Children's emerging ability to balance internal and external cognitive resources

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Abstract

Humans have increasing opportunities to offload internal cognitive demand, such as by setting reminders to aid future memory performance. Here, we examine how children begin to balance mind and world: weighing up when to offload cognition and when to rely on their unaided capacities. Australian children aged 6 to 9 years (N = 120) were tasked with remembering the locations of 1, 3, 5, and 7 targets hidden under 25 cups. In the critical test phase, children were provided with a limited number of 'tokens' to distribute across trials, which they could use to mark target locations and assist future performance. Following the final search period, children were invited to evaluate and adjust their initial allocation. Results showed that 8- to 9-year-olds prospectively allocated proportionately more tokens to difficult trials, whereas 6- to 7-year-olds did so only in retrospect. Throughout childhood, humans become increasingly adept at balancing internal and external cognition.

Keywords: cognitive offloading; metacognition; cognitive development; cognitive strategy; extended mind.

Despite the remarkable achievements of the human mind, in many contexts we find ourselves confronted with our cognitive limits. Memory, for example, is fundamental to complex human behaviour and facilitates a variety of other cognitive processes, but its capacity and precision is severely restricted (Cowan, 2014; Buschman, Siegel, Roy, & Miller, 2011). To our benefit, however, humans can recognise, strategically compensate for, and artificially shift such cognitive performance limits (Armitage, Bulley & Redshaw, 2020; Buschman et al., 2011). Insight into our own cognitive strengths and weaknesses drives us to negate the inherent constraints of internal processing, often by structuring our environment advantageously. Writing lists, setting alarms, and leaving objects in conspicuous places are just a few of the ways that we utilise external resources to compensate for the memory limits of our "naked minds" – thereby transferring internal cognitive demands into the external world (Clark & Chalmers, 1998; Heersmink, 2013; Sutton, 2010). Indeed, using physical actions or external artefacts to alter the information processing requirements of a task so as to alleviate cognitive demand, or *cognitive offloading*, provides a formidable means to solve problems and bypass otherwise unassailable cognitive limits (Risko & Gilbert, 2016).

Consider your ability to recall a task that needs to be performed at a specific moment in the future, such as remembering to buy some groceries on the way home from work (i.e., a prospective memory task). Your chances of enacting such intentions at the right time can be greatly enhanced by setting a reminder, from tying a knot into a handkerchief to setting an alarm on a smartphone (Gilbert, 2015; Bulley et al., 2020). Offloading cognitive demand in such ways often reflects a cost-benefit trade-off, in which one judges that the benefit of externalising the intention is likely to outweigh any costs of time and effort involved in doing so (see Gilbert, Boldt, Sachdeva, Scarampi & Tsai, 2022 for a review of intention offloading). Unaided "mental labour" can be costly – as it demands time and effort that might be better spent on other tasks – and so people regularly distribute their mental work with costs and benefits in mind (Kool & Botvinick, 2018).

Developmental psychologists have extensively studied the emergence of prospective memory, with improvements documented from early childhood to adolescence (see Mahy, 2022 for review). The development of reminder setting, by contrast, has been largely neglected. This oversight is puzzling given that external strategies are widespread and ostensibly provide the most potent means of preventing prospective memory failures. Building on Gilbert and colleagues' investigations into reminder setting in adults (2015a, 2015b, 2020) and primary school-aged children (Redshaw, Vandersee, Bulley & Gilbert, 2018), Bulley et al. (2020) recently developed a method to examine when young children begin to effectively offload cognition with

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reminders. Four- to 11-year-old children were tasked with remembering the hiding locations of one or five targets under a circular array of 25 cups. In one experiment, children were provided with a bucket of tokens and told that they could use them to mark the target hiding locations while the targets were being hidden if they wished. Results indicated that 30% of 4- and 5-year-olds set reminders selectively – using the tokens to aid their performance in the 5-target condition significantly more than in the 1-target condition. These results suggest that even preschool-aged children can prevent cognitive failures by selectively externalising task demands in difficult conditions.

This and other recent studies have focused on establishing the initial emergence of children's proclivity for cognitive offloading, in the context of both reminder setting (Armitage et al., 2022; Bulley et al., 2020; Redshaw et al., 2018) and other domains such as mental rotation and working memory (Armitage et al., 2020; Armitage & Redshaw, 2022; Berry, Allen, Mon-Williams & Waterman, 2019). Although these studies provide insight into the development of binary offloading choices under various conditions, children's capacity to proportionately weigh up limited internal and external cognitive resources remains unknown. In a world where external cognitive resources are increasingly available but internal resources remain as limited as ever, do children know how to distribute external resources to successfully manage internal load?

Measuring such a capacity with existing methods is troublesome for multiple reasons. For one, it is difficult to ascertain whether children who offload under both high and low cognitive load do so because they do not understand the differential benefit of offloading in these cases, or simply because they believe they will derive at least some benefit in both cases (or because they do not wish to expend the internal effort in either case). Conversely, children who selectively offload under high but not low cognitive load may do so simply because they have learned to associate feelings of cognitive difficulty with help-seeking behaviour, and not because they have explicitly assessed that there is relatively more to gain from offloading in such cases (see Gilbert et al., 2022). To overcome these measurement difficulties, in the current study we gave children the opportunity to distribute a limited pool of external cognitive resources among trials of varying internal difficulty. Children who can balance internal and external cognitive resources should be expected to distribute more external resources to more difficult trials, such that internal demands remain manageable across all trials.

Children aged six to nine years were tasked with remembering the hiding locations of targets (coins) under an array of 25 cups (as in Bulley et al., 2020). There were three experimental phases, each consisting of a 1-target, 3-target, 5-target, and 7-target trial. In Phase 1, children had to rely on internal cognitive processing alone to encode and recall the target cups. In Phase 2, children were instructed to use tokens as reminders by placing them on every target cup, such that each target would be easily identified during the search period. Critically, in Phase 3, children were provided with only a limited number of the tokens and advised to distribute them among the upcoming four trials as they pleased. Following the Phase 3 search period, children were asked to reflect on their earlier allocation of tokens and were given the opportunity to retrospectively adjust this allocation in accordance with their task performance.

Consistent with the fledgling developmental literature on cognitive offloading (Armitage et al., 2020; Armitage & Redshaw, 2022; Berry et al., 2019; Dong, Liu & Lu, 2022; Redshaw et al., 2018), we anticipated that selective reminder setting would increase linearly with age, such that older children would be more likely to allocate their reminders in proportion to cognitive load relative to younger children. That is, if children are able to balance internal and external cognitive resources, this might be reflected in a 'balanced distribution' of reminders, whereby cognitive effort is minimized across trials. In our task, this would translate to a distribution of zero, one, three and five tokens allocated for 1-, 3-, 5- and 7-target trials, respectively, such that no more than two hiding locations need be remembered unassisted on any given trial. When given the opportunity to revise their use of the reminder setting strategy, we expected that older children – and children who performed poorly in Phase 3 – would be more likely to exercise this opportunity to improve their performance (and likely align more so with the aforementioned balanced distribution). We also preregistered our intent to explore several other theoretically interesting questions for which we formed no specific hypotheses. In particular, we examined whether children searched in line with recency or primacy effects, which might provide insight into the internal strategies they use to assist them in encoding and recalling target locations. We also explored at what point in the target hiding sequence children chose to employ their tokens (i.e., the first target hidden versus the last target hidden), as well as the order in which they searched for marked versus unmarked target cups. In theory, children should use tokens on earlier targets rather than later targets, and search for unmarked targets before marked targets, as both behaviours should reduce the time and effort required to rehearse and recall unmarked targets.

Method

Participants

One-hundred and twenty children (49 males and 71 females) aged between 6.03 and 9.95 years (M = 7.93, SD = 1.18) were included in analyses, with seven additional children excluded due to experimenter error. Children of this age were tested given notable transitions in cognitive offloading propensities (Armitage & Redshaw, 2022; Bulley et al., 2020) and metacognition (Schneider, 2008) during this period. A post-hoc power analysis suggested that this sample provided a 92.7% chance of detecting medium age effects (equivalent to r = .30). As pre-registered, age was analysed as a continuous variable and all significant effects involving age were followed up by examining simple effects among 6- and 7-

year-olds (n = 60) and 8- and 9-year-olds (n = 60). Participants were recruited via a university database or at a public museum. The sample was mostly White and middle-class. Ethics approval was granted prior to data collection, and children's guardians provided verbal and written consent. Data were collected between December 2021 and February 2022.

Materials

In all three experimental phases, plastic coins (targets) were hidden under a circular array of 25 identical cups (8 inner circle, 17 outer circle) presented on a round plastic board (see Figure 1; as in Bulley et al., 2020). Participants were provided with a 'wand' to select cups they believed concealed coins. Prior to each phase, one, three, five and seven coins were counted and displayed on a rectangular whiteboard marked with lines to indicate separate trials (see Figure 2). The hiding location of coins was counterbalanced across participants. At the conclusion of each trial, found coins were placed in a small treasure chest next to the participant. In Phase 2 and 3, participants were provided with a number of tokens they could use to mark the locations of hidden coins, simply by placing tokens on top of the cups.

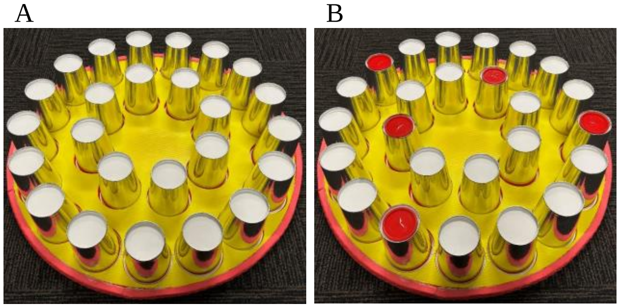

Figure 1: The round plastic board used to present the cups, as viewed from participants' perspective. (A) The appearance of the board during all trials in Phase 1, when tokens were not available to the participant. (B) A possible appearance of the board during Phase 2 or Phase 3, when tokens could be placed on top of target cups by the participant.

Measures and Procedure

Phase 1. Participants were informed that their aim was to fill a treasure chest with coins. To do this, they needed to recall the hiding locations of coins under the array of cups. Participants were only allowed as many guesses as the number of coins hidden and were thus discouraged from liberally guessing locations until they found coins. Following the hiding sequence, the experimenter would enforce a 5-second delay before searching would commence. This process was repeated in all phases, with some constraints for 3-, 5- and 7-coin trials: (a) cups selected by participants were returned to the board prior to their next selection, (b) the experimenter counted out loud the number of 'guesses' left after every selection, (c) coins correctly found by the participant were held by the experimenter until the end of each trial so as to not interrupt the participant's memory recall, and (d) unfound coins remaining on the board at the end of each trial were seized by the experimenter.

Phase 2. Sixteen tokens were introduced in Phase 2, with a token provided for every coin to be hidden. The experimenter demonstrated how to use the tokens by placing one on top of a cup, stating that the participant should place a token on the corresponding cup immediately after each coin was hidden. After the hiding sequence, a 5-second delay was again imposed before searching was permitted. In Phase 2 (and 3), the experimenter seized the tokens as target cups marked with tokens were searched.

Phase 3. Participants were provided with nine tokens to allocate as they pleased across the 1-, 3-, 5-, and 7-coin trials before the game began. They were reminded that they could only use each token once, and any coins without a token would have to be remembered. At the conclusion of Phase 3, participants were reminded of their initial allocation of the nine tokens by the experimenter re-placing the tokens where the participants had placed them. Participants were then asked: "if we were going to play again, would you use the tokens the same way or would you use them differently?". If the participant indicated that they would use them differently, they were invited to adjust their distribution of the tokens. Children who made adjustments universally agreed that their revised distribution would allow them to obtain more coins.

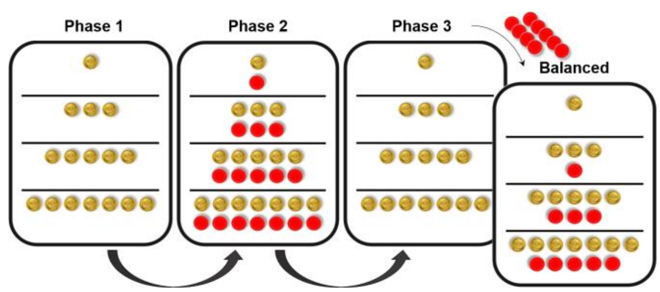

Figure 2: Depiction of the whiteboard used to display the number of coins/tokens involved in each trial of every phase, whereby the child was asked to distribute the tokens for Phase 3. The experimenter removed the relevant coins from the whiteboard as each trial commenced and placed them in target cups according to the pre-determined sequence. The right-side whiteboard shows what might be termed the 'balanced' distribution of tokens across Phase 3 trials.

Results

Accuracy

In Phase 1 and 3, search accuracy was scored as the proportion of correctly identified target cups selected out of the number of searches allowed on each trial (i.e., number of targets hidden). Scores on all trials therefore continuously ranged from 0 (no targets correctly identified) to 1 (all targets correctly identified). General linear models (GLMs) were

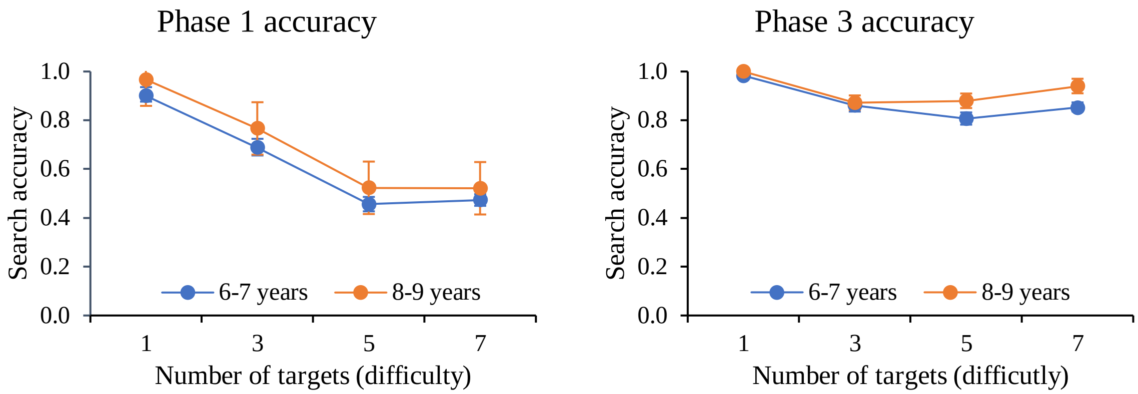

Figure 3: Phase 1 (unassisted) and Phase 3 (offloading-assisted) accuracy, split according to younger and older children. Accuracy is represented as the proportion of correctly identified targets per trial. Error bars indicate standard error of the mean.

used to analyse these data, with a within-subjects factor of *difficulty* (1, 3, 5 and 7 targets) and a between-subjects factor of *age* (continuous, mean-centred). Continuous *deviation scores* (i.e., the number of tokens allocated that varied from the balanced strategy; see Figure 2) were included as an additional between-subjects factor for the Phase 3 analysis.

Phase 1. GLM results revealed a significant linear effect of difficulty ($F(1, 118) = 353.90$, $p < .001$, $\eta p^2 = .75$), indicating that, as intended by the task design, children became less accurate as the number of targets increased (see Figure 3). There was also a significant effect of age ($F(1, 118) = 14.81$, $p < .001$, $\eta p^2 = .11$), indicating that older children were more accurate than younger children, $r = .32$. The interaction between difficulty and age was not significant, $F(1, 118) = .02$, $p = .879$, $\eta p^2 < .01$, such that the effect of difficulty on Phase 1 accuracy was similar for younger and older children.

Phase 2. Participants correctly identified all marked target cups, except for two children who misidentified one cup each.

Phase 3. Unlike in Phase 1, the effect of difficulty was not significant in Phase 3, ($F(1, 117) = 1.12$, $p = .291$, $\eta p^2 = .10$), suggesting that the opportunity for cognitive offloading alleviated internal demands and supplemented children's performance in more difficult trials. There was, however, a significant interaction between difficulty and deviation from balanced reminder use ($F(1, 117) = 24.49$, $p < .001$, $\eta p^2 = .17$). This indicates that the difficulty effect was stronger for children who did not allocate their reminders as proportionately. For instance, on the 7-target trial there was a strong negative correlation between accuracy and deviation from balanced reminder use (controlling for age), $r(117) = -.50$, $p < .001$, suggesting that children who were less balanced in their reminder allocation performed more poorly on these most difficult trials.

Reminder Setting

Children's prospective and retrospective proportional token allocation was analysed with a series of preregistered GLMs, with a within-subjects factor of *difficulty* (1, 3, 5 and 7 targets) and between-subjects factors of *age* (mean-centred, continuous) and *accuracy* (scored as total coins found out of 16 for each phase, mean-centred, continuous). For each trial, proportional token allocation was defined as the number of tokens allocated divided by the number of targets on the trial.

Prospective reminder allocation (before Phase 3). The effect of difficulty on prospective reminder allocation significantly interacted with age ($F(1, 117) = 28.21$, $p < .001$, $\eta p^2 = 0.19$), which was followed up by examining simple effects among younger and older children. The 8- and 9-year-olds showed a significant linear relationship between the number of targets and the proportion of reminders allocated ($F(1, 58) = 81.89$, $p < .001$, $\eta p^2 = .59$), whereas 6- and 7-year-olds did not, $F(1, 58) = 0.55$, $p = .463$, $\eta p^2 = .01$. This demonstrates selective allocation of external cognitive resources among older children, but not younger children (see Figure 4). None of the effects involving the Phase 1 accuracy were significant, both $F < 2.63$, $p > .107$.

Retrospective reminder allocation (after Phase 3). A significant linear effect of difficulty ($F(1, 116) = 101.12$, $p < .001$, $\eta p^2 = .47$) was qualified by interactions with age ($F(1, 116) = 6.50$, $p = .012$, $\eta p^2 = .05$), and Phase 3 accuracy ($F(1, 116) = 8.18$, $p = .005$, $\eta p^2 = .07$). Follow-up testing revealed that both 6- and 7-year-olds and 8- and 9-year-olds showed a significant linear relationship between the number of targets and the proportion of reminders allocated following Phase 3 (younger children: $F(1, 57) = 18.86$, $p < .001$, $\eta p^2 = .25$, and older children: $F(1, 57) = 204.85$, $p < .001$, $\eta p^2 = .78$, respectively). Although the difficulty effect remained stronger for older children, this provides evidence that 6- and 7-year-olds became more selective with their reminder allocation after seeing how their initial allocation functioned during Phase 3.

Children who scored above the median in accuracy (≥ 15 out of 16; $n = 54$) showed a stronger linear difficulty effect for retrospective reminder allocation, $F(1, 52) = 177.54$, $p < .001$, than those who scored below the median in accuracy (≤ 14 out of 16; $n = 66$), $F(1, 64) = 19.67$, $p < .001$. There was also, however, a significant negative correlation between

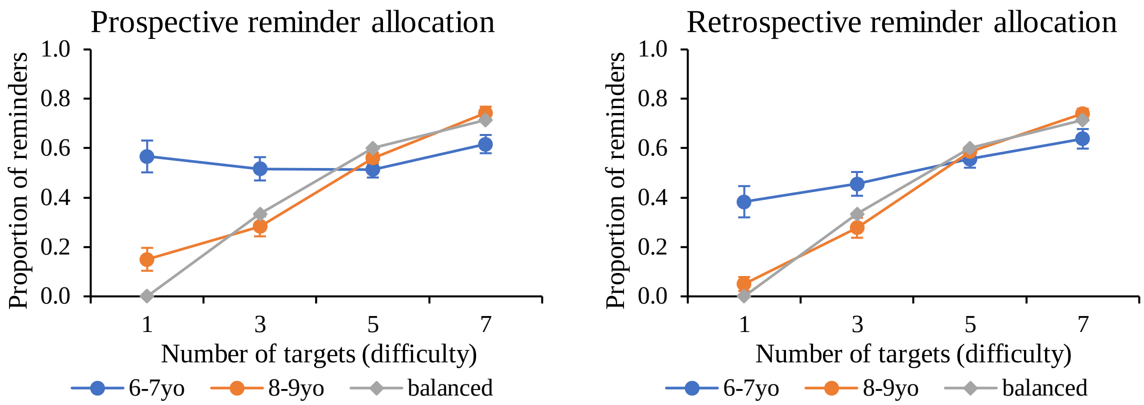

Figure 4: Prospective (prior to Phase 3) and retrospective (following Phase 3) reminder allocation, split by age group. Reminder allocation is represented as the proportion of reminders allocated per trial. Error bars indicate standard error of the mean, and the pre-defined balanced strategy (i.e., no more than 2 targets to remember unaided on each trial) is shown in grey.

Phase 3 accuracy and reminder allocation *adjustments* (categorical variable: yes or no), such that children who performed poorly in Phase 3 were more likely to retrospectively change their reminder allocation than children who performed well, $r(118) = -.379$, $p < .001$. Allocation adjustments also negatively and significantly correlated with age, $r(118) = -.288$, $p = .001$.

Exploratory Analyses

Initial search preference (Phase 1). While attempting to remember the locations of various targets, children might rehearse target locations in the order they are hidden and try to recall these locations in the same sequence. On other occasions, children may instead simply try to recall the last target hidden – the freshest in memory – and only then attempt to recall preceding targets. Across the 3-, 5- and 7-target trials in Phase 1, participants were therefore scored for whether their first cup selected was (1) the first target hidden (possibly exploiting the primacy effect) or (2) the last target hidden (possibly exploiting the recency effect). Trials on which participants first selected an incorrect cup were excluded from analyses (as we cannot deduce a strategy from this failure), and scores on all included trials were then averaged for each participant. Across all children, the mean proportions of trials in which participants first selected the first target hidden ($M = .39$, $SD = .35$) and first selected the last target hidden ($M = .39$, $SD = .33$) were similar. However, age was significantly and positively associated with first selecting the first target hidden ($r(118) = .218$, $p = .017$), whereas age was significantly and negatively associated with first selecting the last target hidden ($r(118) = -.230$, $p = .012$). This suggests that older children may have been more likely to rehearse and recall the targets in the order they were hidden, whereas younger children may have been more likely to opt for the target associated with the most recent memory trace. Intriguingly, controlling for age, overall Phase 1 accuracy was significantly and positively associated with recency searches ($r(117) = .298$, $p = .001$), but not primacy searches ($r(117) = -.167$, $p = .069$). A Fisher r-to-Z transformation test revealed that the difference between these correlations was significant, $Z = 5.16$, $p < .001$, which suggests the younger children's seemingly preferred strategy of starting with the freshest item in memory was better for improving overall memory performance in Phase 1.

Marked versus unmarked targets (Phase 3). When searching for targets in Phase 3, children might consider the order in which they should select marked versus unmarked target cups. Selecting a marked cup prior to searching for unmarked targets would presumably interfere with memory for the unmarked locations. By contrast, "saving" the marked cups for last and retrieving unmarked targets while they are fresher in memory is presumably more efficient. Participants were accordingly scored for their initial search preference across 3-, 5- and 7-target trials in Phase 3 – i.e., whether they selected a marked or unmarked cup first. Instances where a participant had no markers available for the trial or marked all target cups were excluded from analyses, and scores on all included trials were then averaged for each participant. Age was significantly associated with selecting an unmarked cup first ($M = .75$, $SD = .36$), $r(111) = .289$, $p = .002$. This suggests that older children were more likely to employ the more efficient strategy of selecting unmarked cups first, prior to retrieving marked (i.e., guaranteed) targets. In line with this explanation, selecting an unmarked cup first was also significantly and positively associated with Phase 3 accuracy ($r(111) = .517$, $p < .001$), and this correlation held even when controlling for age and deviation from balanced reminder use, $r(109) = .413$, $p < .001$.

Reminder placement timing (Phase 3). Placing a marker on the first target hidden should arguably also improve one's ability to remember the remaining targets, as opposed to placing a marker on the middle or last targets hidden while simultaneously attempting to remember earlier targets. Participants were therefore scored for whether they placed a marker on the first target hidden across 3-, 5- and 7-target trials in Phase 3, excluding trials in which they had no markers available or marked all target cups, and then averaged across all included trials. Although marking the first target hidden (M = .78, SD = .34) did not significantly correlate with age ($r(112) = -.068$, $p = .473$), it did positively correlate with Phase 3 accuracy ($r(112) = .210$, $p = .025$), and this correlation held when controlling for age and deviation from balanced reminder use, $r(110) = .233$, $p = .013$.

Discussion

We provided children with a novel opportunity to allocate external cognitive resources across trials with varying levels of internal cognitive demand. Results showed that 8- to 9-year-olds prospectively allocated external resources in proportion to internal demand, whereas 6- to 7-year-olds did so only in retrospect. Older children were also more likely than younger children to select unmarked targets in the order they were hidden (in Phase 1), and to search for unmarked targets before marked targets (in Phase 3). On the whole, our findings suggest that during middle childhood, humans become considerably more adept at understanding the limits of their own cognitive abilities and seeking workarounds.

Unlike in previous studies, which have found that even 4- and 5-year-olds offload more frequently on hard than easy trials (Armitage et al., 2020; Bulley et al., 2020), the children in our sample were not provided with sufficient resources to offload all internal demands on every trial. Children were also tasked with weighing the relative difficulty of the trials in advance and in parallel, rather than during each trial of a sequence of easy and hard trials. Under these conditions, only 8- to 9-year-olds showed evidence of selective cognitive offloading when distributing the tokens. One possibility is that, when younger children selectively offload cognitive demand in other tasks, they typically do so as a function of the direct experience of cognitive difficulty on hard trials, rather than sophisticated metacognitive reflection on their unaided cognitive capacities and limits across various conditions (see Gilbert et al., 2022).

Many of the younger children in our study allocated a relatively high proportion of reminders to the comparatively easy 1- and 3-target trials—especially during the prospective allocation period—leaving them having to remember more than two targets in the more difficult 5- and 7-target trials. Older children, however, were more adept at equating cognitive load across trials. This could be due to a more nuanced understanding of the interaction between internal memory processes and external artefacts and how these can work in tandem to perform cognitive tasks. Indeed, our findings may be interpreted in light of the "law of less work", which was originally developed to model patterns of physical effort (Hull, 1943) but has recently been applied to mental effort (Kool & Botvinick, 2018; Kool, McGuire, Rosen & Botvinick, 2010). From this perspective, thinking is considered a costly activity and courses of action are planned and chosen based on anticipated cognitive demand. It is possible that the older children, but not younger children, recognised that by allocating the reminders proportionately before Phase 3, they were correspondingly allocating their mental labour proportionately across trials. Nonetheless, many younger children appeared to recognise and correct their oversight when asked to retrospectively consider their allocation. Younger children may therefore require more experience in order to perform this delicate balancing of internal demands and external resources (although it remains to be seen whether their performance would reach the level of older children with even more trials).

Not only were older children superior to younger children in their distribution of tokens, they were also more likely to "save" marked targets for later during the Phase 3 search period. And critically, this behaviour improved children's overall accuracy. Indeed, searching for unmarked targets prior to marked targets presumably diminished the decay of these older children's memory for the unmarked target locations. Our pre-trial, post-trial, and during-trial measures therefore provide compelling and complementary evidence that older children were actively reflecting on and knowingly compensating for their cognitive limits throughout Phase 3. Intriguingly, however, when the tokens were unavailable in Phase 1, the younger children's seemingly preferred strategy of initially searching for the last target hidden (also see Morey et al., 2018) was a better predictor of performance than the older children's seemingly preferred strategy of searching for the first target hidden (when controlling for the basic age effect). Future research may wish to further explore the relationship between children's use of internal and external cognitive strategies, and the question of why some developmental transitions in such strategies may not immediately support better performance.

Future research should also examine whether our findings generalise to other memory tasks, other cognitive domains, and to non-WEIRD populations of children. Even so, it is worth noting that humans across the world have long been offloading the internal demands associated with remembering what to do where and when. Physical or written calendars, for instance, appeared in numerous cultures across every continent following the last ice age, often functioning to help people schedule group activities and prepare for seasonal changes (Suddendorf, Redshaw, & Bulley, 2022). Given the widespread innovation and use of such technology, it stands to reason that the ability to exploit external resources to overcome memory limits may emerge as a function of robust and universally human developmental processes.

In conclusion, the current study is the first to investigate how children directly weigh up and allocate limited internal and external cognitive resources. We found that, from around eight years of age, children pre-emptively allocated limited external resources in proportion to internal cognitive load. Although younger children did not initially demonstrate this competency, they retrospectively adapted their strategy to be more selective after experiencing the consequences of their initial approach. Our results shed light on the emergence of the human ability to implement and reflect upon cognitive offloading strategies, which enables children, like adults (Clark & Chalmers, 1998), to overcome the natural limits of their naked minds.

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