Children's familiarity preference in self-directed study improves recognition memory

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Abstract

In both adults and school-age children, volitional control over the presentation of stimuli during study leads to enhanced recognition memory. Yet little is known about how very young learners choose to allocate their time and attention during self-directed study. Using a recognition memory task, we investigate self-directed study in low-income preschoolers, who are at an age when attention, memory, and executive function skills rapidly develop and learning strategies emerge. By pre-exposing children to some items before self-directed study, we aimed to discover how familiarity modulates their study strategies. We found that children showed a preference for studying pre-exposed items. Overall, items studied longer led to increased recognition of those items at test. We also compared recognition task performance and strategies with measures of cognitive control skills, finding that children's selective attention skills support recognition performance. These findings may inform both theory and educational intervention.

Keywords: active learning; recognition memory; executive function; attention; cognitive development

Introduction

Children learn through active exploration of their environments. They ask questions, test hypotheses, and probe novel or confounding objects that could shed new light on how the world works (Schulz & Bonawitz, 2007). Recent research in cognitive science suggests that school-age children learn better when allowed to control the content and timing of information flow compared to passively receiving information (Partridge, McGovern, Yung, & Kidd, 2015; Sim, Tanner, Alpert, & Xu, 2015). Little is known, however, about how self-directed information gathering develops during preschool ages, a time of great plasticity in the neural networks that support executive function, attention, and memory (Blair & Raver, 2015). Understanding patterns in young children's active information gathering and examining the mechanisms through which self-directed control affects learning may inform cognitive science as well as educational initiatives, particularly for low-income preschoolers at higher risk of poor learning outcomes (Ursache, Blair, & Raver, 2012).

Episodic memory is one ability that has been found to benefit from active learning. Memory is aided by top-down, meta-cognitive control processes, such as when learners prioritize study of items close to mastery and avoid content that is already learned or that is too difficult to master (Markant, Ruggeri, Gureckis, & Xu, 2016). Bottom-up influences of cognitive control can also support episodic memory. In adult recognition memory tasks with self-paced study, alignment of stimulus exposure with attentional resources improved later recognition (Markant, DuBrow, Davachi, & Gureckis, 2014). These active control behaviors enhance representations and strengthen associative networks, both of which help to encode and retrieve experienced stimuli (Markant et al., 2016).

Voss and colleagues (Voss, Galvan, & Gonsalves, 2011; Voss, Gonsalves, Federmeier, Tranel, & Cohen, 2011) examined how adults' study patterns influence the benefits of active encoding for recognition memory. They tasked participants with memorizing a set of objects arranged in a 5x5 grid. A moving window allowed only one object to be visible at a time, with control over the window given to the participant during active blocks. During yoked blocks, participants watched the window move according to the recorded movements of a previous participant. Importantly, the yoked condition allowed the authors to distinguish the effects of active control over and above the visual stimulus information experienced during study. They found both an overall active study advantage, as well as benefits to particular study patterns. Recognition improved when objects were studied for longer duration and revisited within a short time frame, but the benefits of these study features were only found in active and not yoked conditions.

Ruggeri, Markant, Gureckis, and Xu (2016) adapted the Voss et al. paradigm to examine study patterns during active encoding with school-age children. They found that 6-to 8-year-olds had better recognition memory when given volitional control over the presentation of stimuli during study, as compared to being yoked to study sequences generated by other children. Moreover, the recognition memory advantages of self-directed study were present following a one-week delay. In contrast to Voss et al.'s findings in adults, school-age children showed generalized benefits of certain study patterns on their memory encoding: participants had improved recognition memory in both active and passive conditions for items visited often and studied longer (Ruggeri et al., 2016). The authors suggest that children benefited in both conditions from attentional cues (red outlines that indicated which object would be presented for study next). For school-age children, attentional cueing appears to support benefits of longer study even in the yoked condition. This finding is consistent with previous research showing that even subtle opportunities to coordinate the learner's attentional state to incoming information (i.e., by giving learners control over when the next stimulus appears) can improve episodic memory (Markant et al., 2014).

These studies suggest that multiple levels of control may enhance memory from an early age, but the developmental course of these processes remains unclear. One possibility is that the effects of active encoding vary based on the maturation of the neural networks that support volitional control, working memory, and attention. These neural networks undergo tremendous growth during the preschool years, leading to meaningful individual differences in children's attention and self-regulatory control (Blair & Raver, 2015). These cognitive control skills support school readiness, and are targeted for intervention to close income-based early achievement gaps (Ursache et al., 2012). Little is known about the effects of active encoding on recognition memory at preschool ages. Young children's variability in attentional control may make study duration and attentional coordination particularly critical factors for active encoding. Developing cognitive control skills may also affect children's metacognitive ability to strategically allocate study effort based on their current familiarity with the materials.

This study examines whether low-income preschoolers use active control to engage in strategic study during a recognition memory task. If so, what patterns of sampling emerge, and how do these patterns change with varied stimulus familiarity? Another gap in the research literature is whether individual differences in young children's control skills influence the effects of active sampling on encoding. This study addresses these questions by examining active memory performance in a large sample of low-income preschoolers. We use a novel extension of the Ruggeri et al. (2016) task design that varies stimuli pre-exposure, as well as a battery of well-validated executive function and attention measures.

Experiment

Methods

Participants Ninety-four 5-year-olds from low-income backgrounds were recruited and tested as part of a school readiness study run in collaboration with two Head Start preschool centers. An additional 16 participants were tested but excluded due to incomplete data due to experimenter error or connectivity problems, or because of difficulty understanding task instructions. Children were tested in their preschools by trained assessors. Administration of the tasks was divided over two testing days scheduled within one week of each other. EF and attention tasks were administered on day 1, and lasted about 5 minutes each for a total of 15 minutes. The recognition memory task was administered on day 2 and lasted about 10 minutes.

Memory Task

Materials Stimuli were taken from Ruggeri et al. (2016), which included 149 color line drawings of animals and objects that are used frequently by children younger than 5-years-old in everyday conversations (MacWhinney & Snow, 1985). Items were randomly sampled from the stimulus set and presented in a series of 4x3 grids. Stimuli not presented during the practice or study phases were randomly sampled in the test phase and used as novel foils. The task was presented on a touchscreen laptop, with timing and choice data logged to a database via *psiTurk* (Gureckis et al., 2015).

Procedure The task was presented as a simple memory card game (see Figure 1). Children were instructed to study a grid of images on the touchscreen tablet, presented initially "face-down" as empty rectangles. Children could "turn cards over" by touching the empty rectangle to reveal the image underneath. Later, they were asked to recognize studied items presented among novel distracter images. The design and procedure closely followed described in Ruggeri et al. (2016), with a key design modification: this version experimentally manipulates the pre-exposure of items during the study phase in order to examine the role of exposure on children's active study behavior.

Practice phase. Children were presented with a 2x2 practice grid. Half the items on the grid were simultaneously revealed during a pre-exposure phase that lasted 6 s while the other half remained face down, and children were instructed to "Remember these pictures!" The practice study phase (30 s) followed, with all cards presented face down. Children were told to tap the cards they wanted to see. Once a card was touched, the image underneath was revealed until the child "tapped" off by touching the image again, or touched another card. Only one item was revealed at a time. Next the untimed test phase presented a 3x2 grid showing all 4 items in the study phase as well as 2 additional novel distracter items, in random grid locations. Children were instructed to touch all the "old" pictures they saw before, and not touch the "new" pictures. A red box appeared around each item when selected, and was toggled off if tapped again. Children were not restricted in how many or few items could be selected during the test phase. Once children indicated that their selections were complete, the assessor praised correct answers and gave feedback on incorrect answers. The practice phase could be played 1 to 3 times with different stimuli. If the child was unable to understand directions, the task was ended.

Study phase. The study phase consisted of 3 blocks, each presenting a 4x3 grid of randomly sampled images. The procedure is similar to that described in the practice phase. Simultaneous pre-exposure of half the items lasted 2 s per item (12 s in the two half pre-exposed blocks, and 24 s in the all pre-exposed block) before cards were turned over and the child could then actively select and turn over cards to study for 36 s. This shorter duration of the active study phase (as compared to Ruggeri et al., 2016) was chosen to enhance the potential effect of pre-exposure on search behavior. The 3 study grids were presented consecutively before the test phase.

Test phase. The test phase consisted of 6 blocks. Each 4x3 test grid was a random sample drawn without replacement from a pool of 72 stimuli, including the 36 included in the study phase along with 36 novel images. The number of old items in each grid ranged from 0 to 12 (randomly chosen) in order to minimize strategic responding based on the proportion of items selected within each block. All 36 studied stimuli and all 36 novel stimuli were presented only once at test. Children were instructed to "Touch the pictures you remember!" and not to select new pictures. Once the child indicated that they were done with selection, the assessor prompted. "Are you sure you touched only the pictures you saw before and not any new pictures?" If the child said yes, the assessor advanced to the next test grid. If the child answered no, the assessor reminded them to choose only "old" pictures seen before.

Both hit rate (proportion of studied items correctly selected as "old") and correct rejection rate (proportion of novel items correctly not selected) were calculated. In addition, total study time per item and study repetitions per item was computed for pre-exposed vs. non-pre-exposed items and conditions.

Executive Function and Attention Tasks *Attention Network Test.* The Attention Network Test (ANT; Rueda et al., 2004) is a well-known behavioral measure thought to map onto the neural networks supporting attentional control. The child version of the ANT presents either a single fish or a horizontal row of five fish. Children are instructed to feed the center fish by pressing a blue box in the lower corners of either side of the screen indicating in which direction the central fish is swimming. Children are asked to ignore the flanker fish pointing either in the same (congruent) or opposite direction (incongruent) as the target middle fish. Mean accuracy and reaction time are computed.

Visual Search Task. The Visual Search task (Steele, Karmiloff-Smith, Cornish, & Scerif, 2012) measures the ability to select relevant stimuli (targets) while ignoring distracters (non-targets). Children are presented with a search display on the touch screen monitor. Each display contains 90 items, made up of 20 targets (animals) and

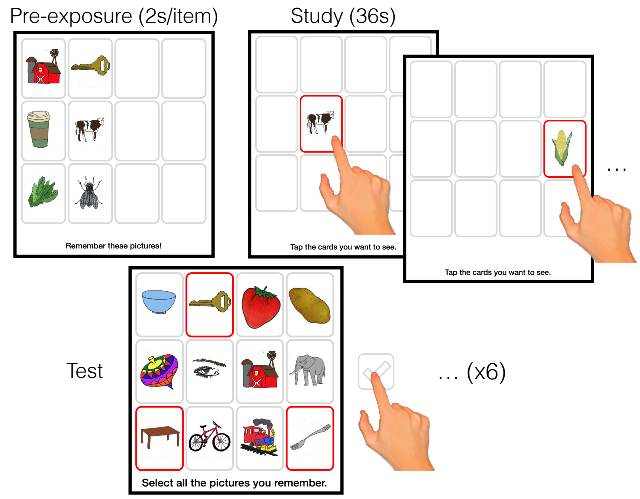

Figure 1: Each study phase of the experiment was preceded by pre-exposure of half (6) or all (12) of the items, for 2 s per item (i.e., 12 s in the two half-pre-exposed conditions and 24 s in the all-pre-exposed condition). All three cycles of pre-exposure and study were completed before the six screens of testing were performed.

70 non-targets (objects). Children are instructed to find animals, which are replaced with a star when successfully touched. The task ends when a total of 18 correct responses is reached, or 40 responses are made overall. Mean search speed (time between touches), and number of errors are recorded.

Continuous Performance Test. The Continuous Performance Test (CPT; (Steele et al., 2012) measures the ability to sustain attention for a prolonged period without distraction. In this version, the child is instructed to touch the screen as soon as an animal appears. One hundred pictures are randomly presented one at a time, including 20 presentations of the target stimuli (animals) and 80 presentations of nontarget stimuli (objects). Each stimulus appears on the screen for 300 ms followed by a blank screen for 1250 ms. In addition to response time, number of missed responses to targets (omission error) and incorrect touches to distracters (commission error) are recorded.

Digit Span. Digit Span is a widely used executive function task that assesses children's working memory. Children are instructed to repeat number sequences of sequentially longer length in forward and backward conditions. Total number of correct responses per condition is recorded. Children in this sample were largely unable to repeat sequences backwards, so only performance on the forward condition are used here.

Results

Data from 94 participants were analyzed with respect to recognition (selection) of studied items (i.e., hit rate), correct rejection of unstudied items, and the number of repetitions and total study time for studied items. Participants' mean hit rate (HR) was 0.65, and the mean correct rejection (CR) rate was 0.56.

Study Behavior Studied items were selected for study on average 1.78 times (median: 1; maximum: 10). The mean study time for old items was 3037 ms (median: 2067 ms). Table 1 shows the distribution of how many times children repeated study items and cumulative study time per item (median, mean, and SD). Children most often studied items a single time (38.6%), but it was not uncommon to study an item twice (22.6%) or even three times (10.6%). A surprising number of items (23.4%) were not actively selected for study at all, and these were well-distributed among the participants, who left a median of 6 of the 36 items unstudied (mean 8.3, bootstrapped 95% confidence intervals: (6.8, 10.1)).

Reps	Median Time	Mean Time	SD	N
0	0 ms	0 ms	0 ms	783
1	1,452	2,443	3,137	1,307
2	2,305	3,371	3,331	766
3	2,860	3,528	2,413	360
4	3,645	4,491	2,891	121
5	5,069	6,622	5,028	37
> 5	5,467	6,984	5,552	8

Table 1: Statistics of study repetitions and time (ms).

Pre-exposure Effects To investigate the impact of pre-exposure on study time and repetitions, we fit mixed-effects regression models to separately predict trial-level study time and study repetitions (both scaled and centered to [-1,1]) for only the blocks with half pre-exposed items. Subject was included as a random factor, and item pre-exposure as a binary predictor (R syntax: `Study Time ~ Preexp + (1|Subject)` and `Repetitions ~ Preexp + (1|Subject)`. Shown in Table 2, the regression predicting study time found a significant positive intercept ($\beta = 0.19$, $Z = 5.02$, $p < .001$). Moreover, there was a significant positive effect of pre-exposure ($\beta = 0.11$, $Z = 2.23$, $p < .05$), indicating that pre-exposure led to increased study time.[1] On average, pre-exposed items in these conditions were studied for 3477 ms, whereas the hidden items were studied for 3001 ms. Shown in Table 3, the regression predicting study repetitions found a significant positive intercept ($\beta = 0.32$, $Z = 5.58$, $p < .001$). There was a positively-trending effect of pre-exposure ($\beta = 0.07$, $Z = 1.88$, $p = .06$), suggesting that pre-exposed items may be selected more often for study. On average, pre-exposed items in these conditions were selected 1.80 times, while the hidden items were selected 1.65 times.

[1]The coefficients (β) are interpretable as log-odds, but can also be transformed to an odds ratio ($OR = e^{\beta}$).

	β	SE	Z-score	p-value
Intercept	0.185	0.037	5.016	$p < .001$***
Pre-exposed	0.112	0.050	2.233	$p < 0.05$*

Table 2: Regression predicting study time.

	β	SE	Z-score	p-value
Intercept	0.315	0.057	5.578	$p < .001$***
Pre-exposed	0.070	0.037	1.884	$p = 0.06$.

Table 3: Regression predicting study repetitions.

Recognition Accuracy To investigate the impact of pre-exposure, repetitions, and study time on recognition performance, we fit two logistic mixed-effects regression models to the item-level accuracy data for old stimuli, separating study time and repetitions since they are correlated. Subject was included as a random factor, and study repetitions and study time (scaled and centered to [-1,1]) were included in their respective models as fixed, continuous predictors, allowed to interact with item pre-exposure, a binary predictor (R syntax for study time model: `Correct ~ Preexp * Time + (1|Subject)`; and substitute Reps for Time in the other model).

In the study repetitions model, there was a significant positive intercept, showing that participants were more likely to correctly recognize rather than miss the old items ($\beta = 0.95$, $Z = 5.16$, $p < .001$). There was a significant positive effect of study repetitions ($\beta = 0.52$, $Z = 4.19$, $p < .001$), showing that studying items more often led to higher recognition of those items. There was also a significant positive effect of pre-exposure ($\beta = 0.27$, $Z = 2.37$, $p = .02$), showing that pre-exposure increased the likelihood of correctly recognizing an old item. Finally, there was a significant negative interaction of pre-exposure and repetitions ($\beta = -0.31$, $Z = 2.23$, $p = .03$): with pre-exposure, there was less accuracy benefit of more study repetitions. Figure 2 shows the mean hit rate as a function of pre-exposure and study repetitions, along with the relative frequency of each level of repetitions.

In the study time model, in addition to a significant positive intercept, ($\beta = 1.05$, $Z = 5.83$, $p < .001$), there was a significant positive effect of study time ($\beta = 0.36$, $Z = 3.19$, $p = .001$), showing that studying items longer led to increased recognition of those items. There was also a positively-trending effect of pre-exposure ($\beta = 0.21$, $Z = 1.92$, $p = .06$), suggesting that pre-exposure may increase their chance of recognizing old items. Finally, there was a significant negative interaction of pre-exposure and repetitions ($\beta = -0.29$, $Z = 2.32$, $p = .02$), showing that pre-exposure lessens the accuracy benefit of longer study time.

The AIC of the study repetition model was 2712.8, and the AIC of the study time model was 2722.6, making the

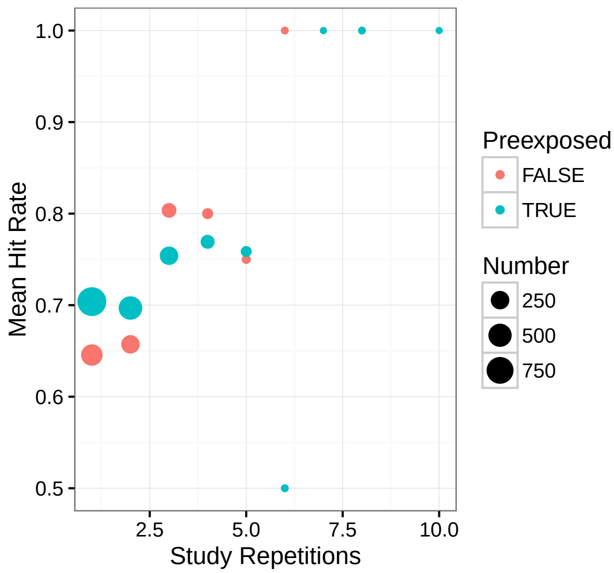

Figure 2: Items that were studied more often had higher hit rates, but most items were not studied more than one or two times. (Not pictured: participants were at chance for unstudied 'old' items.)

relative likelihood of the study time model 0.007. Thus, although both models have similar interpretations, the repetitions model provides a better account of the data.

Self-directed Memory and Executive Function

We next examined the link between behavior in the self-directed memory task and the various attention and executive function (EF) measures using three mixed-effects regression models to predict item-level (N = 2,770) 1) recognition accuracy, 2) study time, and 3) study repetitions for old items. All three models included subject as a random factor, and the following EF measures (scaled and centered to [-1,1]) as fixed predictors: working memory, visual search errors, visual search reaction time, commission errors, and omission errors, and ANT accuracy and RT (R syntax: `Correct ~ + EFvar1 + EFvar2 + .. + (1|Subject)`).

For the logistic model predicting recognition accuracy, besides a significant positive intercept ($\beta = 0.77$, $Z = 4.35$, $p < .001$), there was a negatively-trending coefficient for visual search errors ($\beta = -0.41$, $Z = -1.92$, $p = .05$). All other predictors were insignificant (p's $> .1$). In summary, this suggests that fewer visual search errors, an index for selective attention skills, is associated with increased recognition.

The model predicting study time (log-transformed, scaled and centered to [-1,1]) found a positive coefficient for visual search time ($\beta = 0.05$, $Z = 2.11$, $p = .03$), with all other predictors insignificant (p's $> .1$). This indicates that participants with longer visual search times also spent longer studying items during the study phase. The model predicting study repetitions (with a Poisson linking function) found no significant predictors in the EF measures.

Discussion

The present study examined low-income preschool children's study behavior in a self-directed recognition memory task, and compared 5-year-olds' active study behaviors to patterns found in older samples in previous literature. We next examined if stimuli pre-exposure affects active encoding. Finally, we explored how individual differences in executive function and attention skills may influence study strategies and recognition.

First, we found that children were above-chance at recognizing old items and correctly rejecting new items, indicating that they can meaningfully engage in a developmentally-complex paradigm requiring self-directed study. We found increased recognition accuracy for items with greater repetitions, and for items with greater study time, replicating classic repetition effects from both traditional (experimenter-directed) recognition memory experiments, as well as self-directed versions (e.g., Voss et al., 2011a; Voss et al., 2011b).

Second, we found that pre-exposure significantly *increased* study time, suggesting a preference to allocate study effort to familiar material at the outset of study. Pre-exposed items were also more likely to be recognized, but this effect appeared to overlap with other helpful study behaviors. For pre-exposed items, both repetitions and study time showed less benefit to recognition compared to items without pre-exposure. Thus, although children use their familiarity with items to guide their study, they appeared to benefit more generally from stimulus exposure, be it through passive pre-exposure or active selection (i.e., increased study time or repetitions). Ruggeri et al. (2016), finding similar results for 6- to 8-year-olds who had better recognition memory in both active and yoked conditions for items visited often and studied longer, suggested that children in yoked conditions were able to benefit from attentional cueing, allowing them to coordinate their attention with the presentation of new information. Notably, we found that preschoolers benefited from passive pre-exposure, which provides no attentional cueing. These findings suggest that duration of stimuli exposure alone may be particularly important for memory encoding at preschool ages.

Third, we found that greater recognition accuracy was predicted by both fewer visual search errors and longer visual search response times in a developmental selective attention task. These data suggest that selective attention skills support children's active study during preschool, a period of neurocognitive plasticity in systems that support attention, executive function, and memory (Blair & Raver, 2015). While it may be surprising that longer visual search time supports recognition memory, it is important to note that these behavioral measures often exhibit a speed-accuracy trade off (Davidson, Amso, Anderson, & Diamond, 2006). Young children who search more carefully may be slower to respond but more successful in encoding stimulus information. The relation between stimuli pre-exposure and increased study time suggests that one possible study strategy for children is to focus attention on familiar items. As attentional focus is a more effortful and limited resource at this young age, children may benefit from allocating study time to known items. Prioritizing study of items close to mastery is a learning strategy described in Metcalfe's zone of proximal development framework (Metcalfe, 2011). In this framework, optimal learning strategies should focus on the easiest possible as-yet-unlearned items, as focus on items too difficult may be maladaptive and potentially disheartening. In this task, the difficulty of unexposed items to encode is unknown until they are "turned over" and revealed, whereas young children have time during pre-exposure to evaluate pre-exposed item difficulty and engage attentional resources. Continued experimental investigation is needed to better understand the role of attention skills and search strategies on young children's active encoding.

This study is a first step in examining the effects of executive function and attention on low-income preschool children's active learning. We found that selective attention supports recognition memory, but measures of inhibitory control and working memory were not significant unique predictors. One possibility is that demands of the recognition memory task were particularly dependent on visual search and attentional focus skills. Future experimental studies should aim to tease apart how various cognitive control skills might contribute to different types of active learning tasks. A limitation to this study is that the narrow range of socio-economic status (SES) for our sample may limit generalizability of the findings. Notably, long-term exposure to chronic stress associated with poverty has been found to have negative consequences on children's selective attention and memory (McEwen, 2000). Thus, examining mechanisms that support active encoding may be particularly important for understanding the effects of poverty on early learning. We are planning additional data collection with a higher income cohort to examine relations between SES, cognitive control skills, and active encoding. Future work may also seek not only to measure children's self-directed study strategies, but to improve them via intervention.

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