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Two heads are better than one: the use of social cognitive offloading in working memory in six-year-olds and adults

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Abstract

Cognitive offloading becomes increasingly essential with the advancement of AI-powered technology, as it helps to free up mental resources and optimize overall performance. To better understand how children offload cognitive resources to external intelligent agents, the present study attempted to examine the use of social cognitive offloading in children and adults in a working memory task. 6-year-old children (Experiment 1) and adults (Experiment 2) completed a working memory task that required remembering 5 or 7 colored circles. We investigated whether and how children's and adults' working memory performance changed in the presence of a virtual agent who always remembers two of the colors within a trial (that participants could ask for help with). Results showed that both children's and adults' memory performance benefited from the introduction of a virtual agent. Furthermore, the use of the cognitive offloading strategy was dependent on the memory load.

Keywords: social cognitive offloading; children; working memory; metacognition

Introduction

What makes human beings unique from non-human animals is their critical ability to create and use tools. Over the historical process of human evolution, tools have been extensively used not only to transform our living world but also utilized to promote cognitive levels. Cognitive offloading refers to the use of external aid to reduce cognitive demand with the goal of achieving a task that otherwise may be hard (Risko & Gilbert, 2016). By offloading certain tasks or information to external resources including technology or people, one can optimize their cognitive performance and improve overall productivity.

Cognitive offloading plays a critical role in freeing up cognitive resources in working memory to support ongoing information processing. Working memory is the fundamental system that underlies regular information processing and is known for its extremely limited capacity (e.g., Cowan, 2012). When you are trying to remember one's number on the phone, verbally rehearsing the number or chunking the digits into a unit of three might be good ways to retain the information. These strategies have been supported by previous findings in overcoming the limitation of working memory capacity in children and adults (Feigenson & Halberda, 2004; Baddeley et al., 1975; Kibbe & Feigenson, 2016). For example, previous work showed that re-encoding information into "chunks" and applying labels that are easy to recall help reorganize large information into memorized storage units within the capacity (Miller, 1956). Additionally, verbal rehearsal also helps to promote working memory performance by continuously activating the attentional processes to retain information stored in the working memory and prevent decay (Baddeley et al., 1998). However, such mental strategies can be easily disrupted by a random conversation with a friend or a longer delay. Instead, seeking external solutions, such as note-taking, or asking your friend to remember the sequence together with you may be more resistant to external noises.

Children are known for their limited working memory capacity (Cowan, 2010). Cognitive offloading can help children offload the exceeding memory demands to improve memory performance and even protect them from catastrophic forgetting. To offload cognitive resources effectively, the ability to accurately evaluate one's own unaided ability in the current task, or the metacognitive ability, is essential to identify when one should offload (Risko & Dunn, 2015). If one can do the work well or even better than offloading it to an external tool or agent, then offloading may not be an optimized strategy. Previous work has shown that starting at age 4, children's metacognitive ability emerges, and they can evaluate based on the task difficulty to adjust the offloading behaviors. For example, when unsure about the answers, 4- and 5-year-olds may raise their hands to ask teachers for help (Beran et al., 2012). Similarly, when given options with the trade-off between magnitudes of rewards and tasks, children tend to choose a smaller but safer reward rather than taking a higher reward for greater risks (Neldner et al., 2015) or even skip a trial

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when uncertain about the memory outcome (Balcomb & Gerken, 2008).

Previous studies have examined children's use of cognitive offloading to lower memory demand in working memory and have captured a developmental improvement from 4 to 11 years of age (Armitage et al., 2022). In their study, children were invited to track the locations of the hidden objects and were prompted to use stickers as an external aid to save up working memory space. While 4-year-old children benefited from the use of the external assistant tool to help them find the hidden target, only older children can generalize the learned strategies in a novel context.

Their ability to calibrate the task difficulty to the offloading strategy is also developing between the age of 4 and 11 years old (Bulley et al., 2020; Armitage et al., 2020). Armitage and colleagues (2020) asked children to complete a task that required mental rotation, and children were given options to manually rotate the table to reduce the cognitive demands of mental effort, only children older than 8 years old showed selective rotation which was related to task demands, whereas children younger than 7 years were indiscriminative to conditions that offloading seems to improve the performance outcomes.

With the advancement of technology including AI, understanding how children interact with intelligent agents is one of the urgent questions that need to be solved. While the boundary to define an intelligent agent as social or non-social becomes vaguer than ever, they appear more frequently in children's learning experiences. Existing literature has examined the social cognitive offloading behavior when interacting with other people and has found that same as adults, children use competence to evaluate social agents (Bridgers et al., 2023). However, adults showed a systematic bias in unnecessary offloading (Gilbert et al., 2020; Kirk et al., 2021; Sachdeva & Gilber, 2020) where adults may engage in an erroneous underestimation of their capacity (Gilbert et al., 2020). Less work has examined the factors that influence children's decision to engage a social agent in cognitive tasks (but see Armitage & Redshaw., 2023).

The present study aimed to examine children's ability of social cognitive offloading by comparing children's working memory performance in the presence and absence of a virtual agent. We chose to test 6-year-old children as previous work showed that children have demonstrated greater improvements in cognitive offloading with physical tools starting at age 6 (Armitage et al., 2020; Armitage et al., 2022). We also conducted the same experiment to adults (Experiment 2) to compare children's social cognitive offloading behavior to adults. We have two research questions: 1) Does introducing a virtual agent in a working memory task increase their memory performance? 2) How do children use this external virtual assistant in their working memory processes?

To examine the questions, we asked children to complete a working memory task with two conditions. Children saw a number of colored circles which were later covered by occluders. Children were then shown a target color that had appeared before and were asked to find the location of it either with no agent's help (Baseline condition) or they had choices to ask a robot to give them some clues (Agent condition). Specifically, the robot is always reliable but gives only partial information (the robot only remembers two colored circles), so that children may come up with different ways to offload cognition to the social agents.

For the first research question, we hypothesized that If children cannot offload memory demand to the virtual agent, then we would see children's performance in the Agent condition to be similar to or lower than the performance in the Baseline condition. If children can offload memory demand to the virtual agent, then we would observe children's performance in the Agent condition to be higher than the performance in the Baseline condition.

For the second question, we hypothesized that children may either use the virtual agent as an additional 'hint' or be more strategic to divide labor with the robot during encoding. Since one critical factor in cognitive offloading is the metacognitive ability, we would also examine whether children's use of the virtual agent is dependent on the task difficulty. If so, they would outsource cognition to the virtual agent more in trials that they are not quite sure about, and offload more often in harder trials than easier trials. Therefore, we would expect that children's performance for the trials that they did not outsource to the external agent in the Agent condition to be higher than the performance in the Baseline, where they cannot outsource to an external agent. We would also expect that children offload more often in harder trials (where they need to remember seven colored circles) compared to easier trials (where they need to remember five colored circles). If children develop a more specific strategy to divide labor with the robot, children may leave the two colored circles for the robot to remember and only remember the rest of the colored circles. If so, we may observe children tend to seek help more often in the trials that the target was in the robot's memory range compared to those that the target was not in the robot's range.

Experiment 1

Method

Participants

Thirty-four 6-year-old children (range: 5 years 11 months – 6 years 11 months, Mean age: 6.54 years, 14 girls) participated. The final sample size was large enough to detect a medium effect size (f = .25) with 80% power in a repeated measure ANOVA with two factors (condition: Baseline vs. Agent; set size: five vs. seven), based on the power analysis that was calculated in G*Power (n = 24). The study was approved by The Hong Kong University of Science and Technology Institutional Review Board.

Participants were recruited from a local kindergarten in Shenzhen, China. All children were identified as Han nationality.

Apparatus & Stimuli

The study was conducted in the corner of a quiet classroom. The experimenter sat with the child participants one by one and presented the experimental stimuli on a 13-inch MacBook Air. The stimuli were created using Keynote software.

Design

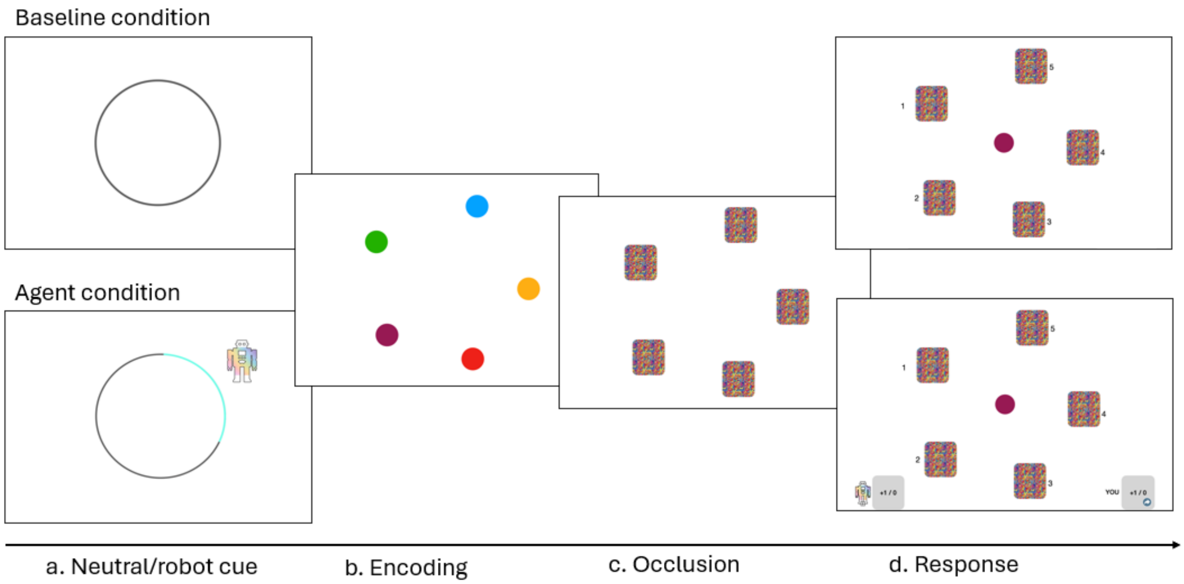


Figure 1. Procedures of Experiment 1 and Experiment 2.

Children were invited to complete a computerized memory game. There were two conditions: Baseline condition and Agent condition. In the Baseline condition, children saw either five or seven colored circles that were later occluded by blocks. A target color would appear in the center and children were asked to guess which place the child saw the target color previously. The Agent condition was the same as the Baseline condition except that children were introduced to a robot that would remember two colored circles depending on where it sat. Children had the choices to guess the location of the target color by themselves or seek help from the robot. Whether children completed the Baseline or the Agent condition first was counterbalanced across participants. Within each condition, children completed six trials of set size 5 and six trials of set size 7, with the order also counterbalanced across participants.

Procedures

Introduction. The experimenter first introduced to children that "This is a memory game." Children saw a ring appear in the center of the screen and then three colored circles appeared surrounding the disappeared ring. Children were asked to remember the color-location binding before the colored circles were hidden by blocks. A target color circle appeared in the center of the previously disappeared ring and digital numbers appeared next to the hidden circles. The experimenter asked children to guess where the target circle was "hiding". Children were prompted to respond with the number next to the spot. The experimenter then explained the reward rule by saying, "If you get it right, I will put two coins into your piggy bank". If children got it wrong, children cannot get any coins into the piggy bank. Children heard the rules and watched the animation of the coins flying into or flying away from the piggy bank.

Baseline condition.

Practice. After the introduction, children were presented with two practice trials. The practice session followed the same procedures as in Introduction except that after children gave verbal responses, the experimenter would provide feedback on whether children answered correctly or not and show the corresponding reward animation. If children were incorrect, the experimenter would replay the trial. Children were asked to remember five colored circles in the first practice trial and seven colored circles in the second practice trial. This was to familiarize children with the Test session with trials of Set Size 5 and Set Size 7. The presentation of each step was controlled by the experimenter.

Test. The Test session proceeded similarly to the Practice trials except that children received no feedback on whether they did correctly. To avoid distraction and fatigue, children were not shown the reward animations and were told that the experimenter would track "how many coins you won". The timing of each presentation step was fixed and pre-determined. The ring was present for 2.5s, after its disappearance, the colored circles appeared and stayed on screen for 1s in Set Size 5 trials and 1.4s in Set Size 7 trials (0.2s per circle). After the presentation of visible colored circles, the occluders flew in to cover the circles. After a delay of 1s, the target color circle appeared in the center position of the disappeared ring and the numbers next to the occluders were presented (see Figure 1).

Agent condition.

Introduction. The second condition started with the experimenter saying, "Let's do something different." The experimenter introduced a robot that "always remembers two things at a time". Children then saw a robot appear in different locations surrounding the ring and were told that "depending on where it sits, it will remember the two circles that appear on its blue part of the ring. Children were told to still remember as much as they could, but because this time the robot was on the child's team, if the child was not sure about the location of the target circle, he or she could ask the robot to show the colors that the robot remembered.

Children first saw a robot appear along with the ring; a part of the ring was marked blue to help children know that the robot would remember the colored circles near that blue part. Then the robot and the ring disappeared, and the trial proceeded similarly as in the Baseline. After seeing the target-colored circle, children saw two grey buttons appear on the sides of the bottom of the screen. The experimenter then explained the rules of the Agent condition. Children now have two options to respond. If children chose to answer by themselves, the rule was the same as in the Baseline: win two coins for correct trials and nothing for incorrect trials. Children were also told that "since now you have the robot on your team, and you can ask it for help if you want." The experimenter then explained that if the child chose to ask the robot to show him or her the two circles it remembered, if the target was one of them, children would get two coins. If the target color was not one of them, then children had another chance to guess from the remaining circles. If children got it correctly, children would still get two coins, but if they got it wrong, children would not get any coins. Children saw the animation of coins flying into or flying away from the piggy bank during the experimenter's demonstration.

Practice. After introducing children to the robot, children completed two practice trials with the same procedure as in the Introduction. Children saw one trial with five colored circles and the other trial with seven colored circles. Children received feedback on whether they did it correctly and were also shown the animation of coins being put into or away from the piggy bank. If children were incorrect, the experimenter would repeat the trial. The presentation pace was controlled by the experimenter.

Test. The test session proceeded similarly to the Practice session (see Figure 1). Children received no feedback on the correctness. Children completed 6 trials of Set Size 5 and 6 trials of Set Size 7, with the order counterbalanced across participants.

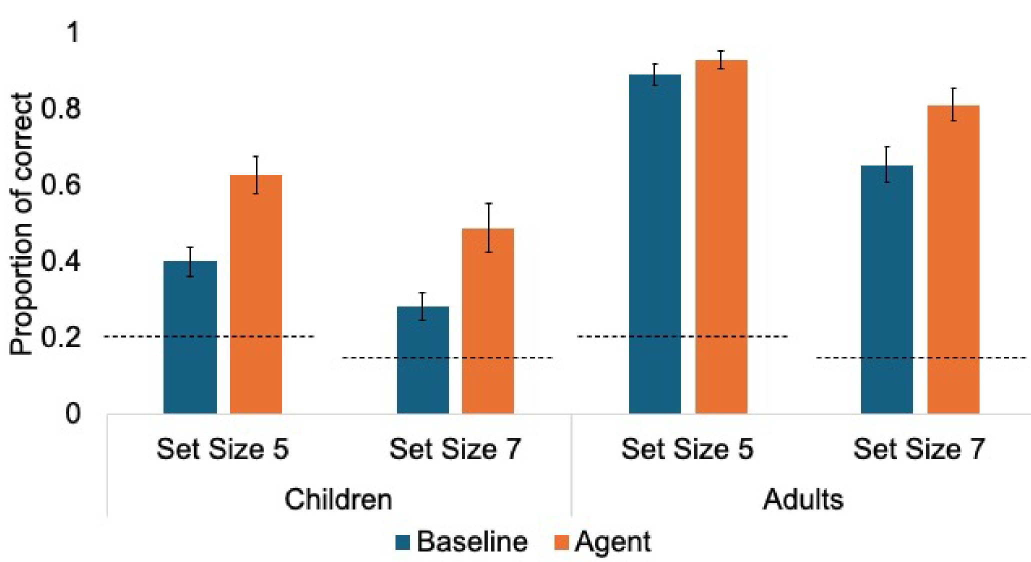
Coding

Children's performance on each trial was coded as 1 (correct) and 0 (incorrect).

Results

We first examined whether children could perform the memory task by conducting one sample t-test. Results in the Baseline condition showed that children's performance was significantly above chance in Set Size 5 trials (chance level = .2, M = .40, SD = .22, $t(33)$ = 5.32, p < .001, BF_{10} > 1000, Cohen's d = 1.85) and Set Size 7 trials (chance level = .167, M = .28, SD = .22, $t(33)$ = 3.18, p = .003, BF_{10} = 9.8, Cohen's d = 1.11). This suggested that children understand the task and can remember up to seven color circles with above chance performance.

In the Agent condition, we first sorted trials into one group that children answered by themselves and the other group that children asked the robot for help. We then analyzed the



Fi ildren and adults. The performance in the Agent condition depicted excluded trials where children asked the robot for help. Error bars show standard error.

proportion of correct in the trials that children answered by themselves, the chance levels were the same as in the Baseline. One sample t-tests showed that children performed significantly above chance in both Set Size 5 ($M = .63$, $SD = .28$, $t(33) = 8.78$, $p < .001$, $BF_{10} > 1000$, Cohen's $d = 3.06$) and Set Size 7 trials ($M = .49$, $SD = .33$, $t(29) = 5.32$, $p < .001$, $BF_{10} > 1000$, Cohen's $d = 1.98$).

To compare whether children's memory performance benefited from the introduction of the robot, we submitted children's performance in Set Size 5 and Set Size 7 in the Baseline condition and in the Agent condition for the trials that were answered by children themselves into a repeated measure ANOVA. We observed a main effect of condition ($F(1,29) = .17.97$, $p < .001$, $\eta^2_p = .38$); children's performance in the Agent condition was significantly higher than the performance in the Baseline condition. We also observed a main effect of set size ($F(1,29) = 10.01$, $p = .004$, $\eta^2_p = .26$) as expected because the chance level in Set Size 5 was higher than in Set Size 7. We did not see an interaction effect between condition and set size ($F(1,29) = .014$, $p = .91$, $\eta^2_p < .001$), suggesting that the introduction of the robot brought similar levels of boost to the performance (Figure 2).

Next, we examined children's cognitive offloading behavior by analyzing whether children sought external resources for help more often when the task was more difficult. In the Agent condition, children on average asked robot for help 2.18 times out of six trials ($SD = 1.45$) in Set Size 5 and 3.03 times out of six trials ($SD = 1.64$) in Set Size 7, Wilcoxon Signed Ranks Test showed that children asked the robot more often when the task was harder (in Set Size 7) than when the task was easier (in Set Size 5) ($Z = 2.79$, $p = .005$).

Finally, we asked whether children strategically allocated attention during the encoding period, so the labor was divided between the child and the robot. To examine whether children adopted such a strategy, we compared the number of times that children sought for help when the target was in the range of the robot's capacity versus when the target was out of the range of the robot's capacity. Since for each set size, there were three trials that the target color was in the robot's memory range and three trials that the target color was outside the robot's memory range. If children did not attend to the robot's location and plan encoding accordingly, then the number of times for children to ask for help should not differ between whether the target was in or outside the robot's memory range. If children divided labor between themselves and the robot, they would distribute their attention strategically to encode the colored circles that were not in the robot's memory range to maximize encoding efficiency. Therefore, children would be more likely to seek help when the target was within the robot's memory range. Results showed that children were more likely to seek for help when the target was within the robot's memory range than when the target was outside the robot's memory range in Set Size 5 (Mean_in = 1.35, Mean_out = .82, Wilccoxon Signed Ranks Test, $Z = 2.36$, $p = .018$), but when the task becomes harder, children's help-seeking behavior was unselective (Set Size 7, Mean_in = 1.50, Mean_out = 1.53, Wilcoxon Signed Ranks Test, $Z = .033$, $p = .97$) trials. This evidence showed that children's selective help-seeking behavior was dependent on the memory load. When the memory demand is lower (in Set Size 5), children asked the robot for help more often when the target was in the robot's memory range, suggesting some extent of labor division in memory encoding between children and the robot. However, when the memory demand is higher (in Set Size 7), children are more likely to ask the robot for help and this offloading behavior was not selective to whether the robot had the useful information, but children tended to treat the robot as a general information source.

Experiment 2

Participants.

Thirty-one adults between the age of 18 and 24 years old participated in the study. All adults are identified as Han ethnicity.

Apparatus, Design, Material, Procedures

All materials and procedures are the same as in Experiment 1.

Results

The analysis plan was identical to Experiment 1. We first examined adults' proportion correct in Baseline, and in the Agent condition, we only analyzed the trials that was not asked for help. Results showed above chance in both set sizes in both conditions (all $t(30) > 11.13$, $p < .001$, Cohen's $d > 1000$). To examine the effect of set size and condition, we observed a main effect of condition ($F(1,30) = 9.84$, $p = .004$, $\eta^2_p = .25$) and a main effect of set size ($F(1,30) = 30.87$, $p < .001$, $\eta^2_p = .51$) that children performed better in the Agent condition than the Baseline condition and better in Set Size 5 than Set Size 7. We also observed an interaction effect between condition and set size that while adults performed similarly in the Agent ($M = .93$, $SD = .13$) and Baseline ($M = .89$, $SD = .15$) condition in Set Size 5, adult participants' performance was higher in the Agent ($M = .82$, $SD = .23$)

in Set Size 7 compared to Baseline ($M = .66$, $SD = .26$) ($F(1,30) = 4.85$, $p = .036$, $\eta^2_p = .14$), suggesting that they benefited more by having a robot available to help than when they had to remember all by themselves.

Comparing the frequency for adults to ask for help, we found that adult participants asked the robot for help more often in Set size 7 ($M = 1.5$, $SD = 1.5$) when the task was more difficult than Set size 5 ($M = .23$, $SD = .50$) (Wilcox Signed Ranks Test, $Z = 3.70$, $p < .001$). Finally, we examined whether adults' help-seeking was selective to whether the target was in or outside the robot's memory range, we found that participants' frequency in asking the robot for help was low in Set size 5 trials and there was no difference between when the target was in the robot's range ($M = .13$, $SD = .43$) or outside the robot's range ($M = .10$, $SD = .30$) ($Z = .33$, $p = .74$). However, adults asked the robot more often in Set size 7 trials when the target was in the robot's memory range ($M = .97$; $SD = 1.14$) than when it was not in the robot's memory range ($M = .48$, $SD = .81$) ($Z = 1.98$, $p = .047$), suggesting that adults use a division of labor strategy during encoding and pay more attention to the colored circles that were outside robot's memory range.

General Discussion

Offloading cognition to external tools and agents is a critical component of human intelligence. With the advancement of technology, children may have more chances to interact with social agents, smart devices, and human-like robots. When and how do children interact with agents and make use of external resources during cognitive tasks? In two experiments, the current study examined children's and adults' social cognitive offloading behavior in a working memory task. Participants completed the Baseline condition where they need to remember either five or seven colored circles and later recall the locations of the target-colored circles. In the Agent condition, participants were introduced to a robot, and the robot can remember two colored circles at a pre-determined location, from whom participants could ask the robot to reveal the circles that it remembered when responding.

We found that both children's and adults' memory performance with and without the robot was significantly above chance, and this was true for both easy (Set Size 5) and hard (Set Size 7) trials. For children, they indeed benefited from the introduction of the robot, as children's performance in the Agent condition for the trials when children did not seek the robot for help was significantly higher than that in the Baseline condition.

We further explored how children used the external assistant in the working memory task: whether children's higher performance in the Agent condition was a result of children's strategy in asking the robot for help when they were generally uncertain, or a more strategic way of usage by dividing the labor between themselves and the robot. Results showed that children's strategic help-seeking behavior was dependent on the memory load. When the memory load was lower, children selected the robot to help them more often when the target was in the robot's memory range. This suggested that children had some extent of understanding in labor division which was tailored by the robot's own knowledge, and children were able to employ strategic attention allocation during encoding based on the location of the robot. However, when the memory load is higher, children 's help-seeking behavior occurred more often and they no longer showed a location-specific offloading, but their behavior was mostly driven by uncertainty in general.

Since adults completed the same tasks as 6-year-old children, we did not observe significant benefit of having a robot in helping remember information in Set Size 5 because their performance in Baseline was at ceiling. However, in Set Size 7, we observed similar behavioral improvement in adults as in children that their memory performance was significantly higher in the Agent condition than in the Baseline condition. In Set Size 7, adults tended to ask the robot for help more often when the target was in the robot's memory range.

Together these findings suggested that both adults and 6-year-old children showed social cognitive offloading behavior in a working memory task and their performance was benefited by using the offloading strategy. There are other cognitive abilities that may be closely related to the development of social cognitive offloading. For instance, proactive planning and cognitive flexibility have been shown to develop rapidly during the middle childhood and are important factors for cognitive activities (e.g., Chevalier et al., 2014). Future work can examine the relationship between social cognitive offloading and other cognitive functions in different developmental stages to capture a more complete picture of the early development of social cognitive offloading.

Children are social learners. Multiple factors may work together to influence children's use of social agents in aiding their learning experience. For example, in the current study, the robot has limited capacity as he can only remember two circles but is always reliable to show the correct colors. Both reliability and capacity may be potentially crucial for children's social cognitive offloading behavior. In real life, a real person or a smart device may not always be reliable or may only be true in some contexts. As adults, we evaluate these social agents' reliability and validity before making the decision to outsource to external agents or not. Future directions can investigate what factors influence children's behavior regarding whether to offload or not when making instant decisions.

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