The Cost of Learning: Interference Effects on Early Learning and Memory

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Abstract

A great deal of work in cognitive science has focused on how learning and memory can interact through proactive and retroactive interference effects. However, the mechanisms underlying these effects are still debated, and little is known regarding how interference affects learning in human development. This work addresses these questions by comparing children's and adults' performance on a new associative learning task in which information was either unique or overlapping across three phases. Robust interference effects were found for overlapping, but not unique information. Additionally, proactive interference was comparable between age groups, while retroactive interference was more robust in child participants. Results of two experiments suggest that interference is likely not driven primarily by differences in consolidation or active inhibitory processes, but may be influenced by configural encoding processes.

Keywords: Memory development; learning; proactive interference; retroactive interference.

Interference

People learn almost constantly. Most of the information that we learn, however, contains a great deal of overlap with previous experiences. Most of the words that we read are already familiar, for example, and have been experienced in many different contexts. Previous knowledge clearly influences how and what information we learn in the present, which in turn can affect our memory for past learning, such that learning and memory are not independent processes but interact in different ways.

In some cases these interaction are facilitative. Expertise in a particular domain, for example, increases memory capacity for information within that domain (Chi, Glaser, & Rees, 1982). At the same time, interactions between learning and memory can also produce interference effects, in which learning new information attenuates subsequent learning (proactive interference, or PI) or memory for previous learning (retroactive interference, or RI). Consider a child in a bilingual environment who learns from her mother that the new family pet is called a "cat," but later hears her father referring to the animal as "el gato." It will likely be difficult to learn the "gato" label since the concept of cat has already been associated with a label, resulting in PI (Markman & Wachtel, 1988). Similarly, when the new label has been successfully mapped onto the concept, the association with the initial label ("cat") is likely more difficult to recall since two labels are now mapped onto the same concept, resulting in RI.

Interference effects have been found to empirically influence a number of developmental phenomena. For example, some work suggests that young infants demonstrate PI in a face-recognition paradigm (Tyrrell, Snowman, Beier, & Blanck, 1990), and RI in the mobile-reinforcement paradigm (Rossi-George & Rovee-Collier, 1999). Additionally, a long tradition of developmental work has investigated early perseveration effects with tasks such as A-not-B and the Dimensional Change Card Sort task (Piaget, 1963; Zelazo, 2006), in which infants and children learn a set of contingencies and have difficulty responding appropriately after these contingencies change, similar to PI. Interference effects can also influence findings in unexpected ways. One recent study (Opfer & Thompson, 2008) concluded that previous work reporting a surprising lack of transfer of numerical concept learning in children may have stemmed from PI induced by the pre-test, and that transfer effects could be found with proper experimental design mitigating PI. Clearly, interference effects are essential topics of study for researchers interested in learning, memory, and cognitive development.

Proposed Mechanisms of Interference

Interference effects have been studied extensively in adults (Anderson & Neely, 1996; Wixted, 2004), and a number of mechanisms have been proposed to account for PI and RI. M. C. Anderson and colleagues (Anderson, 2003; Anderson & Spellman, 1995) have argued that interference does not result from learning per se, but rather from active engagement of inhibitory processes during retrieval. Specifically, when a cue activates memory, the strongest competitor may not be contextually appropriate and so must be inhibited in order to retrieve the weaker but appropriate response. This inhibition enables one to overcome PI and learn new contingencies but makes it more difficult to retrieve the original association that has been inhibited, producing RI.

Another theory of interference has been proposed by Wixted (2004). According to this account, interference arises when new learning disrupts the consolidation process, in which memories gradually migrate from the hippocampus to cortical regions (McClelland, McNaughton, & O'Reilly, 1995). New learning results in interference of recently learned information still contained in the hippocampus (Wixted, 2004). As a result, this account predicts that any effortful new learning should produce interference (Wixted,

2004).

Finally, some work has suggested that initial encoding may modulate the extent of interference effects (Humphreys, Bain, & Pike, 1989). According to this framework, memories are protected from interference when they are encoded in complex configural structures, such as between a cue, target, and context. The encoding of more complex structures may be effective at reducing interference because it reduces the amount of overlap between learning sets, resulting in less interference (Humphreys et al., 1989). More recent work has examined the development of configural encoding and found that young children have difficulty encoding complex structures of associations (Rudy et al., 1993), and that the the ability to form more complex associative structures increases between age of five and adulthood (Yim, Dennis, & Sloutsky, 2013).

The current work aims to gain insight into the developmental and mechanistic underpinnings of interference effects. Specifically, we sought to understand the roles of consolidation (Wixted, 2004), active inhibition (Anderson, 2003), and configural encoding (Humphreys et al., 1989; Yim et al., 2013) in producing interference effects in preschoolers and adults. To this end, a number of specific hypotheses may be made. First, if interference is driven primarily by a disruption of consolidation (Wixted, 2004), PI and RI effects should not differ between items that are unique and those that contain overlapping features, as this theory predicts that any effortful new learning should disrupt consolidation and as a result produce interference. Additionally, analysis of developmental differences in the magnitude of interference effects may produce insight into the mechanistic source of these effects. Specifically, if interference is a function of inhibition at retrieval (Anderson, 2003), adults should demonstrate stronger RI effects than children, since the ability to inhibit prepotent responses increases with age (Brocki & Bohlin, 2004). Conversely, stronger interference in children may suggest a role of encoding, as recent work has suggested that children are less likely to encode complex associative structures than are adults (Yim et al., 2013).

Experiment 1

In Experiment 1 we sought to gain insight into developmental change by comparing the magnitudes of PI and RI between preschoolers and adults. 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 developed by this age range. Unlike RI effects, some work suggests that PI effects decrease between childhood and adulthood (Kail, 2002; Yim et al., 2013).

We also investigated the mechanisms of interference in Experiment 1 by manipulating the amount of overlap between associated elements in a new experimental paradigm designed to measure effects of PI and RI on associative learning. This design allowed us to compare interference effects between elements that were unique across different phases of the task and elements that overlapped. 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.

Methods

Participants Thirty-four preschool-aged children (m=5.31 years, SD=0.24 years, range=4.8-5.8 years, 18 females) and 28 adults (9 females) participated in this experiment. Children were tested in local preschools and received stickers for participating. Adults were recruited from introductory psychology classes and received partial course credit.

Stimuli Experimental stimuli consisted of illustrations of three familiar objects from each of four categories–animals (e.g. turtle), vehicles (e.g. boat), clothing (e.g. baseball cap), and furniture (e.g. lamp)–for a total of 12 objects. Objects were presented to participants in pairs selected arbitrarily from different categories. Additional stimuli included a visual occluder and two characters familiar to children–Winnie the Pooh (referred to as Pooh Bear) and Mickey Mouse.

Across three experimental phases participants learned to associate pairs of objects with one of the two characters. The first and third phases contained the same set of contingencies, whereas a different set was learned in Phase 2, creating an ABA set structure across phases, with order counterbalanced. Each set of stimuli contained two types of pairs: overlapping and unique. 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 A.B $\rightarrow$ X and C.D $\rightarrow$ X, in Phase 2 the new pairings might be A.C $\rightarrow$ Y and B.D $\rightarrow$ Y. Each set contained four pairs in total: two overlapping and two unique.

Figure 1 shows the stimulus setup for the beginning of a typical trial. The spatial locations of stimuli remained constant throughout the experiment. In contrast, the colors of the background and the occluder provided contextual cues that co-varied with the set of pairs presented in a particular phase. Specifically, pairs could be presented on a light grey background with a black occluder or on a dark grey background with a white occluder.

Procedure The task was presented to child participants on a touchscreen monitor in their preschool, and to adults on a standard monitor in a quiet lab room. 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 one-minute 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

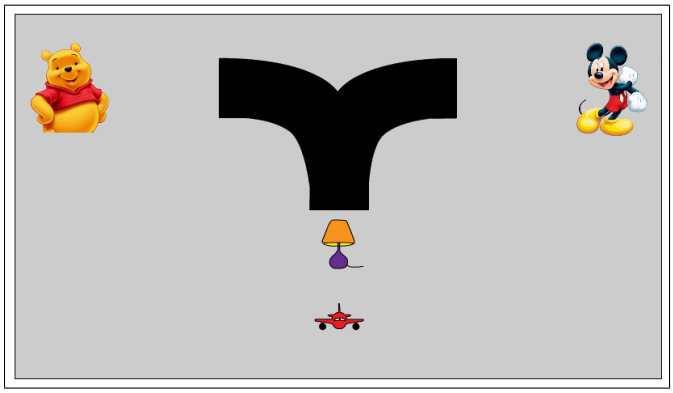

Figure 1: An example trial

trials across the experiment. Each pair of objects was seen twice per block, with trial order randomized for each block and each participant.

Participants were instructed before the task began that the objects would disappear behind the occluder and pop out by one character, and that their job was to predict whether the objects would reappear by Pooh Bear or by Mickey Mouse. Child participants responded on each trial by touching the appropriate character on the touchscreen, while adult participants 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 2s later by the correct character. Participants heard a high tone following correct responses or a low tone following incorrect responses. Children also received additional verbal feedback by the experimenter, e.g. "Great job, those do go to Pooh Bear" or "Uh oh, those actually go to Mickey Mouse."

Results and Discussion

Six children were not included in analyses due to fatigue (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 in 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 = 4.8-5.8 years, 12 females) and 24 adults (8 females).

To measure PI and RI effects we compare accuracies for specific blocks in the first and subsequent phases. Accuracy in Phase 1 is considered baseline as it reflects 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 differences in accuracy in Phase 3. The analysis, however, is not straightforward, as simply comparing accuracies across phases leads to ambiguity regarding the locus of any differences. For example, attenuation of accuracy could be due to simple memory decay or other task effects, with interference playing no significant role. We approach this problem by calculating interactions between phases and pair types. This approach allows us to both control for memory decay and task effects, as well as ask whether any new learning potentially causes interference as predicted by the consolidation account (Wixted, 2004). We also include a between-subjects age factor to compare interference between children and adults in order to to examine any developmental differences.

To measure PI effects we compare accuracies in the beginning (i.e. Block 1) of Phase 1 and the beginning of Phase 2 between pair types (see Figure 2). This focused analysis is performed because effects of interference may be strongest in the beginning of a new phase (i.e. Phase 2), and quickly attenuate as learning progresses.

To analyze PI we performed a 3-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-subject factor. There was a significant phase by pair type interaction, $F(1,47) = 9.29$, p=.004, η_p^2=.17, suggesting that PI did affect learning in Phase 2. However, the three-way interaction was not significant, p=.26, suggesting that the magnitude of PI did not differ between children and adults.

We measured RI effects by comparing accuracy during the last block of Phase 1 and the first block of Phase 3 (see Figure 2). 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-subject 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 by Pair type ANOVAs for children and adults. The interaction between Phase and Pair type was significant in children, F(1,24) =32.87, p $< .001$, $\eta_p^2 = 0.58$, but not in adults, p =.62. While children clearly exhibited strong RI, results in adults were somewhat ambiguous: it is not clear if RI affected both pair types, or if participants experienced simple memory decay for both pair types.

To gain more insight into the magnitude of RI effects, we calculated savings effects by comparing performance in the first block of Phase 1 and the corresponding block of Phase 3. We performed a three-way mixed ANOVA with Phase and Pair type as within-subject factors and age as a between-subject 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 by Pair type ANOVAs in children and

adults. A significant interaction was found between these factors in children, $F(1,24) = 12.71$, $p = .002$, $\eta_p^2 = .35$. In contrast, the Phase by 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.

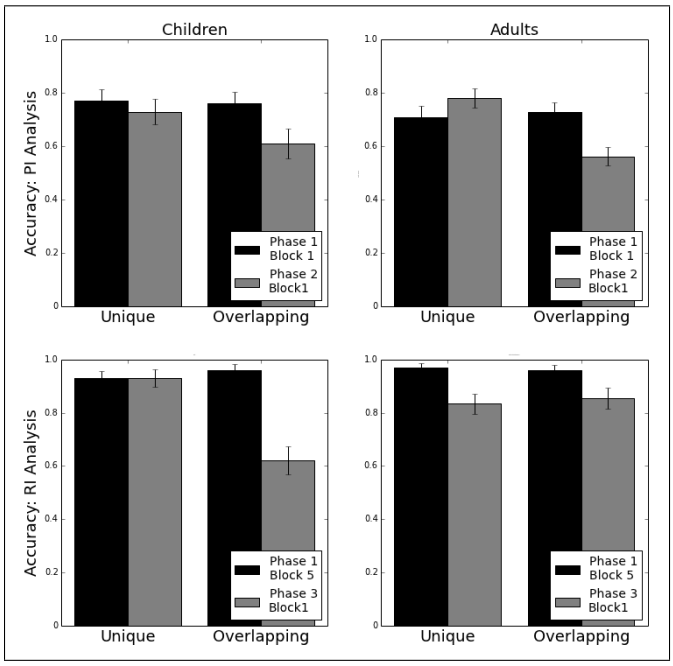

Figure 2: Experiment 1 accuracy results across blocks

In sum, the results of this experiment suggest that (a) evidence for interference was in general found only for contingencies that contained overlap across learning sets, (b) small to moderate PI effects were found in both children and adults, with no magnitude differences between age groups, and (c) severe RI effects were demonstrated in children, whereas attenuation was much more moderate in adults.

The finding that performance attenuated only for overlapping pairs in most cases suggests that disruption of consolidation in and of itself likely did not play a large role in producing interference. If dynamics of consolidation alone were responsible for interference (Wixted, 2004), attenuation should have been equal for both pair types, as pairs were randomly intermixed within each block. Additionally, the developmental pattern of the magnitude of interference effects is inconsistent with the idea that forgetting springs from frontal lobe-mediated inhibition of distracting contingencies (Anderson, 2003). In particular, if interference were mediated by active inhibition we would expect adults to demonstrate more RI and less PI, as a result of efficient inhibition of overlapping contingencies from Phase 1.

Experiment 2

Although results of Experiment 1 do not support the ideas that interference is caused by consolidation processes or active inhibition, it is not clear what the mechanism(s) are. One possibility is that the locus of interference lies in encoding processes. Specifically, the complexity of participants' associative structures may determine how vulnerable these structures are to interference (Humphreys et al., 1989). In order to examine this possibility, in Experiment 2 we attempted to determine the effect of the visual context change in Experiment 1 by eliminating it, such that the visual context was identical in all three phases. If participants spontaneously encoded the visual context in any phase during Experiment 1, and this additional association protected information from attenuation, interference should increase in Experiment 2.

Methods

Participants A total of 37 preschool-aged 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 preschools, and received stickers for their participation. Thirty-five adults also participated (12 females), and received partial credit for an introductory psychology course.

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 the visual context consisted of a light grey 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 due to fatigue ($n = 5$), computer error ($n = 3$), or needing to terminate the task for school activities ($n = 2$). An additional child was excluded due to an undisclosed diagnosis of autism spectrum disorder. As in Experiment 1, we also excluded participants whose mean accuracy during 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, 9 females), and 33 adults (12 females).

As in Experiment 1, we calculated PI by comparing accuracy for each pair type in the first block of Phases 1 and 2 (see Figure 3). 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-subject 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 that PI was a factor in these age groups.

RI was measured by comparing accuracies in the last block of Phase 1 to the first block of Phase 3. 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-subject 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 by 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 adults, $F(1,32) = 7.73$, $p = .009$, $\eta_p^2 = .20$. Note that this in contrast to Experiment 1, in which the interaction was only significant in children.

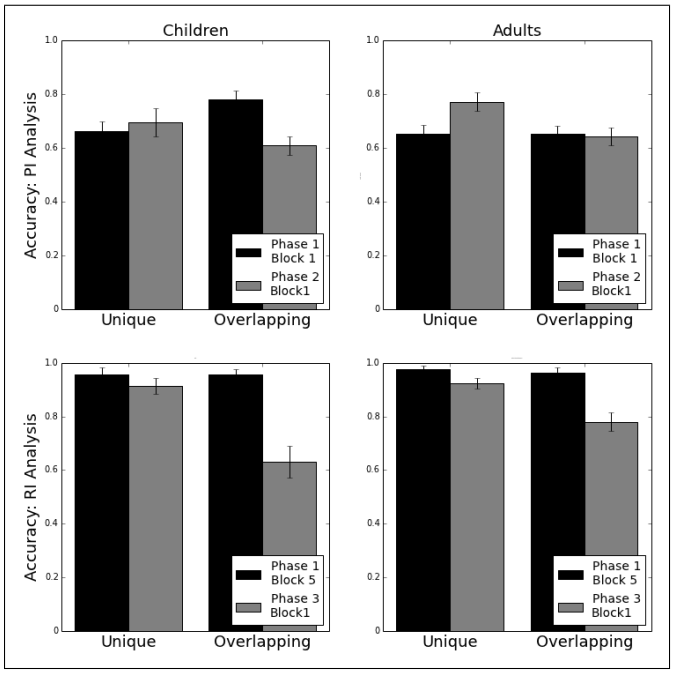

Figure 3: Experiment 2 accuracy results across blocks

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. A three-way ANOVA with Phase and pair type as within-subject factors and age as a between-subject 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, $F(1,32) = 5.64$, $p = .024$, $\eta_p^2 = .15$. Unlike in Experiment 1, then, adults' savings effects varied as a function of pair type.

A primary purpose of Experiment 2 was to determine if removing the subtle contextual variation present between phases in Experiment 1 would increase interference. 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-subject factor for children and adults. The three-way interaction between phase, pair type, and experiment was significant when comparing adults' RI effects, $F(1,55) = 4.42$, $p = .04$, $\eta_p^2 = .074$, suggesting that the magnitude of adults' RI effects was significantly greater when visual contextual cues were not provided in Experiment 2. No other three-way interaction reached significance when comparing PI and RI effects across Experiments 1 and 2 in children or adults. This result suggests that adults may have avoided RI effects in Experiment 1 by encoding covarying contextual information.

General Discussion

The purposes of these experiments were to gain developmental and mechanistic insights into the effects of interference (both proactive and retroactive) on associative learning. The primary findings of this study were that (1) interference is influenced by the amount of associative overlap between sets of information, (2) children are more susceptible to RI than adults (although about as equally susceptible to PI), and (3) encoding of contextual information may reduce RI in adults.

In almost all cases, attenuation of learning only occurred when associative elements were shared (i.e. recombined) across learning sets. Indeed, in some cases learning for unique items was actually facilitated. This finding is consistent with a number of findings suggesting the impact of stimulus overlap and similarity on the extent of interference effects (French, 1999; Anderson & Neely, 1996), but is inconsistent with claims that interference (particularly RI) is caused solely by a disruption of the consolidation process, regardless of stimulus overlap (Wixted, 2004).

Another noteworthy finding of these experiments was the magnitude of RI effects in children. In both experiments, children's accuracy was severely attenuated in the beginning of Phase 3 compared to the end of Phase 1. This attenuation was greater than in adults, which is particularly interesting in that previous work has found comparable RI effects in children between the ages of 4 and 7 (Howe, 1995; Lee & Bussey, 2001), which seems to contradict our finding of a substantial developmental decrease of RI effects. One factor that could account for this difference is that the current study measured all learning within a single session, with little time to consolidate. In contrast, children in Howe's (1995) study were tested for memory 24 hours after initial learning, and those in Lee and Bussey's (2001) study learned different sets of information across several days and were tested three weeks later. Another possibility is that previous studies may have found a developmental difference between children and adults if such a comparison had been made.

What mechanism could account for a decrease in susceptibility to RI effects? One possibility is that changes in configural encoding contributed to this developmental pattern of results. Specifically, adults may more efficiently encode configural associations, protecting information from RI (Humphreys et al., 1989). Indeed, some work suggests that configural encoding exhibits substantial improvement between preschoolers and adults (Yim et al., 2013; Rudy et al., 1993). Our 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.

This idea is not yet conclusive. In Experiment 1 the finding of no RI in adults was ambiguous, in that there was some attenuation of accuracy for both pair types. Future work is needed to more directly test the role of configural encoding in modulating interference. The role of consolidation is also still in need of further investigation. Although we found evidence that disruption of consolidation cannot be the only source of interference, one possibility is that consolidation was not a strong factor because there was little time (approximately one minute) between phases for it to take place, and that with additional time between phases consolidation may have played a larger role.

Finally, the current work has a number of implications for our understanding of cognitive development. For example, this work suggests that interference effects can greatly affect children's learning of overlapping sets of information. A clear question for future work is how children's ability to learn and retain overlapping information is influenced by how this information is encoded. Understanding these fundamental processes of associative learning and memory can help us to better grasp the processes underlying early cognitive development and how to better support them in young learners.

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