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Effects of Learning Item Difficulty and Value on Cognitive Offloading During Middle Childhood

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Abstract

The storage of information in external tools (e.g., notebooks, cellphone) has become increasingly common. Some researchers have defined this behavior as cognitive offloading, which is a type of learning strategy. Studies have indicated that as age increases, children become increasingly capable of calibrating their learning strategies according to the difficulty of learning items. The value of items is also essential in people's daily learning. However, how children apply both cues of item difficulty and item value for cognitive offloading to regulate their learning process remains unclear. In three studies, we investigated children's offloading of learning items by manipulating these items' difficulty and value (Study 1), value alone with difficulty being unvaried (Study 2), and difficulty and value with an emphasis on value (Study 3). The results indicate that children aged 11 years used difficulty cues alone for cognitive offloading when both difficulty and value cues were presented. However, when difficulty was controlled and value was emphasized, the 11-year-old children adopted cognitive offloading strategies based on value cues. The three studies revealed the conditions under which children in middle childhood apply cues of the item value, which are goal-driven cues, for cognitive offloading and provided methods for encouraging children to simultaneously apply item difficulty cues, which are data-driven cues, and item value cues.

Keywords: Metacognitive control, Cognitive offloading, Value, Difficulty, Middle childhood

Introduction

The memory capacity of humans, particularly that of short-term memory, is limited (Schacter, 2001). However, people compensate for such limitations by creating and using tools to record information. With the extensive use of the Internet and mobile devices in the modern age, storing information in external tools has become a ubiquitous practice. For example, people video-record meaningful moments, use their smartphone calendars to remind themselves of upcoming events, and store information in computer files. Such behaviors are examples of cognitive offloading, which refers to externalizing cognitive processes to technological aids (Scarampi & Gilbert, 2021; Risko & Gilbert, 2016). Sometimes individuals offload all information (e.g., capture screenshots to save content during online learning), and sometimes they offload only some information (e.g., take notes in class, recording only main points as clues for review). In this era of ubiquitous information storage techniques, offloading has profoundly changed how humans think and remember information (Firth et al., 2019). Philosophers, biologists, and psychologists have been attracted to study the mechanism of how humans decide to offload information (Gilbert et al., 2020; Risko & Gilbert, 2016; Sparrow, Liu, & Wegner, 2011). The present research focused on strategies of cognitive offloading in children. Children have a limited working memory capacity, and cognitive offloading can help them reduce cognitive demand and optimize performance on subsequent memory tasks. For example, children use sticky notes to record tasks (all contents or main points) in order to be better at homework. Previous studies have demonstrated that children became able to offload information according to the difficulty of a task during elementary school (Armitage, Bulley, & Redshaw, 2020); however, how children offload on the basis of cues related to learning item difficulty and value remains unknown. In the present research, we conducted a preliminary investigation of this topic.

Studies have revealed that adults can offload information on the basis of the difficulty of a task (i.e., the level of cognitive demand). For example, in one study, when adults studied strings of English letters for a subsequent memory test, the likelihood of offloading learning items to an external tool increased as the number of letters in the string increased (Risko & Dunn, 2015). Similar results were reported when the item difficulty was represented by the relatedness of the words in a word pair. The adults were more likely to offload difficult pairs of unrelated words than easy pairs of semantically related words (Hu et al., 2019). Risko and Gilbert (2016) explained adaptive offloading behavior from the perspective of metacognition. In general, individuals offload items that they are not confident they can recall in the future. The metacognitive evaluation of task performance partially relies on one's confidence level, which can be decreased by item difficulty (Boldt & Gilbert, 2019). Therefore, item difficulty might affect metacognitive evaluation, which eventually guides learning strategies (e.g., spending time learning specific items and using external aids such as cognitive offloading to improve memory).

Learning strategies are determined by not only difficulty but also the characteristics of an item (Koriat et al., 2006). In studies on self-regulated learning, two mechanisms have been identified in the regulation process: bottom-up, data-driven regulation, in which the qualities of items play a crucial role, and top-down, goal-driven regulation, in which personal goals and plans for future performance are essential (Koriat et al., 2006). Item difficulty is an indicator of the quality of an item and is involved in data-driven regulation, whereas item value is relevant to personal goals of learning more valuable items and involved in the goal-driven regulation of the learning process (Dunlosky & Thiede, 1998).

The value of an item refers to the benefit that a learner can obtain from remembering it. Item value can be operationalized as the number of points an item carries in experimental studies. If learners can recall items worth more points, their reward is higher. Koriat (2017) asked participants to study items with a high value (5 points) or low value (1 point) for a subsequent memory test and informed them that their goal in the memory test was to obtain as many points as possible. He reported that the participants allocated more time to learning high-value items than to learning low-value items. Thus, individuals can regulate their learning process on the basis of item value to obtain more rewards.

Ariel et al. (2009) observed that when both item value and difficulty were presented, adult participants were more likely to rely on item value cues than on item difficulty cues to determine the appropriate study time for each item. This finding suggests that for adults, the effect of value incentive can override the effects of item difficulty when allocating study time. In addition to study time allocation, cognitive offloading during the study process is another method of learning behavior regulation (Hu et al., 2019; Risko & Gilbert, 2016), which involves adjusting learning strategies to improve memory performance and maximize reward. However, how individuals utilize both item value and difficulty cues for cognitive offloading remains unclear.

Studies have indicated that children apply appropriate cognitive offloading strategies on the basis of the difficulty of a task. Armitage, Bulley, and Redshaw (2020) reported that when provided with opportunities to rotate a turntable manually instead of performing mental rotation, children aged 4–11 years were able to rely on manual rotation as the difficulty of mental rotation increased. In addition, the ability to offload mental demand to manual operation increased with the children's age. Bulley et al. (2020) obtained results similar to the aforementioned ones. When children aged 4–11 years were asked to recall the location of hidden targets and given the option to mark their location, they relied on external aids (offloading) more often when the number of targets increased. When children were provided with a means to devise their own cognitive offloading strategies, children aged 10 and 11 years devised solutions on their own; however, few younger children were able to do so (Bulley et al., 2020). In addition, children aged 9–11 years old could mark targets more often as the number of targets increased, whereas children aged younger than nine years demonstrated no difference in offloading behavior in terms of the number of targets (Redshaw, Bulley, & Gilbert, 2018). Studies regarding study time allocation have yielded similar results. Children aged older than nine years can allocate learning time on the basis of item difficulty, whereas children aged between 6 and 8 years cannot (Dufresne & Kobasigawa, 1989; Koriat et al., 2009).

However, how item value affects cognitive offloading in children remains unclear. Studies regarding study time allocation have revealed that 9-year-old children are generally unable to adjust study time on the basis of item value (Lockl & Schneider, 2004); however, they can do so when learning performance is emphasized (Lockl & Schneider, 2004) and when the cognitive demand of the learning task is low (Lipowski et al., 2017). These findings suggest that 9-year-olds can adjust their learning processes on the basis of goals and agendas. The ability to selectively remember high-value information improves from childhood to young adulthood (Castel et al., 2011). Studies on the allocation of learning time indicate that item value might also affect children's cognitive offloading.

To the best of our knowledge, studies on children have only investigated the effect of task difficulty on cognitive offloading. The effect of item value on cognitive offloading is unknown, and neither is the combined effect of item difficulty and item value. Studies have demonstrated the role of item value in the regulation of learning processes such as study time allocation and item selection (e.g., Ariel, 2013; Ariel & Dunlosky, 2013; Lipowski et al., 2017). Therefore, this research investigated how item value and difficulty together affected children's cognitive offloading behavior in a learning task.

We investigated children aged 10–12 years because children in middle childhood have a basic ability to utilize data-driven and goal-driven cues to regulate learning processes. For example, regarding item difficulty (i.e., data-driven cue), in a self-paced learning process in which participants decided how much time they would spend studying each item, third-grade students (approximately nine years of age) allocated more time for studying difficult items than for studying easy items (Lockl & Schneider, 2004). By contrast, first-grade students (approximately seven years of age) spend a similar amount of time learning easy and difficult items (Koriat et al., 2009). Fifth-grade students (approximately 11 years of age) but not second-grade students (approximately eight years of age) can regulate their study time for each item on the basis of its difficulty (Dufresne & Kobasigawa, 1989; Koriat et al., 2009). Similarly, regarding item value (i.e., goal-driven cue), 7- and 9-year-old children do not allocate different amounts of study time to items with and without subsequent rewards (Lockl & Schneider, 2004), whereas 11-year-old children can allocate more time to studying items with greater rewards (i.e., high-value items; Koriat et al., 2014). However, when item value and difficulty cues are accessible to children, whether they use both or one of the cues in their learning strategies is unclear.

We conducted three studies and adopted the research paradigm of Koriat et al. (2014) to investigate cognitive offloading. In Study 1, we recruited participants in middle childhood (approximately 10–12 years of age) and presented them with cues related to both item difficulty (i.e., word pair relatedness) and item value (i.e., the number of points for each word pair) when they studied word pairs. Numerous studies have used word pair relatedness to operationalize item difficulty (e.g., Gönül, Tsalas, & Paulus, 2021; Hertzog et al., 2002; Hu, Luo, & Fleming, 2019; Koriat, Ackerman, Lockl, & Schneider, 2009; Lockl & Schneider, 2004; Thomas, Lee, & David, 2013) because people may encounter low (high) difficulty recalling the second word when they see the first word if the two words are highly (barely) semantically related. The participants were provided opportunities to offload study items onto a computer to improve their performance in a subsequent memory test. They were instructed to earn as many points as possible in the memory test [they could obtain 5 points (or 1 point) for each high-value (or low-value) item recalled]. Because the 11-year-old children could not monitor both item value and item difficulty cues and relied on item difficulty alone to make metacognitive judgments (Koriat et al., 2014), we predicted that our participants would rely on item difficulty cues alone for cognitive offloading. Studies have demonstrated that 11-year-old children can use item value cues to regulate study time when only value cues are presented (Koriat et al., 2014). The participants' goals of obtaining rewards enabled them to focus on the item value cues (Gilbert et al., 2019). Therefore, we predicted that our participants would also use item value cues under certain conditions. In Study 2, we controlled item difficulty and only presented item value cues to the participants. In Study 3, we presented both difficulty and value cues but explicitly emphasized the importance of the value cues by incentivizing the participants to offload high-value items. We hypothesized that the 11-year-old children would offload items on the basis of value when the variation in item difficulty was eliminated and when item value was highlighted.

Study 1

Method

Participants

A calculation in G*power revealed that a minimum sample size of 17 was required to obtain a medium effect size of 0.25 with a power of 0.80 at an α level of 0.05 in a repeated measures analysis of variance (ANOVA). This sample size estimation was consistent with that in other studies (Koriat et al., 2014; Koriat et al., 2009). A total of 26 children [age: mean (*M*) = 11.03 years, standard deviation (*SD*) = 0.45, and range = 10.04–11.86 years; 15 boys] were recruited from an urban elementary school in central China. They were required to learn word pairs during the study phase and then recall the second word of the word pair when the first word was provided during the recall phase. The participants received a gift (one ballpoint pen) for participating regardless of their performance. Ethical approval was obtained from the institutional review board of the authors' university, and parental consent was obtained before the study.

Materials

We selected 28 pairs of Chinese words from another study (Zhou, Liu, & Zhang, 2004). Half the word pairs were easy; that is, they contained highly related words (e.g., car–driver, 汽车–司机 in Chinese). Moreover, the other half of the word pairs were difficult; that is, they contained unrelated words (e.g., waterfall–key, 瀑布–钥匙 in Chinese). The associative strength for related pairs (*M* = 6.29, *SD* = 0.39) was significantly higher than that for the unrelated pairs [*M* = 2.24, *SD* = 0.85, *t*(13) = 16.91, *p* < 0.001, Cohen's *d* = 4.5]. All word pairs were nouns consisting of two Chinese characters. The word frequency did not differ between the related (*M* = 0.004, *SD* = 0.005) and unrelated pairs [*M* = 0.007, *SD* = 0.006, *t*(13) = 1.40, *p* = 0.17].

Seven of the 14 easy pairs (difficult pairs) were high-value (low-value) items for which the participants received 5 points (1 point) if they recalled the pairs correctly in the memory test. The value of each word pair was invariant (either 1 or 5 points) for all the participants. The word pairs were presented to each participant in random order. Four word pairs were used in the practice trials, and the remaining 24 word pairs were used in the test trials.

Procedure

We adopted the cognitive offloading paradigm used in other studies (Hu, Luo, & Fleming, 2019; Koriat et al., 2014). The participants were tested individually on a laptop in a quiet room. An experimenter read the following instructions to each child.

"Welcome to the game! In this game, you will first learn 24 word pairs and then complete a memory test on those word pairs. During the memory test, you will recall the word on the right while viewing the word on the left. The word pairs will be presented to you one by one. Before each word pair is presented, you will see one or five stars on the computer screen for 2 seconds. One star means that the word pair to be learned is worth 1 point. If you can correctly recall this word pair during the memory test, you will receive 1 point. Five stars mean that the word pair to be learned is worth 5 points. If you can correctly recall this word pair during the memory test, you will receive 5 points. After the stars disappear, the word pair will appear on the screen, and you will have 3 seconds to memorize it. After the word pair disappears, you can decide whether to save the word pair on the computer. If you choose to save the pair, you will receive memory hints during the memory test. If you choose not to save the pair, no hint will be provided during the memory test. The hint will be one Chinese character of the word on the right of a word pair. Please press 1 to save the pair, and press 0 to not save the pair. Please note that your goal is to obtain as many points as possible in the memory test. You can save a maximum of 12 word pairs. It is up to you whether to use all 12 chances to save. The number of pairs that you have saved and the maximum number of pairs that you can save will appear at the bottom of the screen. Now, let's practice."

The procedure of the practice phase was the same as that of the formal experiment. The difference was that only four word pairs were studied and tested in the practice phase. At the end of the practice phase, the experimenter asked participants why they chose to save. If participants could give a reasonable answer, such as "I can't remember" or "choosing to save would help me", then we assumed that they understood the meaning of saving. If participants could not give a reasonable answer, the experimenter would re-read the instruction and let them practice again until they understood it.

A 2 (item value: high vs. low) × 2 (item relatedness: related vs. unrelated) within-subjects design was adopted in Study 1. We conducted six trials each for high-value related words, high-value unrelated words, low-value related words, and low-value unrelated words. The same set of stimuli was assigned to each value condition, and the order of the items was randomized during the study. The trials were presented in random order. Children were told that word pairs had different values prior to the study phase, but they were not told that the relatedness of the word pairs was different. In each trial (Figure 1), the value (represented by either 1 star or 5 stars) was presented for 2 seconds, and the word pair was presented for 3 seconds. The participants were required to memorize the word pair. After the word pair was presented, the participants were allowed to save or not save the pair. There was no cost to save. The number of remaining pairs that a participant could save on the computer was presented on the screen. The participants were asked to press "1" on the keyboard to save a pair (if they still had room) and "0" to not save a pair.

During the memory phase, 24 trials were conducted. In each trial, the word on the left side of a word pair learned during the study phase was presented on the computer screen. A blank was presented on the right side of the word (e.g., 瀑布–____). The participants were asked to type in the word on the right side of the word pair. If a participant opted to save the word pair on the computer, then half of the word to be recalled was presented as a memory cue (e.g., 瀑布–钥__). If the participant opted not to save the word pair, they had to recall the entire word without any memory cues.

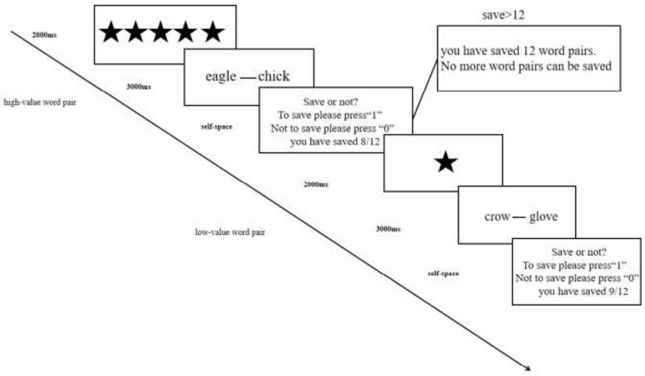


Fig 1. Learning phase in Study 1

Results

Percentage of word pairs selected for cognitive offloading during the study phase

The percentage of offloaded word pairs was calculated by dividing the total number of offloads per condition by the total number of items in that condition. The overall percentage of offloading was 46.31%, which suggested that the participants used almost all of their offloading allowance (i.e., 12 out of 24 words, 50%). We discovered that item relatedness had a main effect [$F(1, 25) = 5.42$, $p = 0.03$, $\eta^2_P = 0.18$], where the proportion of word pairs saved during the learning phase to be significantly higher for unrelated pairs ($M = 0.56$, $SD = 0.25$) than for related pairs ($M = 0.37$, $SD = 0.29$). These results suggest that the children's decisions to offload were sensitive to item difficulty (word pair relatedness). However, no significant main effect of item value was observed [$F(1, 25) = 0.05$, $p = 0.83$, $\eta^2_P = 0.002$]. The proportion of word pairs saved during learning was similar between the 5-point ($M = 0.47$, $SD = 0.29$) and 1-point ($M = 0.46$, $SD = 0.24$) words, which indicated that the children did not offload in response to the item value. The interaction between relatedness and value was nonsignificant [$F(1, 25) = 0.19$, $p = 0.67$, $\eta^2_P = 0.08$].

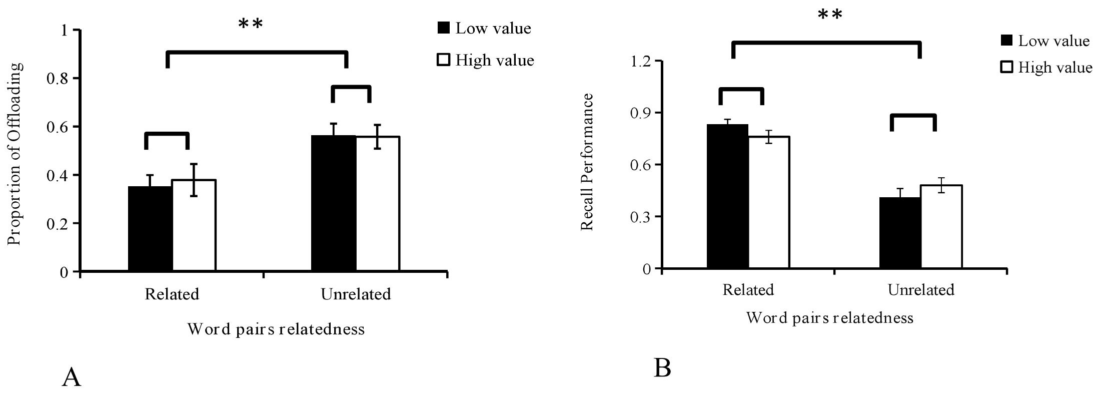


Fig 2. Children's Cognitive Offloading and Recall Performance for High- and Low-value and Related and Unrelated Items in Study 1. Note: ** $p < 0.01$. (A) Mean proportion of items selected for offloading. (B) Mean recall performance. Error bars represent standard errors of the means.

Recall performance

The results indicate that relatedness had a significant effect [$F(1, 25) = 66.40$, $p < 0.001$, $\eta^2_P = 0.73$]. Recall performance under the related condition ($M = 0.80$, $SD = 0.17$) was significantly better than that under the unrelated condition ($M = 0.45$, $SD = 0.24$). Value had no main effect [$F(1, 25) = 0.007$, $p = 0.94$], and memory performance under the high-value ($M = 0.62$, $SD = 0.20$) and low-value conditions did not differ significantly ($M = 0.62$, $SD = 0.21$). The interaction between relatedness and value was marginally significant [$F(1, 25) = 4.08$, $p = 0.05$, $\eta^2_P = 0.14$]. We conducted follow-up simple-effect tests. No differences were observed between the high- and low-value items under the related [$M_{low\ value} = 0.83$, $SD = 0.16$; $M_{high\ value} = 0.76$, $SD = 0.19$, $F(1, 25) = 1.33$, $p = 0.26$, $\eta^2_P = 0.05$] and unrelated conditions [$M_{low\ value} = 0.41$, $SD = 0.26$; $M_{high\ value} = 0.48$, $SD = 0.23$, $F(1, 25) = 2.22$, $p = 0.15$, $\eta^2_P = 0.08$].

Effect of offloading on recall performance

The results of paired-samples *t*-tests revealed that the children's memory performance under the saving condition ($M = 0.79$, $SD = 0.14$) was significantly better than that under the not-saving condition [($M = 0.47$, $SD = 0.23$), $t(25) = 5.60$, $p < 0.001$, Cohen's $d = 1.10$]. This result suggests that cognitive offloading can help improve memory.

Discussion

On the basis of other studies (Hu et al., 2019; Koriat et al., 2009; Dufresne & Kobasigawa, 1989), we operationalized item difficulty by using the relatedness of word pairs. The results of Study 1 suggest that children in middle childhood apply difficulty cues (relatedness) only for cognitive offloading when both difficulty and value cues are presented. These results are consistent with those of other studies regarding metacognitive monitoring (Koriat et al., 2014). In the study of Koriat et al. (2014), when both difficulty and value cues were presented, 11-year-old children could only make metacognitive judgments based on the difficulty cue. Our results also indicate that 11-year-old children might be more sensitive to difficulty cues than to value cues in terms of metacognition when both cues are presented. However, this conclusion needs to be further tested by future studies.

Koriat et al. (2006) proposed that regulation based on difficulty cues is a bottom-up process driven by learning materials (e.g. relatedness of word pairs), whereas regulation based on value cues is a top-down process driven by goals. The bottom-up process is more automatic than the top-down process (Kahneman, 2011). Therefore, children's ability to use difficulty cues might be automatic and develops prior to the use of value cues. If difficulty cues are constant and only value cues are presented, 11-year-old children might utilize value cues for cognitive offloading. We investigated this prospect in Study 2 by controlling item difficulty. We adopted a between-subjects design for the item difficulty conditions and maintained a within-subjects design for the item value conditions. Therefore, the participants in each condition (unrelated and related) received value cues only.

Study 2

Method

A calculation in G*power revealed that a minimum sample size of 49 was required to obtain a medium effect size of 0.25 with a power of 0.80 at an α level of 0.05 in a mixed-model ANOVA. A total of 50 children (age: M = 10.82 years, SD = 0.45, and range = 9.93–11.82 years; 28 boys) were recruited from an urban elementary school in central China for a word pair memory task. Half the participants were randomly assigned to the unrelated group, who had to recall unrelated word pairs, and the other half were assigned to the related group, who had to recall related word pairs. The participants received a gift (one ballpoint pen) for participating, regardless of their final memory performance. Ethical approval was obtained from the institutional review board of the authors' university, and parental consent was obtained before the study.

We used a 2 (value: 1 vs. 5 points) × 2 (relatedness: related vs. unrelated) mixed-model design, with relatedness being a between-subject variable and value being a within-subject variable. The relatedness of word pairs was manipulated to represent item difficulty. The adopted procedure and instruction in Study 2 were the same as those in Study 1. A total of 26 difficult word pairs and 26 easy word pairs comprised the material pool (Zhou, Liu, & Zhang, 2004). The associative strength of the related pairs was significantly higher ($M = 6.27$, $SD = 0.56$) than that of the unrelated pairs [$M = 2.09$, $SD = 0.72$, $t(13) = 21.64$, $p < 0.001$, Cohen's $d = 4.22$]. All the word pairs were nouns with two Chinese characters. The word frequency did not differ between the related ($M = 0.007$, $SD = 0.007$) and unrelated pairs [$M = 0.006$, $SD = 0.008$, $t(50) = 0.19$, $p = 0.85$]. In each group, four word pairs were used in the practice trials, and 22 word pairs were used in the test trials, with half the 22 word pairs being worth 1 point and the other half being worth 5 points. The maximum number of word pairs that could be offloaded was 11, but it is up to participants whether to use all 11 chances to save.

Results

Percentage of word pairs selected for cognitive offloading during the study phase

The percentage of items offloaded in the easy and difficult groups was 42.00% and 46.73%, respectively. A 2 (item value: high vs. low) × 2 (relatedness: related vs. unrelated) mixed-model ANOVA was performed, with item value as the within-subjects factor and relatedness as the between-subjects factor. We observed no main effect in relatedness [$F(1, 48) = 2.43$, $p = 0.13$, $\eta^2_P = 0.05$] but a significant main effect in value [$F(1, 48) = 11.47$, $p < 0.01$, $\eta^2_P = 0.19$]. The cognitive offloading rate for high-value items ($M = 0.50$, $SD = 0.17$) was significantly higher than that for low-value items ($M = 0.39$, $SD = 0.17$). The interaction of relatedness and value was significant [$F(1, 48) = 9.42$, $p < 0.01$, $\eta^2_P = 0.16$]. Additional simple-effects analyses revealed that the proportion of offloaded high-value word pairs ($M = 0.58$, $SD = 0.16$) was significantly higher than that of offloaded low-value word pairs ($M = 0.36$, $SD = 0.16$) in the unrelated condition [$F(1, 48) = 20.84$, $p < 0.001$, $\eta^2_P = 0.30$]; however, the proportion of offloaded high-value word pairs ($M = 0.43$, $SD = 0.15$) did not differ from that of offloaded low-value word pairs ($M = 0.41$, $SD = 0.18$) in the related condition [$F(1, 48) = 0.05$, $p = 0.82$, $\eta^2_P = 0.001$].

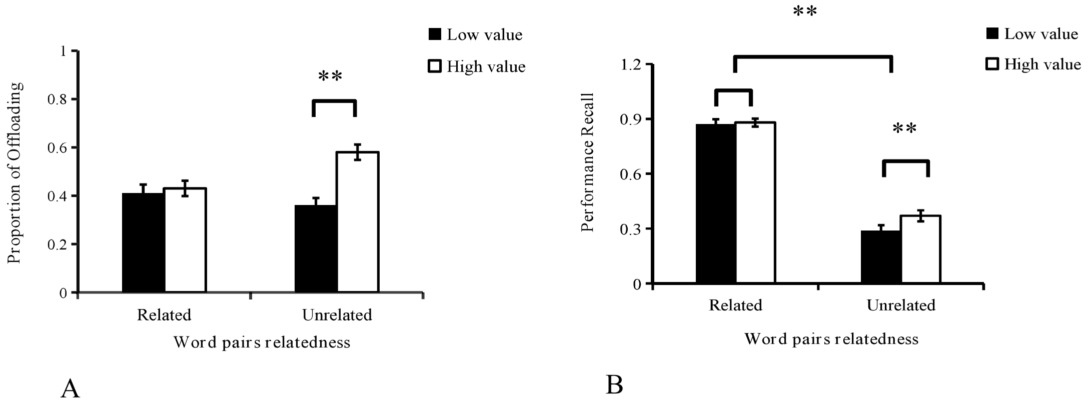


Fig 3. Children's Cognitive Offloading and Recall Performance for High- vs. Low-value and Related vs. Unrelated Items in Study 2. Note: ** $p < 0.01$. (A) Mean proportion of items selected for offloading. (B) Mean recall performance. Error bars represent standard errors of the means.

Recall performance

We performed a 2 (item value: high vs. low) × 2 (relatedness: related vs. unrelated) mixed-model ANOVA. We observed a main effect in relatedness [$F(1, 48) = 276.57$, $p < 0.001$, $\eta^2_P = 0.85$]. The recall of related items ($M = 0.88$, $SD = 0.13$) was significantly higher than that of unrelated items ($M = 0.33$, $SD = 0.14$). The main effect of the item value was significant [$F(1, 48) = 5.81$, $p = 0.02$, $\eta^2_P = 0.11$]. The recall performance was better for high-value word pairs ($M = 0.63$, $SD = 0.14$) than for low-value word pairs ($M = 0.58$, $SD = 0.12$). The interaction between value and relatedness was marginally significant [$F(1, 48) = 3.36$, $p = 0.07$, $\eta^2_P = 0.07$]. We conducted follow-up simple-effect tests. The results indicated that high-value item recall performance ($M = 0.37$, $SD = 0.15$) was significantly better than low-value item recall performance ($M = 0.29$, $SD = 0.10$) in the unrelated condition [$F(1, 48) = 9.00$, $p = 0.004$, $\eta^2_P = 0.16$]; however, no significant difference between high-value ($M = 0.88$, $SD = 0.14$) and low-value items ($M = 0.87$, $SD = 0.14$) was observed in the related condition [$F(1, 48) = 0.17$, $p = 0.68$, $\eta^2_P = 0.003$].

Effect of offloading on recall performance

To account for the effect of cognitive offloading on recall performance, we conducted a 2 (relatedness: related vs. unrelated, between-groups) × 2 (offloading: items being offloaded vs. items not being offloaded, within-subjects) mixed-model ANOVA with recall performance as the dependent variable. The results revealed a main effect in whether the participant offloaded items [$F(1,48) = 106.40$, $p < 0.001$, $\eta^2_P = 0.69$], with recall performance for word pairs selected for offloading ($M = 0.75$, $SD = 0.13$) being better than that for word pairs not selected for offloading ($M = 0.47$, $SD = 0.15$). The main effect of relatedness was significant [$F(1, 48) = 279.22$, $p < 0.001$, $\eta^2_P = 0.85$], with the recall performance of the related group ($M = 0.88$, $SD = 0.14$) being better than that of the unrelated group ($M = 0.34$, $SD = 0.14$). The interaction between offloading and difficulty was significant [$F(1,48) = 27.76$, $p < 0.001$, $\eta^2_P = 0.37$]. Simple-effects analyses indicated that in the related condition, recall performance for offloaded words ($M = 0.95$, $SD = 0.09$) was better than that for nonoffloaded words [$M = 0.82$, $SD = 0.19$; $F(1, 48) = 12.73$, $p = 0.001$, $\eta^2_P = 0.21$]. In the unrelated condition also, recall performance for offloaded items ($M = 0.56$, $SD = 0.18$) was significantly better than that for nonoffloaded items [$M = 0.12$, $SD = 0.10$; $F(1, 48) = 121.42$, $p < 0.001$, $\eta^2_P = 0.72$]. The aforementioned offloading effect was more pronounced for the unrelated ($M = 0.42$, $SD = 0.22$) condition than for the related condition [$M = 0.14$, $SD = 0.16$, $t(48) = 5.27$, $p < 0.001$, Cohen's $d = 1.46$]. The aforementioned results suggest that cognitive offloading improved memory performance in the unrelated and related conditions and that the effects of cognitive offloading were more pronounced in the unrelated condition.

Discussion

The results indicate that the 11-year-old participants used cognitive offloading strategies based on the value of the unrelated study items. However, item value did not affect their decision to offload related items; thus, the cognitive offloading strategies may have been moderated by the difficulty of the items. A possible explanation for this phenomenon is that the unrelated items created a sense of disfluency in the children's metacognitive processing (Koriat, 1997). This lack of fluency forced the children to search for other cues, including value cues, before making a decision to offload. Future studies can further examine this inference.

Study 1 revealed that the children applied difficulty cues (word pair relatedness) but not value cues for offloading when the two types of cues were accessible to participants for the within-participant designs. Study 2 indicated that the children used cognitive offloading strategies based on high-value items when the items were unrelated word pairs. These results suggest that children use cognitive offloading strategies based on the value of items under certain conditions. In Study 3, item value was emphasized through feedback and instruction that a high score on the recall test would lead to additional rewards. Such emphasis was expected to motivate children to offload high-value items more often than low-value items, thus leading to an offloading strategy based on item value.

Study 3

Method

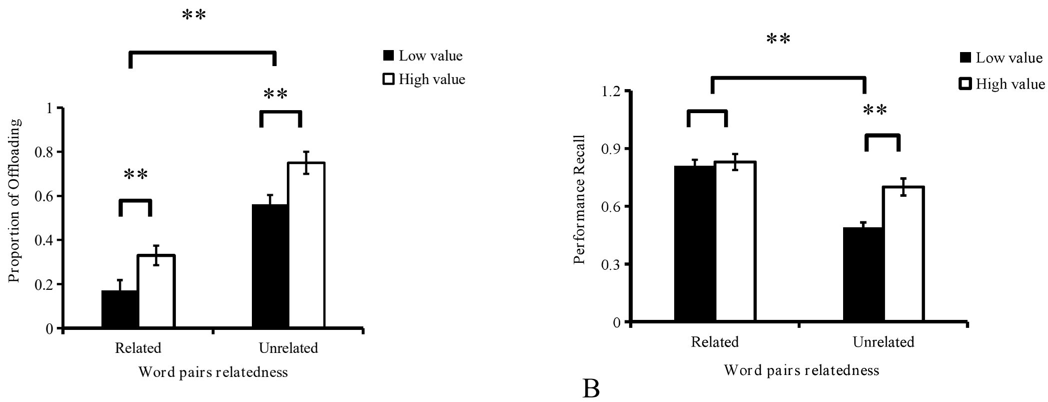
A calculation in G*power revealed that a minimum sample size of 17 was required to obtain a medium effect size of 0.25 with a power of 0.80 at an α level of 0.05 in a within-model ANOVA. A total of 25 participants (age: M = 10.85 years, SD = 0.54, and range = 9.94–11.57 years; 14 boys) were recruited from an urban elementary school in central China for a word pair memory task. The participants received a gift for participating. Ethical approval was obtained from the institutional review board of the authors' university, and parental consent was obtained before the study.

We used a 2 (item value: high vs. low) × 2 (relatedness: related vs. unrelated) within-subjects design. The relatedness of word pairs was manipulated to represent item difficulty. The materials used in Study 3 were the same as those used in Study 1; however, the procedure of Study 3 differed from that of Study 1. In Study 3, first, the participants were provided the total scores on the memory test. Second, the participants were informed that if their total scores from the memory test were 40 points or above, they would receive an additional reward (a colored pen popular among Chinese children) as an incentive in addition to the compensation. This incentive served as a goal-directed method for emphasizing the value cues. The instructions in Study 3 were similar to those in Study 1, except that children were told in Study 3 that they would receive an additional reward if their total scores from the memory test were 40 points or above. In addition, children were not directly told how to present their scores in the instruction, but their total scores were presented on the screen at the end of the practice phase and the formal experiment.

Results

Percentage of word pairs selected for cognitive offloading during learning

A total of 46% of all the study items were cognitively offloaded. A 2 (value: low vs. high) × 2 (relatedness: related vs. unrelated) within-subjects ANOVA with the offloading rate as the dependent variable revealed a main effect in relatedness [$F(1, 24) = 31.45$, $p < 0.001$, $\eta^2_P = 0.57$], with the cognitive offloading rate for unrelated items (M = 0.66, SD = 0.23) being higher than that for related items (M = 0.25, SD = 0.23). We observed a significant main effect in value [$F(1, 24) = 16.58$, $p < 0.001$, $\eta^2_P = 0.41$], with the cognitive offloading rate for high-value items being higher (M = 0.54, SD = 0.24) than that for low-value items (M = 0.37, SD = 0.23). No interaction was observed between difficulty and value [$F(1, 24) = 0.28$, $p = 0.60$, $\eta^2_P = 0.01$].



B

A

Fig 4. Children's Cognitive Offloading and Recall Performance for High- and Low-value and Related and Unrelated Items in Study3. Note: ** $p < 0.01$. (A) Mean proportion of items selected for offloading. (B) Mean recall performance. Error bars represent standard errors of the means.

Performance recall

A 2 (value: low vs. high) × 2 (relatedness: related vs. unrelated) repeated measures ANOVA was performed. We observed a main effect in relatedness [$F(1, 24) = 75.03$, $p < 0.001$, $\eta^2 = 0.76$] and a significant effect in value [$F(1, 24) = 8.4$, $p < 0.01$, $\eta^2_P = 0.26$]. The interaction between relatedness and value was significant [$F(1, 24) = 9.74$, $p < 0.01$, $\eta^2_P = 0.29$]. A simple-effects analysis revealed that the recall performance did not differ between the high-value items (M = 0.83, SD = 0.13) and low-value items (M = 0.81, SD = 0.16) in the related condition [$F(1, 24) = 0.43$, $p = 0.52$, $\eta^2_P = 0.02$]; however, in the unrelated condition, recall performance for the high-value items (M = 0.70, SD = 0.25) was significantly better than that for the low-value value items [M = 0.49, SD = 0.21; $F(1, 24) = 13.08$, $p = 0.001$, $\eta^2_P = 0.35$].

Effect of offloading on recall performance

The results of paired-samples t-tests revealed that the children's memory performance under the saving condition (M = 0.82, SD = 0.13) was significantly better than that under the not-saving condition [(M = 0.61, SD = 0.21), $t(24) = 4.40$, $p < 0.001$, Cohen's d = 0.87]. This result suggests that cognitive offloading can help improve memory.

General Discussion

This study explored the roles of item difficulty (operationalized with the relatedness of word pairs) and item value in the cognitive offloading of children in middle childhood through three experiments. Study 1 revealed that the children mainly relied on item difficulty (relatedness) for cognitive offloading when two types of cues were accessible to participants for the within-participant designs. In Study 2, item difficulty (related vs. unrelated) was controlled. We observed that item value had no effect on the children's cognitive offloading for related items, whereas the children offloaded high-value items more often than low-value items in the unrelated condition. The results suggested that difficulty cues might interfere with children's perception of value cues and that children can use value cues for cognitive offloading. In Study 3, we provided feedback and emphasized the value of the items. The children adopted cognitive offloading strategies based on both item difficulty and value cues. When the children used the value cues for cognitive offloading, they benefited from their offloading strategy during the recall test. In Study 1, the children did not use the value cues for cognitive offloading, and the item value did not influence their recall performance. In Studies 2 and 3, the children used cognitive offloading strategies based on value cues. Because the children offloaded more high-value word pairs, their recall performance for high-value word pairs improved; thus, their total scores on the memory test increased. The three studies revealed how children in middle childhood utilize cues of both item difficulty and item value for cognitive offloading. The results of this research can be interpreted as follows.

First, by middle childhood, children might have developed the ability to rely on data-driven cues for cognitive offloading; however, they may not be completely able to apply data-driven and goal-driven cues accessible to participants for the within-participant designs. Children in the middle and upper elementary grades can allocate learning time on the basis of the difficulty of word pairs (Koriat et al., 2009). The perception of difficulty emerges early in childhood, and the ability to use external tools to compensate for limited cognition continues to develop throughout elementary school (Bulley et al., 2020), which is consistent with the results of Study 1. Children older than nine years of age use cognitive offloading more frequently than children at age below 9 in a high-cognitive-demand task condition (Redshaw et al., 2018). The aforementioned findings suggest that children in middle childhood can apply item difficulty cues for offloading. Other studies have demonstrated that 8-year-old children begin to exhibit goal-oriented behavior (Chatham, Frank, & Munakata, 2009) and that the ability to adjust behavior to achieve personal goals continues to develop through middle childhood until the beginning of adolescence (Lorsbach & Reimer, 2010).

Although fifth- and sixth-grade children (approximately 10.9−12 years of age) utilize goal-driven value cues during metacognitive monitoring, when both item value and difficulty cues exist, they only utilize data-driven difficulty cues and do not perceive goal-driven value cues (Koriat et al., 2014). Risko and Gilbert (2016) suggested that metacognitive monitoring affects the use of cognitive offloading strategies. Because the metacognitive monitoring abilities of children in middle childhood are not fully developed, the children in Study 1 did not engage in cognitive offloading by using both cues; they only used the difficulty cues perceptible through metacognitive monitoring. In Study 2, when the level of difficulty cues was controlled, the children focused on the item value cues for cognitive offloading. When the word pairs were unrelated, the children developed a sense of disfluency (see cue utilization theory, Koriat, 1997) and sought other cues. Consequently, they exhibited different offloading decisions between the high- and low-value items under the difficult condition. Study 3 enhanced the children's awareness of the rewards by providing their total scores on the memory test. The feedback and instruction that a high score on the recall test would lead to additional rewards emphasized the value cues and helped the children apply them to cognitive offloading under the conditions in which both difficulty and value cues were provided. Gilbert et al. (2019) discovered that during metacognitive interventions (manipulation of feedback valence and practice trial difficulty), participants improved their cognitive offloading strategies, which is consistent with our findings. It should be noted that, in Study 1, although efforts were made to ensure that participants understood the instructions, it is still possible that children did not use the value cues because they did not fully grasp the meaning of the item value. In future studies, we will further simplify the experimental procedures and set more effective questions to test children's understanding of the instructions.

Second, automatic, bottom-up, data-driven regulatory processes are triggered more easily than are top-down, goal-driven regulatory processes. Koriat et al. (2006) proposed that learning processes regulated by item difficulty are bottom-up processes, whereas those regulated by item value are top-down processes. Bottom-up, stimulus-driven processing is automated, effortless, and less demanding of cognitive resources, whereas top-down, goal-driven processing is controlled, effortful and highly demanding of cognitive resources (Kahneman, 2011). Therefore, bottom-up processing can be triggered more easily than top-down processing. According to Hertzog et al. (2013), in metacognitive monitoring, individuals utilize internal cues, which are related to the nature of the items (e.g., item difficulty), and external cues, which are related to elements externally attached to the items (e.g., item value). When multiple cues are accessible to participants, the extent to which individuals utilize each type of cue differs. Some cues may be overlooked or underemphasized, whereas others may be easily perceived (Hertzog et al., 2013). In Study 1, the children may have perceived the bottom-up difficulty cues more easily than the top-down item value cues and thus automatically relied on them for offloading. Therefore, in Study 1, only item difficulty affected cognitive offloading. The aforementioned results are supported by neurocognitive studies as well. Bottom-up processes are associated with brain regions such as the superior thalamus, occipital nucleus, parietal lobe, and frontal eye area and involve not only the cerebral cortex but also the subcortical nuclei (Corbetta & Shulman, 2002). By contrast, top-down processing requires the continuous activation of attentional, perceptual, and action systems to achieve goals and is associated with sustained activation of the lateral prefrontal cortex (Braver, 2012). The ability to perform goal-directed, top-down processing is associated with the maturation of the prefrontal cortex, which is developing throughout childhood and adolescence and not fully developed until adulthood (Fandakova et al., 2017; Fiske & Holmboe, 2019; Vink et al., 2014), whereas the brain structures (e.g., the subcortical nuclei) that support bottom-up processing are well developed in the early stage of life (Gogtay et al., 2010). Therefore, children should be more capable of bottom-up processing than top-down processing. As supported by the results of neurocognitive studies, in Study 1, when item difficulty and value cues were presented together, the children were more likely to adopt bottom-up processing and apply cognitive offloading strategies based on item difficulty. In Study 2, the children offloaded more high-value items than low-value items only under the difficult condition. The aforementioned results might have been caused by the difference in cognitive ease between the two conditions. Under the easy item condition, the participants might have experienced a state of cognitive ease and perceived smooth progress during the task without feeling a need to search for other cues to memorize the items. Under the difficult item condition, the participants experienced a state of cognitive strain. They perceived the difficulty of the task and searched for other cues to complete the task (Kahneman, 2011). In Study 3, because the obviousness of the value cues (the emphasis was on high scores leading to additional rewards) triggered top-down goal regulation, the children could offload on the basis of item value when item difficulty and value cues were presented together.

Third, a limited working memory capacity may prevent children from using value cues for cognitive offloading. Berry et al. (2019) suggested that children with a worse working memory ability are less likely to select appropriate strategies to achieve goals. Individuals with a low working memory capacity cannot utilize value cues when items are presented one by one, rather than all together. By contrast, individuals with a high working memory capacity can utilize value cues by selecting high-value targets for relearning (Ariel et al., 2009). In middle and late childhood, children's working memory capacity is not fully developed (Cowan et al., 2006). Therefore, when multiple cues are accessible to children, they can utilize bottom-up difficulty cues but cannot utilize top-down value cues. However, an emphasis on incentive with respect to item value enables children to invest effort in detecting cues, which in turn facilitates the use of both difficulty and value cues.

With regard to practical applications, when multiple cues are accessible to children in a learning environment, teachers and learning facilitators can provide feedback and highlight cues during the learning process to help students select appropriate strategies and improve performance. Some studies have revealed that providing children with scaffolding for learning improves their cognitive performance (Okkinga et al., 2018; Ter Beek et al., 2019). In Study 3, we discovered that when the value cues were reinforced with feedback, the children exhibited cognitive offloading based on value. For challenging tasks, parents and teachers can offer children offloading tools to improve their performance.

This study has several limitations. First, the offloading effect was based on memory performance, which depends on working memory capacity. Ariel et al. (2009) reported that individuals with a high working memory capacity could offload items on the basis of item value cues, whereas those with a low memory capacity cannot. Future studies should use working memory capacity to examine the effect of item value on cognitive offloading. We also presented the word pairs to participants in a certain order, which might have increased the working memory load (Dunlosky & Thiede, 2004; Thiede & Dunlosky, 1999). Subsequent studies can simultaneously present several word pairs to reduce children’s working memory load. Second, we only used word pair relatedness to operationalize item difficulty. Because item difficulty involves other aspects, such as length and complexity, studies can investigate other indicators of item difficulty. Third, in all studies, we preassigned a constant time (3 seconds) for the participants to study each item. One study indicated that the time allotted for participants to complete a task affected the time that they allocated for studying items (Son & Metcalfe, 2000). Subsequent studies should vary the time for each item to identify an interaction between the effects of time and item difficulty on cognitive offloading. Fourth, the participants' confidence in memorizing items was closely related to their decision to offload items; however, the present research did not investigate their confidence in their memory. Confidence in being able to memorize an item is a form of metacognitive monitoring (Metcalfe, 2009), which is a secondary level of cognition. By contrast, the perception of item value and difficulty is a primary level of cognition. According to the metacognitive model of cognitive offloading (Risko & Glbert, 2016), the secondary level of cognition affects cognitive offloading. Studies should include metacognitive monitoring in research on cognitive offloading for comprehensively analyzing the mechanisms underlying cognitive offloading. In addition, most of the previous studies on cognitive offloading have examined the situation where items are fully offloaded, whereas the present study examined the situation where portions of items were offloaded to external media. Although partial offloading can also facilitate future recall by storing information externally, it still differs in degree from full offloading. Future research could further explore the possible differences between them.

In conclusion, the present research expanded on previous research related to the development of cognitive offloading during difficult tasks (Armitage et al., 2020; Redshaw et al., 2018) by exploring the effects of item difficulty and value on cognitive offloading and demonstrating the developmental characteristics and mechanisms of cognitive offloading during cue utilization.

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Figure

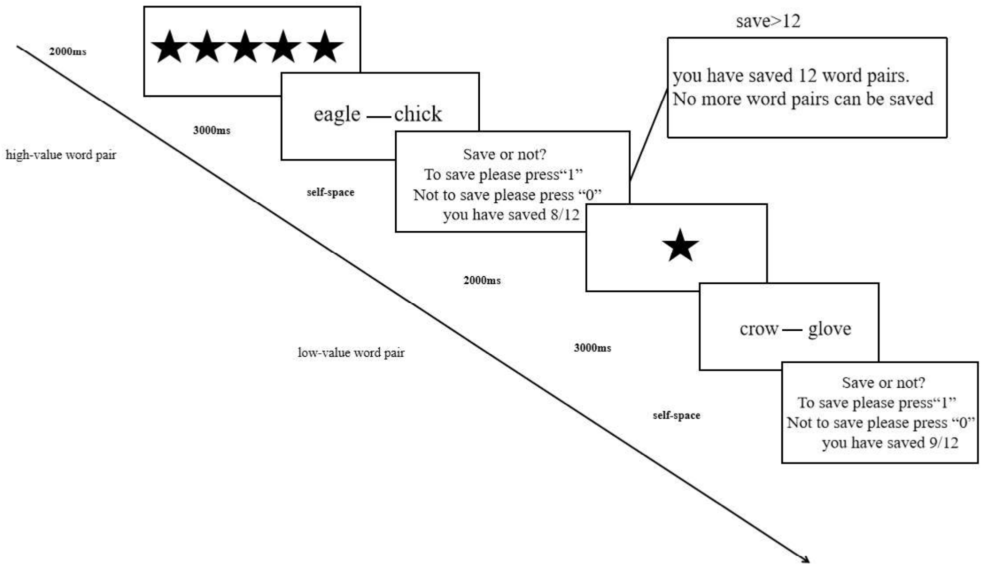
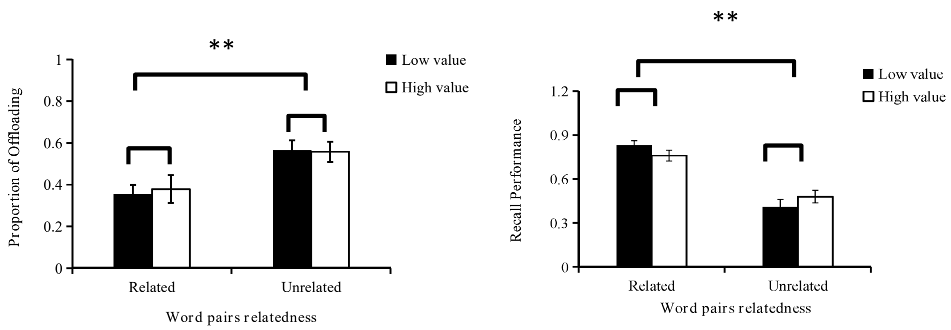


Fig 1. Learning phase in Study 1.



A B

Fig 2. Children's Cognitive Offloading and Recall Performance for High- and Low-value and Related and Unrelated Items in Study 1. Note: ** $p < 0.01$. (A) Mean proportion of items selected for offloading. (B) Mean recall performance. Error bars represent standard errors of the means.

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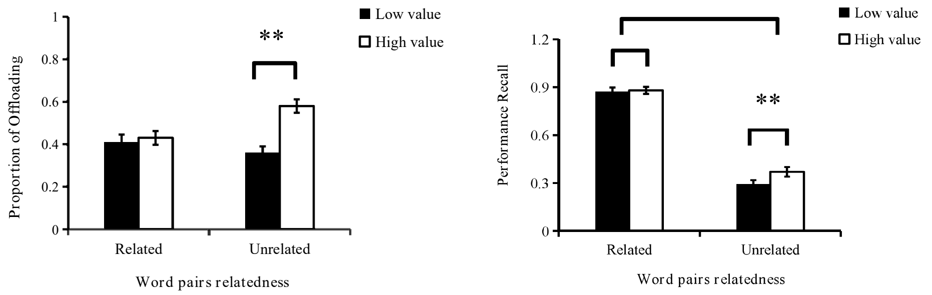
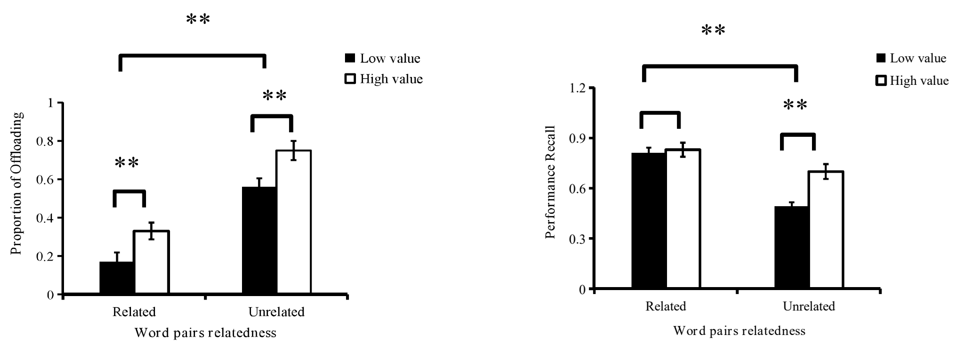


A B

Fig 3. Children's Cognitive Offloading and Recall Performance for High- vs. Low-value and Related vs. Unrelated Items in Study 2. Note: ** $p < 0.01$. (A) Mean proportion of items selected for offloading. (B) Mean recall performance. Error bars represent standard errors of the means.



A B

Fig 4. Children's Cognitive Offloading and Recall Performance for High- and Low-value and Related and Unrelated Items in Study3. Note: ** $p < 0.01$. (A) Mean proportion of items selected for offloading. (B) Mean recall performance. Error bars represent standard errors of the means.