073$. To better understand this interaction, we performed separate two-way repeated-measures ANOVAs for each learner level. A significant interaction was found between Phase and Pair type for low learners, $F(1, 19) = 16.81$, $p = .001$, $\eta_p^2 = .47$, indicating significant savings for unique pairs, $t(19) = 5.51$, $p < .001$, $d = 1.33$, but not overlapping pairs, $p = .60$. In contrast, there was no significant interaction for high learners, $p = .15$, although there was a main effect of phase, $F(1, 19) = 13.11$, $p = .002$, $\eta_p^2 = .41$. These results suggest that high learners experienced savings for both pair types, whereas low learners experienced savings for only unique pairs.

Finally, we performed a median split based on accuracy for unique pairs during the training phase, but no significant three-way interaction was found for RI effects, $p = .89$, or savings, $p = .53$. Again, these results suggest that configural encoding of overlapping information affects susceptibility to RI and experience of savings effects.

In this experiment, we again replicated PI and RI effects in adults with a modified experimental design, and provided evidence that success at configural encoding is associated with reduced RI. Specifically, we trained adult participants to associate objects within a pair together, and with a specific linguistic label, thus encouraging a configural encoding of each pair. Participants' success at encoding overlapping pairs in this way was a significant predictor of the magnitude of RI later in the task: As expected, more successful configural encoding (as evidenced by higher

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[3] Similar to other analyses of PI and RI reported here, we calculated PI effects by measuring the change in accuracy between the first block of Phases 1 and 2 for overlapping and unique pairs, and calculated the difference of these changes for each participant. To measure RI, we took the difference of the change in accuracy between the last block of Phase 1 and the first of Phase 3 for each pair type.

[4] Performing logit transformations on these data resulted in weakened three-way interactions for RI and savings effects, without eliminating any of the constituent effects.

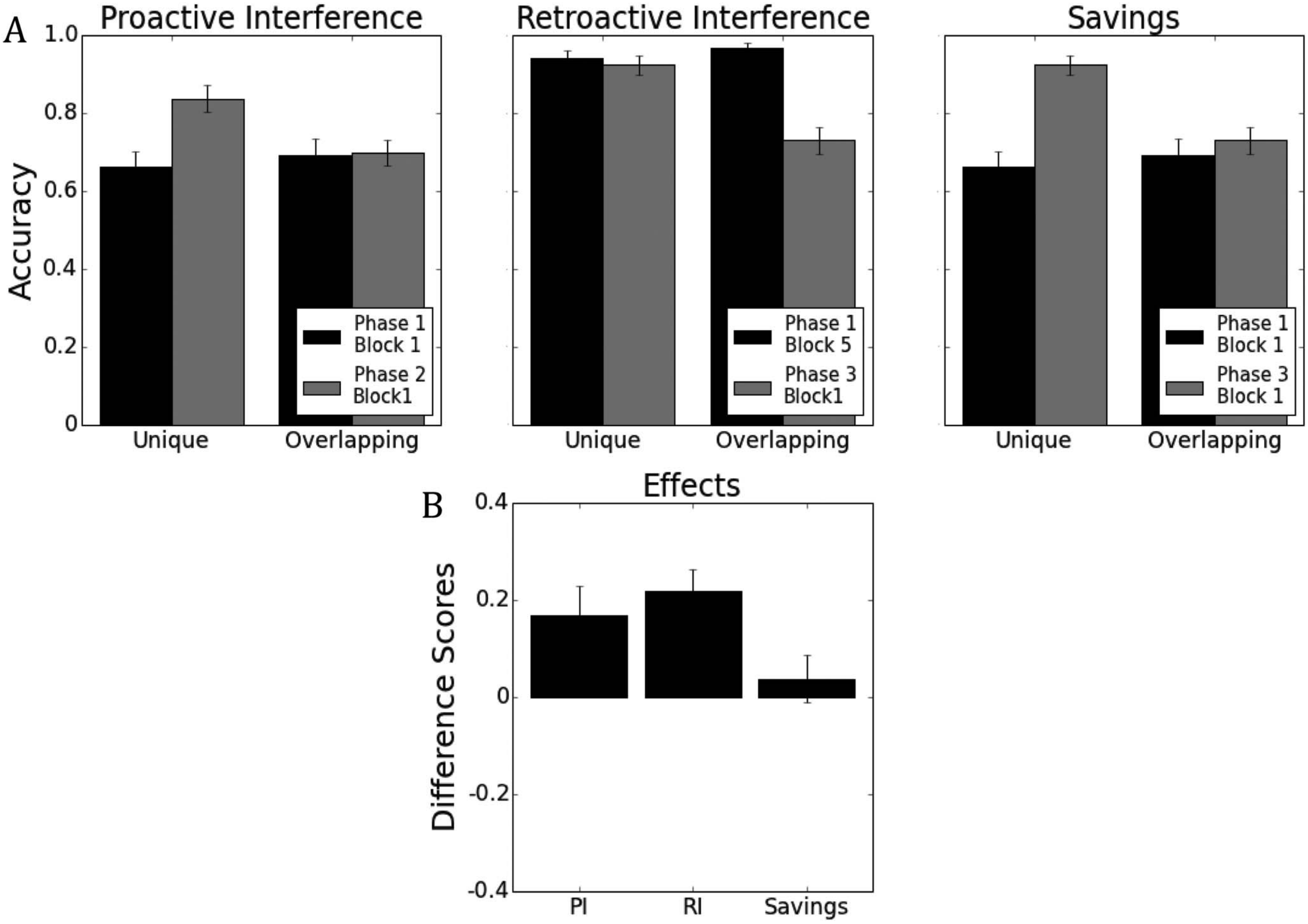

Figure 8. Accuracy results for analyzed blocks in Experiment 3 (A). Also shown are the differences scores depicting PI, RI, and savings effects (B).

training accuracy) was associated with smaller RI effects. This finding suggests that configural encoding acted as a buffer against RI. It was not the case, however, that better configural encoding in general resulted in less RI, as accuracy for unique pairs during training did not predict later susceptibility to RI. Interestingly, no effects of training on PI were found, which further suggests that PI and RI may stem from different mechanisms. We return to this issue again in the general discussion section.

General Discussion

The purpose of this study was to gain developmental and mechanistic insights into proactive and RI effects. In Experiments 1 and 2, we introduced a new experimental paradigm designed to measure interference effects. Results indicated that (a) PI and RI were present only for overlapping sets of information; (b) whereas the magnitude of PI was comparable in children and adults, only children exhibited marked RI; and (c) whereas adults exhibited evidence of savings, young children exhibited *negative* savings.

Comparisons of adult performance in Experiments 1 and 2 suggested that greater contextual separation in Experiment 1 resulted in smaller RI effects in adults; perhaps in Experiment 1, adults formed a configural structure, encoding items along with the context. In Experiment 3, we trained adult participants to encode pairs configurally, and found that participants with greater accuracy for overlapping pairs during training were less susceptible to RI, suggesting that configural encoding of overlapping information may reduce RI. We discuss these findings and their implications in more detail in the remaining sections of the general discussion.

Memory Development

To gain insight into the mechanisms of developmental change in people's susceptibility to PI and RI it is useful to ask whether these forms of interference arise from the same or from different mechanisms. The inhibitory control theory of interference predicts that PI and RI could arise from the same mechanism (Anderson, 2003). Specifically, this account assumes that prepotent, yet contextually inappropriate, memories are inhibited during retrieval by an executive control system. This inhibition allows retrieval of more appropriate traces (even if these traces are weaker than the inhibited ones), thus reducing PI effects. At the same time, attenuating retrieval of the prepotent response increases RI effects. If this is true, the magnitudes of PI and RI should be negatively correlated.

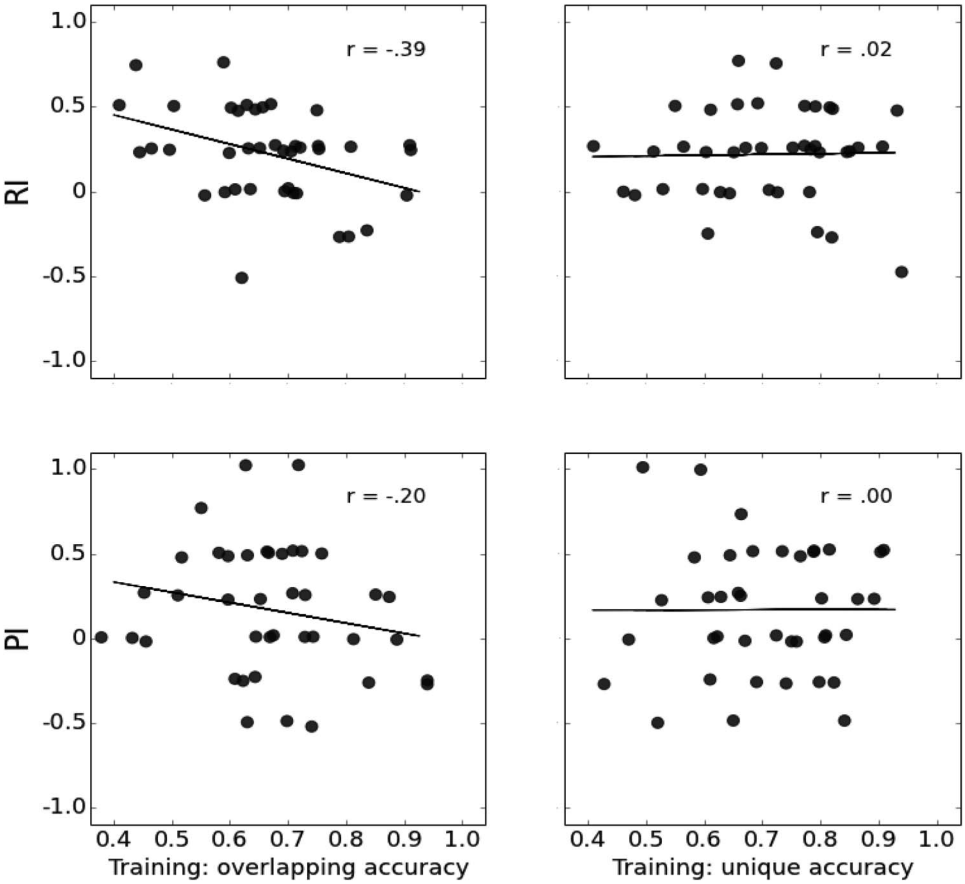

Figure 9. The effect of training accuracy for overlapping and unique pairs on RI and PI effects in the main experiment. Higher values of RI and PI indicate greater interference. Points are slightly jittered for ease of viewing.

A slightly different possibility is that developmental differences lie not in the ability to inhibit prepotent information, but in the ability to release this inhibition. If this is the case, correlations between PI and RI should be particularly pronounced in children. In experiments presented here, however, these magnitudes were not correlated in children or adults. The lack of correlation generates little evidence supporting inhibition-based theories, while supporting the possibility of different mechanisms contributing to PI and RI. Although the reported results are inconsistent with the inhibition-based account, they do not conclusively eliminate the possibility of differential release from inhibition, and this possibility has to be further examined in future research.

The possibility of different mechanisms underlying PI and RI clearly requires additional research, but a number of alternative theories indeed suggest that different neural mechanisms could modulate these effects. PI is generally thought to relate to aspects of executive function, such as active or working memory (Engle, 2002; Kane & Engle, 2000; Morton & Munakata, 2002). In support of this hypothesis, resistance to PI has been associated with PFC activity in neuroimaging studies (Badre & Wagner, 2005; Jonides & Nee, 2006; Shimamura, Jurica, Mangels, Gershberg, & Knight, 1995). Although inhibition theory assumes that RI is also modulated by prefrontal activity (Anderson, 2003), many researchers believe that the hippocampus (and possibly its surrounding cortices) plays a central role in the retention of memory traces and thus resistance to RI (Dewar, Cowan, & Sala, 2007; Kuhl, Shah, DuBrow, & Wagner, 2010; McClelland et al., 1995; O'Reilly & McClelland, 1994; O'Reilly & Rudy, 2001; Wixted, 2004).

Under the assumption that PI and RI are modulated by different neural mechanisms, it is possible to gain some insight into how memory develops. Many elements of episodic memory continue to develop throughout childhood (e.g., Kail, 1990). The neural underpinnings of these changes are unclear, with some researchers suggesting that maturation of the PFC is solely responsible for developmental changes past the preschool years (Gogtay et al., 2006; Sowell et al., 2004), and others suggesting that hippocampal functioning continues to mature as well (Ghetti, DeMaster, Yonelinas, & Bunge, 2010). Although it is clear that the PFC does undergo substantial change throughout childhood, and is likely to cause substantial changes to memory function, our finding of marked differences in the magnitude of RI effects between children and adults suggests that change in the hippocampus is likely contributing to these changes as well. Of course, any inference from behavioral data to the brain requires caution: These inferences are suggestive and have to be examined in future research.

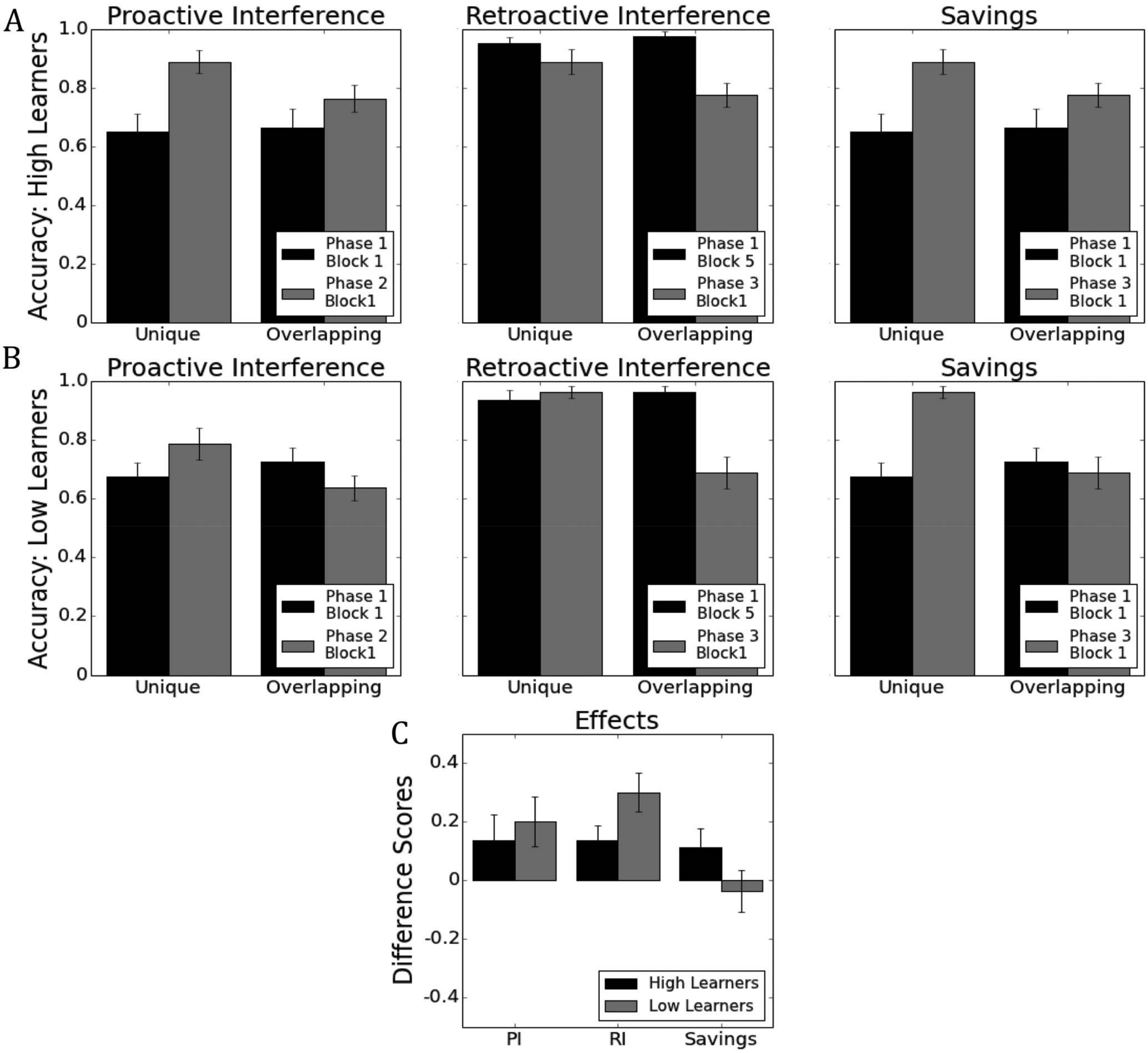

Figure 10. Accuracy results for analyzed blocks in Experiment 3. Results are shown for High Learners (A) as well as Low Learners (B). Also shown are the differences scores depicting PI, RI, and savings effects for each group (C).

Mechanism of Memory

A number of theories of the mechanistic bases of interference have been proposed, including inhibitory control (Anderson, 2003) and configural encoding (Humphreys et al., 1989; O'Reilly & Rudy, 2001). Current results provide evidence capable of distinguishing among these accounts.

One striking result of the reported experiments is the magnitude of RI effects in children, which can be qualified as catastrophic: In Experiments 1 and 2, children's accuracies for overlapping pairs in Phase 3 were significantly lower than at the beginning of Phase 1. This is remarkable, considering that (a) no attenuation was observed for nonoverlapping sets, and (b) for either set type, the same information was presented in Phase 1 and Phase 3. Therefore, not only did children's memory for overlapping information attenuate as a result of learning in Phase 2, it was actually more difficult to learn the same information a second time.

What could cause such a remarkable decline in children's memory? One possibility, consistent with the inhibition at retrieval account (Anderson, 2003; Anderson et al., 1994), is that children inhibited the information presented in Phase 1 in order to learn new pairings in Phase 2. Interestingly, there is some debate in the literature as to whether children are able to efficiently inhibit prepotent memories. Some work suggests that preschool-aged children may not be able to efficiently inhibit nonrelevant memories (Aslan & Bäuml, 2010; Bjorklund & Harnishfeger, 1990; Harnishfeger & Bjorklund, 1994). However, other work suggests that memory inhibition can be explicitly cued or can act as a presumably implicit, automatic process (Knott, Howe, Wimmer, & Dewhurst, 2011; Zellner & Bäuml, 2005), and that preschool-aged and older children are able to implicitly inhibit memory as well as adults. Although both possibilities remain viable, in order for the inhibitory account to explain the reported results, one would need to assume that children are *more* efficient than adults at inhibiting memory. Given that there is no empirical or theoretical basis for this assumption, we suggest that inhibition is insufficient to account for the finding that children experienced much stronger RI effects than adults in this study.

A second possibility, however, is that children and adults inhibit prepotent information to a similar degree, but that children are much less able to release this inhibition. This hypothesis could easily account for the negative savings effects found in children, in which accuracy for overlapping pairs was actually lower in Phase 3 than when initially learning the same information in Phase 1. However, it is unable to account for differences in adults' susceptibility resulting from the presence or absence of contextual separation between phases (Experiments 1 and 2). This account would also not predict a decrease in RI for adults who are better able to form a configural memory structure between items in a pair (Experiment 3). Finally, as discussed in the section on memory development, the release from inhibition account would predict the magnitudes of PI and RI to be negatively correlated, particularly in children, and no correlation was found. If we assume that inhibitory processes do not play a major role in children's forgetting, what can explain negative savings effects? We suspect that negative savings were found in children because of a combination of RI and PI affecting performance in Phase 3. Specifically, children experienced RI when learning in Phase 2 disrupted overlapping memory traces formed during Phase 1, and PI when learning in Phase 2 made it more difficult to relearn this information in Phase 3.

Although we suspect that inhibitory processes did not cause the difference in magnitude between RI effects in children and adults, some insight may be gained by examining other learning systems that experience similar levels of RI. The magnitude of RI in children is reminiscent of the catastrophic interference effects observed in simple connectionist models (McCloskey & Cohen, 1989; Ratcliff, 1990). In these models, new learning quickly causes forgetting of previously learned knowledge. McCloskey and Cohen (1989) found that memory for an initial learning set began declining immediately upon learning new information, and accuracy for previously learned information quickly dropped to zero. Human adults generally demonstrate much more modest RI effects (French, 1999), as they did in this study. A possible explanation for this reduction in RI was proposed by McClelland et al. (1995), who suggested that the interaction of a fast-learning hippocampal system and a slow-learning cortical system could protect information from interference by gradually integrating memory into the neocortex (i.e., by consolidation). In this way, memory is not disrupted by new learning that is rapidly acquired via hippocampal processes. It is possible that immature consolidation processes in the hippocampal-cortical network contributed to the severe RI effects observed in children. This explanation, however, has to be treated with caution because we allowed very little time (approximately one minute) between phases, which, according to many accounts, is insufficient for consolidation. One way to directly implicate consolidation in future work would be to introduce a longer delay between Phase 1 and subsequent phases, allowing consolidation of intact memory traces. If immaturity of consolidation processes does play a role in producing RI, interference should decrease with an opportunity to consolidate information more fully.

Some work suggests that catastrophic interference is not only modulated by the presence or absence of multiple memory systems, as suggested by McClelland et al. (1995), but can be a function of the type of memory representation formed during learning. As argued by Spivey and Mirman (2001), catastrophic interference in neural networks (and in humans) transpire only under some learning conditions, but not others. In particular, the authors distinguished between "pattern-learning" situations that afford generalization and rote memorization situations.

In the pattern-learning situation, in Phase 1, participants (and neural networks) learned pairs of syllables that followed an inversion pattern (e.g., XYZ-ZYX), whereas in Phase 2, they learned syllables that followed a vowel exchange pattern (e.g., XYZ-XAZ). Under these conditions, the authors observed catastrophic-like interference, especially in neural networks. In the "rote memorization" situation, in Phase 1 participants (and neural networks) learned pairs of arbitrarily linked syllables (e.g., XYZ-ABC), and in Phase 2, they learned another list of arbitrarily linked syllables. Under these conditions, the authors observed little RI. In contrast, the current results suggest that even in the "rote memorization" situation RI transpires when the same elements are presented in different configurations across the phases. Therefore, at least in young children, catastrophic-like interference is not limited to pattern-learning situations.

Although more research is needed, the reported results suggest that inhibition accounts are insufficient to account for the pattern of results demonstrated in this study. Our findings do, however, suggest a role of configural encoding in interference effects, especially in RI. Recall that in Experiment 1, RI effects were highly robust in children but were ambiguous in adults. In Experiment 2 we reduced the contextual separation between phases and found that RI effects increased in adults, but not in children. Our hypothesis is that adults used the contextual information available in Experiment 1 to reduce interference by encoding a configural association between the visual context and object-outcome contingencies.

The finding of increased RI in adults (but not in children) when contextual cues were removed (Experiment 2) could suggest that adults are more likely to encode configural associations in the presence of additional cues. Indeed, some work suggests that configural encoding exhibits substantial improvement between preschoolers and adults (Rudy et al., 1993; Yim et al., 2013). Additionally, adults and older children are more likely to bind item and context information (Sluzenski et al., 2006). One possibility, then, is that adults, but not children, were able to take advantage of the contextual information available in Experiment 1.

Why would configural encoding reduce RI effects? One possibility is that it affects the amount of overlap between sets of information (Humphreys et al., 1989). Recall that interference was found only for overlapping sets of information. In this paradigm associations between single elements could result in very similar associative structures between competing representations. For example, it was possible to succeed in Phase 1 by associating a single object with the corresponding character (e.g., Turtle → Pooh Bear). In Phase 2, however, each individual object in overlapping pairs was now associated with the other character (e.g., Turtle → Mickey). These two associations are highly similar in that there is only a single object, which is shared by both. However, integrating the second item of the pair and context information into a configuration (e.g., <Turtle-Boat-Context 1> → Mickey in Phase 1 vs. <Turtle-Hat-Context 2> → Pooh Bear in Phase 2) substantially reduces this overlap, thus potentially reducing RI.

Experiment 3 supported this hypothesis by training adults to form a configural code between both objects within each pair and a label. Higher accuracy for overlapping pairs during training predicted lower magnitudes of RI during the main experimental task. Crucially, accuracy for unique items during training did *not* predict the extent of RI. This suggests an important distinction: It is not that individuals who are generally better able to configurally encode information are less subject to interference, but that better encoding of information helps to protect that specific information from later forgetting.

Interference and Early Learning

There are multiple situations in which children have to learn overlapping information, including (but not limited to) language, social relationships, category learning, and mathematics. Therefore, the current work may have implications for our understanding of early learning across domains.

Language is one example in which people learn overlapping information, thus opening a possibility of interference effects. For example, second language learning creates situations when (a) the same referent has two different symbols, such as English *milk* and Spanish *leche*; or (b) the same symbol refers to different entities across languages, thus creating false cognates (e.g., *magazine*, which means *periodical publication* in English and *store* in Russian). In fact, there is evidence that learning words in a second language may interfere with retrieval of these words in the native language (e.g., Levy, McVeigh, Marful, & Anderson, 2007).

Cross-categorization is another example of learning overlapping information. For example, a child may learn that cats and hamsters are pets, whereas squirrels and foxes are wild animals. Later on, the child may learn that cats and foxes are predators, whereas hamsters and squirrels are prey. Although there is evidence that 4-year-olds can use familiar categories for cross-classification (Nguyen & Murphy, 2003), it is possible that learning categories involving the same members may result in interference effects.

Social relations also involve learning overlapping information. For example, a 4-year-old may learn that he is older in relation to his 2-year-old sister. However, when visiting his relatives, he may learn that he is younger in relation to his 6-year-old cousin. And finally, in learning mathematics, although both integers and fractions are numbers, the way operations (such as addition) are performed on integers and fractions may differ.

Given that these and similar situations may result in massive interference effects, it is reasonable to ask, are there ways of reducing interference? One hypothesis suggested by the current research is that the formation of configural memory structures may reduce (or even prevent) interference. There is some indirect evidence supporting this hypothesis: It has been recently reported that children with highly dense, clustered semantic networks tend to learn language more quickly and have larger vocabulary size (Beckage, Smith, & Hills, 2011; Hills, Maouene, Riordan, & Smith, 2010; Hills, Maouene, Maouene, Sheya, & Smith, 2009).

There is also evidence that the formation of more complex memory structures can be facilitated by presenting different sets of information in rich and highly separated contexts (e.g., Yim et al., 2013), and that strong contextual separation may attenuate or even eliminate interference. For example, infants (Sloutsky & Robinson, 2013), as well as preschool-aged children (Sloutsky & Fisher, 2008), were able to learn to flexibly categorize the same stimuli differently in different contexts, but only when multiple sources of contextual differences were provided (e.g., background color, object size, and spatial location). Interestingly, when such rich contextual separation was provided, infant learning was not attenuated and no interference was observed (Sloutsky & Robinson, 2013). This suggests that even infants may experience some benefit from learning contexts providing a high degree of separation for the to-be-learned sets of information. At the same time, contextual separation may have opposite effects on memory and generalization: High contextual specificity (i.e., learning information only in one context), although facilitating memory, may impede generalization (Goldenberg & Sandhofer, 2013). Therefore, more work is needed to better understand the role of context in learning and memory.

Conclusions

Research presented here demonstrates a striking case of catastrophic-like RI in 4- to 5-year-olds, with much smaller PI. The results also indicate that retroactive effects decrease with age and can be modulated by the ability to form configural memory structures. These findings have important implications for our understanding of the mechanisms of memory as well as the development of memory structures subserving episodic memory.

References

Anderson, M. C. (2003). Rethinking interference theory: Executive control and the mechanisms of forgetting. *Journal of Memory and Language, 49,* 415–445. http://dx.doi.org/10.1016/j.jml.2003.08.006

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering can cause forgetting: Retrieval dynamics in long-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1063–1087. http://dx.doi.org/10.1037/0278-7393.20.5.1063

Anderson, M. C., & Neely, J. H. (1996). Interference and inhibition in memory retrieval. In E. L. Bjork & R. A. Bjork (Eds.), *Memory. Handbook of perception and cognition* (pp. 237–313). San Diego, CA: Academic Press.

Aslan, A., & Bäuml, K.-H. T. (2010). Retrieval-induced forgetting in young children. *Psychonomic Bulletin & Review, 17,* 704–709. http://dx.doi.org/10.3758/PBR.17.5.704

Badre, D., & Wagner, A. D. (2005). Frontal lobe mechanisms that resolve proactive interference. *Cerebral Cortex, 15,* 2003–2012. http://dx.doi.org/10.1093/cercor/bhi075

Bauer, P. J. (2007). *Remembering the times of our lives: Memory in infancy and beyond.* Mahwah, NJ: Erlbaum.

Bauer, P. J., Wenner, J. A., Dropik, P. L., & Wewerka, S. S. (2000). Parameters of remembering and forgetting in the transition from infancy to early childhood. *Monographs of the Society for Research in Child Development, 65,* i–vi, 1–204.

Beckage, N., Smith, L., & Hills, T. (2011). Small worlds and semantic network growth in typical and late talkers. *PLoS ONE, 6*(5), e19348. http://dx.doi.org/10.1371/journal.pone.0019348

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H. L. Roediger & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 309–330). Hillsdale, NJ: Erlbaum.

Bjorklund, D. F., & Harnishfeger, K. K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Developmental Review, 10,* 48–71. http://dx.doi.org/10.1016/0273-2297(90)90004-N

Brainerd, C. J., Reyna, V. F., & Ceci, S. J. (2008). Developmental reversals in false memory: A review of data and theory. *Psychological Bulletin, 134,* 343–382. http://dx.doi.org/10.1037/0033-2909.134.3.343

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26,* 571–593. http://dx.doi.org/10.1207/s15326942dn2602_3

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 1, pp. 7–75). Hillsdale, NJ: Erlbaum.

Dempster, F. N., & Corkill, A. J. (1999). Interference and inhibition in cognition and behavior: Unifying themes for educational psychology. *Educational Psychology Review, 11,* 1–88. http://dx.doi.org/10.1023/A:1021992632168

Dewar, M. T., Cowan, N., & Sala, S. D. (2007). Forgetting due to retroactive interference: A fusion of Müller and Pilzecker's (1900) early insights into everyday forgetting and recent research on anterograde amnesia. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 43,* 616–634. http://dx.doi.org/10.1016/S0010-9452(08)70492-1

Diamond, A. (1985). Development of the ability to use recall to guide action, as indicated by infants' performance on AB. *Child Development, 56,* 868–883. http://dx.doi.org/10.2307/1130099

Diamond, A. (1988). Abilities and neural mechanisms underlying AB performance. *Child Development, 59,* 523–527. http://dx.doi.org/10.2307/1130330

Drummey, A. B., & Newcombe, N. S. (2002). Developmental changes in source memory. *Developmental Science, 5,* 502–513. http://dx.doi.org/10.1111/1467-7687.00243

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11,* 19–23. http://dx.doi.org/10.1111/1467-8721.00160

Fagan, J. F., III. (1977). Infant recognition memory: Studies in forgetting. *Child Development, 48,* 68–78. http://dx.doi.org/10.1111/j.1467-8624.1977.tb04244.x

French, R. M. (1999). Catastrophic forgetting in connectionist networks. *Trends in Cognitive Sciences, 3,* 128–135. http://dx.doi.org/10.1016/S1364-6613(99)01294-2

Ghetti, S., DeMaster, D. M., Yonelinas, A. P., & Bunge, S. A. (2010). Developmental differences in medial temporal lobe function during memory encoding. *The Journal of Neuroscience, 30,* 9548–9556. http://dx.doi.org/10.1523/JNEUROSCI.3500-09.2010

Ghetti, S., & Lee, J. (2011). Children's episodic memory. *Wiley Interdisciplinary Reviews: Cognitive Science, 2,* 365–373. http://dx.doi.org/10.1002/wcs.114

Gogtay, N., Nugent, T. F., III, Herman, D. H., Ordonez, A., Greenstein, D., Hayashi, K. M., . . . Thompson, P. M. (2006). Dynamic mapping of normal human hippocampal development. *Hippocampus, 16,* 664–672. http://dx.doi.org/10.1002/hipo.20193

Goldenberg, E. R., & Sandhofer, C. M. (2013). Same, varied, or both? Contextual support aids young children in generalizing category labels. *Journal of Experimental Child Psychology, 115,* 150–162. http://dx.doi.org/10.1016/j.jecp.2012.11.011

Griffiths, T. L., Sobel, D. M., Tenenbaum, J. B., & Gopnik, A. (2011). Bayes and blickets: Effects of knowledge on causal induction in children and adults. *Cognitive Science, 35,* 1407–1455. http://dx.doi.org/10.1111/j.1551-6709.2011.01203.x

Guida, A., Gobet, F., Tardieu, H., & Nicolas, S. (2012). How chunks, long-term working memory and templates offer a cognitive explanation for neuroimaging data on expertise acquisition: A two-stage framework. *Brain and Cognition, 79,* 221–244. http://dx.doi.org/10.1016/j.bandc.2012.01.010

Harnishfeger, K. K., & Bjorklund, D. F. (1994). A developmental perspective on individual differences in inhibition. *Learning and Individual Differences, 6,* 331–355. http://dx.doi.org/10.1016/1041-6080(94)90021-3

Hills, T. T., Maouene, J., Riordan, B., & Smith, L. B. (2010). The associative structure of language: Contextual diversity in early word learning. *Journal of Memory and Language, 63,* 259–273. http://dx.doi.org/10.1016/j.jml.2010.06.002

Hills, T. T., Maouene, M., Maouene, J., Sheya, A., & Smith, L. (2009). Longitudinal analysis of early semantic networks: Preferential attachment or preferential acquisition? *Psychological Science, 20,* 729–739. http://dx.doi.org/10.1111/j.1467-9280.2009.02365.x

Howe, M. L. (1995). Interference effects in young children's long-term retention. *Developmental Psychology, 31,* 579–596. http://dx.doi.org/10.1037/0012-1649.31.4.579

Humphreys, M. S., Bain, J. D., & Pike, R. (1989). Different ways to cue a coherent memory system: A theory for episodic, semantic, and procedural tasks. *Psychological Review, 96,* 208–233. http://dx.doi.org/10.1037/0033-295X.96.2.208

Jonides, J., & Nee, D. E. (2006). Brain mechanisms of proactive interference in working memory. *Neuroscience, 139,* 181–193. http://dx.doi.org/10.1016/j.neuroscience.2005.06.042

Kail, R. (1990). *Memory development in children* (3rd ed.). New York, NY: Freeman.

Kail, R. (2002). Developmental change in proactive interference. *Child Development, 73,* 1703–1714. http://dx.doi.org/10.1111/1467-8624.00500

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 336–358. http://dx.doi.org/10.1037/0278-7393.26.2.336

Knott, L. M., Howe, M. L., Wimmer, M. C., & Dewhurst, S. A. (2011). The development of automatic and controlled inhibitory retrieval processes in true and false recall. *Journal of Experimental Child Psychology, 109,* 91–108. http://dx.doi.org/10.1016/j.jecp.2011.01.001

Krascum, R. M., & Andrews, S. (1998). The effects of theories on children's acquisition of family-resemblance categories. *Child Development, 69,* 333–346. http://dx.doi.org/10.1111/j.1467-8624.1998.tb06192.x

Kuhl, B. A., Shah, A. T., DuBrow, S., & Wagner, A. D. (2010). Resistance to forgetting associated with hippocampus-mediated reactivation during new learning. *Nature Neuroscience, 13,* 501–506. http://dx.doi.org/10.1038/nn.2498

Lee, K., & Bussey, K. (2001). Children's susceptibility to retroactive interference: The effects of age and degree of learning. *Journal of Experimental Child Psychology, 80,* 372–391. http://dx.doi.org/10.1006/jecp.2001.2638

Levy, B. J., McVeigh, N. D., Marful, A., & Anderson, M. C. (2007). Inhibiting your native language: The role of retrieval-induced forgetting during second-language acquisition. *Psychological Science, 18,* 29–34. http://dx.doi.org/10.1111/j.1467-9280.2007.01844.x

Mareschal, D., Quinn, P. C., & French, R. M. (2002). Asymmetric interference in 3- to 4-month-olds' sequential category learning. *Cognitive Science, 26,* 377–389. http://dx.doi.org/10.1207/s15516709cog2603_8

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review, 102,* 419–457. http://dx.doi.org/10.1037/0033-295X.102.3.419

McCloskey, M., & Cohen, N. J. (1989). Catastrophic interference in connectionist networks: The sequential learning problem. *Psychology of Learning and Motivation, 24,* 109–165.

Morton, J. B., & Munakata, Y. (2002). Active versus latent representations: A neural network model of perseveration, dissociation, and decalage. *Developmental Psychobiology, 40,* 255–265. http://dx.doi.org/10.1002/dev.10033

Munakata, Y., & Yerys, B. E. (2001). All together now: When dissociations between knowledge and action disappear. *Psychological Science, 12,* 335–337. http://dx.doi.org/10.1111/1467-9280.00361

Murphy, G. L., & Allopenna, P. D. (1994). The locus of knowledge effects in concept learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 904–919. http://dx.doi.org/10.1037/0278-7393.20.4.904

Nelson, T. O. (1985). Ebbinghaus's contribution to the measurement of retention: Savings during relearning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 472–479. http://dx.doi.org/10.1037/0278-7393.11.3.472

Nguyen, S. P., & Murphy, G. L. (2003). An apple is more than just a fruit: Cross-classification in children's concepts. *Child Development, 74,* 1783–1806. http://dx.doi.org/10.1046/j.1467-8624.2003.00638.x

Norman, K. A., & O'Reilly, R. C. (2003). Modeling hippocampal and neocortical contributions to recognition memory: A complementary-learning-systems approach. *Psychological Review, 110,* 611–646. http://dx.doi.org/10.1037/0033-295X.110.4.611

O'Reilly, R. C., & McClelland, J. L. (1994). Hippocampal conjunctive encoding, storage, and recall: Avoiding a trade-off. *Hippocampus, 4,* 661–682. http://dx.doi.org/10.1002/hipo.450040605

O'Reilly, R. C., & Rudy, J. W. (2001). Conjunctive representations in learning and memory: Principles of cortical and hippocampal function. *Psychological Review, 108,* 311–345. http://dx.doi.org/10.1037/0033-295X.108.2.311

Piaget, J. (1963). *The origins of intelligence in children*. New York, NY: Norton.

Pipe, M.-E., & Salmon, K. (2009). Memory development and the forensic context. In M. L. Courage & N. Cowan (Eds.), *The development of memory in infancy and childhood* (2nd ed., pp. 241–282). Hove, UK: Psychology Press.

Ratcliff, R. (1990). Connectionist models of recognition memory: Constraints imposed by learning and forgetting functions. *Psychological Review, 97,* 285–308. http://dx.doi.org/10.1037/0033-295X.97.2.285

Roediger, H. L., III, & Marsh, E. J. (2005). The positive and negative consequences of multiple-choice testing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 1155–1159. http://dx.doi.org/10.1037/0278-7393.31.5.1155

Rossi-George, A., & Rovee-Collier, C. (1999). Retroactive interference in 3-month-old infants. *Developmental Psychobiology, 35,* 167–177. http://dx.doi.org/10.1002/(SICI)1098-2302(199911)35:3<167::AID-DEV1>3.0.CO;2-V

Rudy, J. W., Keith, J. R., & Georgen, K. (1993). The effect of age on children's learning of problems that require a configural association solution. *Developmental Psychobiology, 26,* 171–184. http://dx.doi.org/10.1002/dev.420260304

Shimamura, A. P., Jurica, P. J., Mangels, J. A., Gershberg, F. B., & Knight, R. T. (1995). Susceptibility to memory interference effects following frontal lobe damage: Findings from tests of paired-associate learning. *Journal of Cognitive Neuroscience, 7,* 144–152. http://dx.doi.org/10.1162/jocn.1995.7.2.144

Sloutsky, V. M., & Fisher, A. V. (2004). When development and learning decrease memory: Evidence against category-based induction in children. *Psychological Science, 15,* 553–558. http://dx.doi.org/10.1111/j.0956-7976.2004.00718.x

Sloutsky, V. M., & Fisher, A. V. (2008). Attentional learning and flexible induction: How mundane mechanisms give rise to smart behaviors. *Child Development, 79,* 639–651. http://dx.doi.org/10.1111/j.1467-8624.2008.01148.x

Sloutsky, V. M., & Robinson, C. W. (2013). Redundancy matters: Flexible learning of multiple contingencies in infants. *Cognition, 126,* 156–164. http://dx.doi.org/10.1016/j.cognition.2012.09.016

Sluzenski, J., Newcombe, N. S., & Kovacs, S. L. (2006). Binding, relational memory, and recall of naturalistic events: A developmental perspective. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 89–100. http://dx.doi.org/10.1037/0278-7393.32.1.89

Sluzenski, J., Newcombe, N., & Ottinger, W. (2004). Changes in reality monitoring and episodic memory in early childhood. *Developmental Science, 7,* 225–245. http://dx.doi.org/10.1111/j.1467-7687.2004.00341.x

Sowell, E. R., Thompson, P. M., Leonard, C. M., Welcome, S. E., Kan, E., & Toga, A. W. (2004). Longitudinal mapping of cortical thickness and brain growth in normal children. *The Journal of Neuroscience, 24,* 8223–8231. http://dx.doi.org/10.1523/JNEUROSCI.1798-04.2004

Spivey, M., & Mirman, D. (2001). Retroactive interference in neural networks and in humans: The effect of pattern-based learning. *Connection Science, 13,* 257–275. http://dx.doi.org/10.1080/09540090110091830

Sutherland, R. J., & Rudy, J. W. (1989). Configural association theory: The role of the hippocampal formation in learning, memory, and amnesia. *Psychobiology (Austin, Tex.), 17,* 129–144.

Tyrrell, D. J., Snowman, L. G., Beier, J. A., & Blanck, C. M. (1990). Proactive interference in infant recognition memory. *Bulletin of the Psychonomic Society, 28,* 188–190. http://dx.doi.org/10.3758/BF03333999

Wickelgren, W. A. (1973). The long and the short of memory. *Psychological Bulletin, 80,* 425–438.

Wixted, J. T. (2004). The psychology and neuroscience of forgetting. *Annual Review of Psychology, 55,* 235–269. http://dx.doi.org/10.1146/annurev.psych.55.090902.141555

Yim, H., Dennis, S. J., & Sloutsky, V. M. (2013). The development of episodic memory: Items, contexts, and relations. *Psychological Science, 24,* 2163–2172. http://dx.doi.org/10.1177/0956797613487385

Zelazo, P. D. (2006). The Dimensional Change Card Sort (DCCS): A method of assessing executive function in children. *Nature Protocols, 1,* 297–301. http://dx.doi.org/10.1038/nprot.2006.46

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11,* 37–63. http://dx.doi.org/10.1016/S0885-2014(96)90027-1

Zelazo, P. D., Müller, U., Frye, D., Marcovitch, S., Argitis, G., Boseovski, J., . . . Sutherland, A. (2003). The development of executive function in early childhood. *Monographs of the Society for Research in Child Development, 68*(3), vii–137. http://dx.doi.org/10.1111/j.0037-976X.2003.00269.x

Zellner, M., & Bäuml, K.-H. (2005). Intact retrieval inhibition in children's episodic recall. *Memory & Cognition, 33,* 396–404. http://dx.doi.org/10.3758/BF03193058

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