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My tablet's about to go dead! 5- to 6-year-old children adjust their cognitive strategies depending on whether an external resource is reliably available

Yibiao Liang [*], Zsuzsa Kaldy, Erik Blaser

Department of Psychology, University of Massachusetts Boston, 100 Morrissey Blvd., Boston, MA 02125, USA

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ABSTRACT

There are concerns that reliance on external resources (e.g., information on digital devices) may be harmful to our own internal memory. Here, in a pre-registered study, we investigated how the *reliability* of an external resource (i.e., whether the information will be available when needed) affects young children's use of it. In our tablet-based Shopping Game, children picked items from a store based on a shopping list. Importantly, the store and the list were not visible simultaneously, but children could toggle between them. In the *reliable* condition, the list was always available. In the *unreliable* condition, children were led to believe that the list might disappear. We found that 5–6-year-old children ($N = 37$) relied more on the list – referring back to it more often and more briefly, and remembering fewer items – when they perceived the list as reliably available (and vice versa, reducing trips to the list by studying it longer, and remembering more, when it was perceived as unreliably available). Nearly all children also identified the reliable condition as easier and preferred. In short, young children not only recognize the opportunity provided by reliably available external resources, but adapt their cognitive effort accordingly.

1. Introduction

How many phone numbers do you remember? We are so reliant on digital devices (Eliseev & Marsh, 2021) that it is common to feel 'low-battery anxiety' (Zhang et al., 2022). This experience with digital devices starts early in life. According to a national survey in the US by Common Sense Media (Rideout & Robb, 2020), 98 % of 0- to 8-olds had mobile digital devices at home, and 5–8-year-old children had, on average, three hours of screen time a day. There is concern about the adverse effects of digital devices on children (Shanmugasundaram & Tamilarasu, 2023; Sina et al., 2023; Woolford et al., 2023) and correlational studies with children have suggested that earlier and greater exposure is related to poorer performance in academic and cognitive tests (Adelantado-Renau et al., 2019; Dempsey et al., 2019; Sina et al., 2023). That said, while the widespread use of digital devices may be new, the use of external resources is not.

From ancient carved rocks (Van Dyke & Alcock, 2008) to the strings and knots of ancient quipu (Ascher & Ascher, 1981) to writing itself, people have long used external resources of information to complement internal cognitive functions. Indeed, the coupling with these external resources is so tight that it can be thought to form an 'extended mind' (Clark & Chalmers, 1998). According to the Extended Mind thesis, if external information is *accessible* (easily reachable), *trustworthy* (accurate), and *reliable* (available when

* Correspondence to: Institute of Psychology, Goethe University Frankfurt, Theodor-W.-Adorno-Platz, 6, Frankfurt am Main 60323, Germany.
E-mail address: yibiao.liang001@umb.edu (Y. Liang).

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needed), then it can become part of the mind (Clark & Chalmers, 1998; Gallagher, 2018). Previous studies have looked at how *accessibility* affects the use of external information versus internal memory (Draschkow et al., 2021; Hayhoe et al., 1998; Kenderla & Kibbe, 2023; Liang et al., in press; Sahakian et al., 2023). Here, we focus on Clark and Chalmers' second criterion: how the *reliability* of an external resource affects young children's use of it. (In studies of social learning, the term 'reliability' refers to the accuracy of an information source (Harris et al., 2018; Sobel & Kushnir, 2013). Here, consistent with the framing of the *External Mind* thesis, we use it to refer to the *reliable availability* – is it there when you need it? – of external resources.) The current study aims to investigate young children's use of external resources and thereby potentially provide foundations for guiding children in the proper use of them. Some reliance on external resources is inevitable – the key is to maximize their benefits while minimizing their potential adverse effects (Skulmowski, 2023).

1.1. Relationship between external resource availability and memory use in adults

The availability of external resources (e.g., computers, internet, written notes) makes it possible for people to rely less on their internal memory (Eskritt & Ma, 2014; Grinschgl et al., 2021; Henkel, 2014; Kelly & Risko, 2019, 2022; Lu et al., 2020; Sparrow et al., 2011). Adults were shown to remember less detailed information and only keep the gist or the path to retrieve the information (Lu et al., 2022; Sparrow et al., 2011), which potentially increases their susceptibility to memory manipulation (Risko et al., 2019). For example, in Sparrow et al. (2011)[1], participants were asked to read and type trivia facts into a computer. Half of the participants were told this information could be accessed later, whereas the other half were told it would be erased. They found that participants who thought they could use the saved information performed worse in a subsequent free recall task. This effect was also found when people could take notes (Eskritt & Ma, 2014) or photos (Henkel, 2014). This trend extends to the ubiquity of information access in general; adults both overestimate what they remember from searching the internet (Fisher et al., 2021) and are likely to come to rely on the internet for more tasks after having used it for one (Storm et al., 2017).

To relate this 'memory cost' to the *availability* of external resources, Kelly and Risko (2022) proposed the *study effort hypothesis* based on cost/benefit models of effort allocation, such as the Expected Value of Control (Shenhav et al., 2017). The model assumes that memorizing information is valuable but costs effort. When a (presumably) perfectly accurate external record is expected to be available, the 'expected value' of memorization is lower. Therefore, people tend to avoid exerting effort to memorize and instead rely on external resources when possible. To test this, Kelly and Risko (2022) gave a list of words to participants to study for a later recall test, with the study time controlled by the participants themselves. Participants had access to the word list during the recall test in the first three trials but not in the fourth trial. Only half of the participants were informed of this change in advance. They found that participants who had not been informed about the impending unavailability of the list performed worse in the fourth trial. Even more importantly, the uninformed participants also made less effort (as indexed by shorter study times and less mnemonic strategy usage) during the study. In short, if external resources are expected to be available, people will memorize less, thereby reducing the effort that committing information to memory requires. However, the flip side of this reliance means that if the resource suddenly becomes unavailable, people will find themselves lacking the information they need.

1.2. Relationship between external resource availability and memory use in children

Children also use less of their memory when external resources are available. In an early study (Eskritt & Lee, 2002), 10–12-year-old children were divided into two groups and played a memory card game. In the *studying* group, children were just instructed to study the cards. In the *note-taking* group, children could take notes when studying the cards. In their first game, children in the note-taking group could access their notes, but, importantly, in their second game, their notes were removed unexpectedly. The results showed that, in that second game, the note-taking group's children performed worse than those in the studying group, implying that they memorized less when external resources were available.

Few studies have looked into the reason behind this pattern of behavior in children, and consider specifically the availability of external resources. In a recent study, 11-year-olds chose to save the difficult word pairs, instead of the easy ones, on devices for a later memory test (Dong et al., 2022). According to their self-report, the reasons they used external resources as memory aids were to increase accuracy and reduce effort (Iley & Medimorec, 2024). These studies indicate that older children can use external resources or their memory spontaneously and adaptively in the sense that they will consider different factors, such as the availability of resources, the difficulty of the task, and effort in using memory. It is worth noting that children still have trouble when external resources need to be used in an unfamiliar way. While in an older study, 9-year-olds could store a target in a distinct place (e.g., the corner of a complex matrix) (Heisel & Ritter, 1981), in a more recent one, same age children (8- to 10-year-olds) were not able to group blocks by color to facilitate solving a later search task (Berry et al., 2019).

As for children younger than 9, they are less likely to adopt strategies that rely on external resources (such as reminders) and do not seem to be able to use them spontaneously. While 4- to 5-year-olds are able to use strategies that were explicitly taught to them, for example, to mark the locations of hidden targets for a later memory task, they do not spontaneously devise the strategy themselves even given all the necessary tools, in contrast to 10- to 11-year-olds who are able to do so (Bulley et al., 2020). Similar results were found with younger children, where even 3-year-olds could adopt the instructed strategy of marking a target location, but not until 6

[1] While Experiment 1 of Sparrow et al. (2011) did not replicate (Camerer et al., 2018), Experiment 2, the relevant experiment here, was corroborated (Eskritt & Ma, 2014; Henkel, 2014; Kelly & Risko, 2022).

could they create a new strategy if the task settings were changed slightly (Armitage et al., 2023). Interestingly, if the task was familiar or naturalistic enough, this helped considerably. In interviews, even 5-year-olds said they would opt to write down a number if asked to remember it (Kreutzer et al., 1975) and 4-year-olds will spontaneously rotate a turntable physically, instead of mentally, especially when the angular disparity is large (Armitage et al., 2020). These studies indicate that experience might also contribute to the spontaneous and adaptive use of external resources. However, most of these studies did not study how the *availability* of external resources affects their use. They also focused on the use of external resources only, without looking at the use of internal (memory) resources (except for the study by Eskritt and Lee (2002)). But importantly, children do not simply memorize the least amount possible when given the opportunity: instead, they strike a strategic balance between using memory versus using external resources, given the costs of each (Blaser & Kaldy, revision under review; Liang et al., in press).

The study-effort hypothesis suggests that shifts in the use of external resources versus memory require monitoring the effort required to use working memory (Kelly & Risko, 2022). However, there is uncertainty about how well young children can weigh and adjust their effort. Children's ability to gauge their effort spontaneously may only begin to emerge around 5–7 years of age (Niebaum & Munakata, 2020) based on studies showing children at this age did not opt to play, nor were able to consistently identify as 'easier'', a less demanding game (Niebaum et al., 2019, 2021; O'Leary & Sloutsky, 2017). Some form of scaffolding, such as visual cues to task difficulty, a simple prompt (e.g., "Choose the *easier* task"), or performance feedback can facilitate children to choose a less demanding (or avoiding a more demanding) task (O'Leary & Sloutsky, 2017, 2019; Wang & Bonawitz, 2022). This seems consistent with findings that instruction can encourage younger children to use external resources.

In our recent study, we used a novel, naturalistic paradigm to demonstrate that 5–8-year-old children are able to strategically trade off memorizing versus checking an external source depending on the costs of accessing the source (Liang et al., in press). When the cost of access was higher, children spent more time memorizing items, accessed the resource fewer times, and remembered more in each visit. Accessibility, however, is just one of Clark and Chalmers' criteria for what can work as an optimal external resource (Clark & Chalmers, 1998). In the current study, we focused on another factor: the source's *reliability* (i.e., will it be there when you need it?).

1.3. *The current study*

In the current study, we manipulated the *perceived* reliability of external resources; children's impression, but not the actuality, of their reliability. In most of the studies reviewed above (Eskritt & Lee, 2002; Kelly & Risko, 2022; Sparrow et al., 2011), external resources were *actually* removed, so researchers could not measure their subsequent use, as the resources were no longer there to be used. By leaving the external resources in place we could measure how children adjust their use (versus internal memory) based on how reliably available they appeared to be. To manipulate the perceived reliability, we used an innovative, naturalistic working memory task (a tablet-based "Shopping Game") (Liang et al., in press). In the Shopping Game, children need to find items in a store based on a shopping list. Importantly, the list and the store are not visible simultaneously, but children could toggle between them. With this design, we can not only measure the effort children devote to memorization by recording the time they spend studying the list, but also measure children's active use of external resources - here, the shopping list – by measuring how often children refer back to it. In addition, we tested whether children were able to monitor our manipulation of reliability by asking two follow-up metacognitive questions ("Which game did you think was easier?", "Which game would you play again to earn more stars?").

We focused on the 5–6-year period, when children's developing working memory abilities (Ahmed et al., 2022) start to face more explicit challenges as they begin formal schooling, and the use of external resources (e.g., books, or notes written on paper, or stored digitally) becomes more important (Brod et al., 2017; Haith & Sameroff, 1996). In addition, this is the age when children's ability to spontaneously monitor their own effort may be emerging (Niebaum & Munakata, 2020). While previous studies of this age period have looked at children's use of external resources (Armitage et al., 2020; Armitage et al., 2023; Bulley et al., 2020), they have not looked at how the reliability of the external resources affects the use of those resources versus internal memory. The current study can shed light on the relation between their spontaneous metacognition and behaviors, laying the groundwork for understanding how to cultivate the proper use of external resources. We expected that children would be sensitive to our manipulations of perceived reliability: referring to the list more often, spending a shorter time studying it, and, ultimately, remembering fewer items per visit when they perceived the shopping list to be reliably available.

2. Method

2.1. *Open science statement*

The study was preregistered on the Open Science Framework. The preregistration, experiment scripts, raw data, and data analysis scripts are all accessible online at (https://osf.io/wyv59/).

2.2. *Participants*

We calculated the planned minimum sample size, $N = 34$, based on a medium effect size ($d = 0.5$) with 0.8 power and $\alpha = 0.05$ (since our design was quite simple, instead of basing power analyses on complex simulations for the linear mixed models (Kumle et al., 2021), we based them on a simpler, analogous paired t-test). 47 5–6-year-old children were tested at three children's museums in the New England area (Easton, MA, Acton, MA, and Dover, NH). 10 of these children were excluded: 4 because of parental interference during the test and 6 decided not to complete the study (all told, this is not an excessive proportion of data loss for a public space for

5–6-year-olds). The final sample included 37 children ($M = 5.98$ years, range: 5.00–6.91, $SD = 0.59$, 18 females). Caregivers reported that their children were Asian ($n = 5$), White ($n = 26$), more than one race ($n = 4$), or did not report their children's race ($n = 2$). Of the 37 children, two were reported as being Hispanic/Latino. This research was approved by the Institutional Review Board of the University. Consent was obtained from the caregivers and assent from the children before the start of the experiment.

2.3. Procedure

The Shopping Game was programmed with PsychoPy (v2022.1.2) (Peirce et al., 2019) on a Surface Go tablet (Fig. 1). Children were asked to pick items from a virtual store (of 20 items) based on a shopping list (of 10 items). Importantly, the store and the list were not visible simultaneously. Instead, children could toggle between them by tapping the appropriate icons (an arrow icon or a list icon). We minimized visual search demands by keeping items in the same locations on the store shelves across all trials in a condition. In addition, the items on the four shelves were grouped by category: fruits, vegetables, proteins, and baked goods. The experimenter guided the children in naming all the items during the practice trial.

To motivate children to pick the items that were on the list (correct picks) and avoid items that were not on the list (incorrect picks), every correct pick was rewarded with a star and a pleasant sound, while every incorrect pick resulted in losing a star and an unpleasant sound. Children were told that the stars indicated how many stickers they would earn, but in reality, they could get as many stickers as they wanted and their caregivers allowed. When children made a *trip* back to the list, any correctly picked items were crossed out to indicate there was no need for them to be picked again. There was no time limit on the task and, crucially, children were told that they could refer back to the list as many times as they wanted.

The key manipulation was the *perceived reliability* of the list. Children were informed of the difference between two conditions with a plausible framing story. In the *reliable* condition, the shopping list icons appeared on an image of a clipboard (to represent the stability of an on-paper list). In the *unreliable* condition, the list icons appeared on an image of an iPad tablet where - kids were told - the battery might die soon (Fig. 1). Consistent with this backstory, in the *reliable* condition, the list was always available when children referred back to it. These trials are referred to as *present* trials. In the *unreliable* condition, in addition to *present* trials, we intermixed *absent* trials to create the impression of unreliability. On *absent* trials, the items on the list disappeared after one or two trips (i.e., the iPad image where the list items had been shown now appeared blank). To remind children of the potential unavailability ("failing battery") of the items in *unreliable* condition, the opacity of the items on the iPad varied randomly from 50 % to 100 % from visit to visit in all trials. Since the disappearance was not immediate, at the outset of any given *unreliable* condition trial, children had no way of knowing which type of trial (*present* or *absent*) they were in. Data from absent trials were not analyzed as they served only to create the impression of unreliability, in order to affect behavior in the *present* trials.

In each trial, the store was presented first. Children only needed to find six out of the ten items on the list in each trial, but this information was not disclosed to the child explicitly. The rationale for this was so that children, throughout the trial, always had a relatively large set of yet-to-be-selected items. After the child reached six correct picks, the trial ended, and feedback appeared, reminding the children how many stars they had earned. A shopping cart button in the corner of the screen allowed children to end a trial early, before having finished selecting items from the store. Children in our sample only ever opted to do this as a way to end the *unreliable*, *absent* trials, after the disappearance of the list.

Conditions were blocked, and each child participated in both conditions, with the order counterbalanced across children. As a reminder of the condition, a clipboard or iPad icon was presented before each trial. Another reminder was provided in the form of the list button (appearing as either a clipboard or an iPad) that children had to press to refer back to the list. Children had practice trials before beginning a condition. Practice trials were identical to test trials except that all elements of the procedure were explained to children during these trials. In the *reliable* condition block, one practice trial was followed by three test trials. In the *unreliable* block, there were two practice trials (the first was a *present* trial, and the second was an *absent* trial with the list disappearing after the first trip) followed by six test trials (three *absent* and three *present*). The order for these six test trials was fixed: 1) *absent* trial (with the list disappearing after the first trip), 2) *absent* trial (with the list disappearing after the second trip), 3) *present* trial, 4) *present* trial, 5) *absent* trial (with the list disappearing after the first trip), and, finally, 6) *present* trial. As mentioned above, data from *absent* trials were not analyzed. In this way, three test trials were included in the analyses from each condition. After the testing session, we showed the two icons that reflected the two different conditions (clipboard or iPad) on the screen of the tablet and asked children two metacognitive questions: "Which game did you think was easier?" ('Easier' question) and "Which game would you play again, to earn more stars?" ('Preferred' question). (Note that we had pre-registered this second question as, "Where would you put your shopping list (clipboard or iPad) if you had to go shopping in the future?" However, early testing with this question revealed that children found it confusing (often requiring further explanation), so we switched to the more straightforward "Which would you play again" phrasing. All data that appear here reflect the revised version of the question.) A typical test session lasted approximately 15 minutes.

3. Measures & analyses

We measured three dependent variables: 1) *Trips* (the number of times children referred back to the list during a trial), indicating children's use of the list, 2) *Dwell Time* (the time a child spent studying the list on each trip), indicating their effort to use working

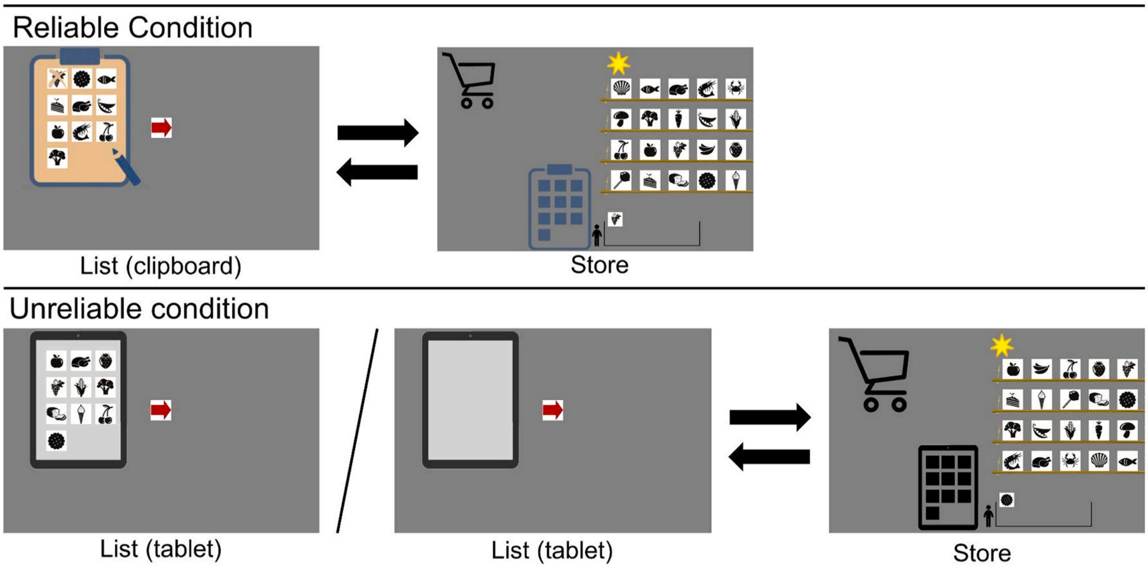

Fig. 1. Schematic overview of the tablet-based Shopping Game. *Note.* In each trial, the store was presented first. Children could then tap on the 'list' icon to make a *trip* to the list, and then tap on the 'store' icon (arrow) to revisit the store. In the *reliable* condition, the items on the list were always present when children visited. In the *unreliable* condition, there were two types of trials. In present trials, the items on the list were always present. In absent trials, the items disappeared (the iPad was blank) after 1 or 2 trips. Absent trials were designed to create an impression of unreliable availability; only present trials were analyzed. (Some on-screen elements are enlarged here for visibility.).

memory, and 3) *Streak Correct* (the length of the run of correct picks before the first incorrect pick (Sahakian et al., 2023) or the end of the current visit to the store after each trip to the list, whichever comes first), indicating memory performance.[2] We expected that children would have more *Trips*, shorter *Dwell Time*, and lower *Streak Correct* in the *reliable* compared to the *unreliable* condition. We fit our data with linear mixed-effect models or generalized linear mixed-effect models.[3] There was no biological sex effect in our measures (see Supplementary Material Table S5); all analyses here are collapsed across sexes. For the main analyses, we fit each response variable with condition (*reliable/unreliable*) as the fixed effect with a by-participant random slope and intercept. To analyze children's responses to the metacognition questions, we compared the ratio of choosing the *unreliable* condition as 'Easier' and 'Preferred' to chance level (50 %) with a binomial test. To explore age effects (these analyses were not preregistered), we fit each response variable with condition, age, and their interaction as fixed effects, with a by-participant random slope and intercept.

4. Results

4.1. Main analyses

Trips showed a significant main effect of condition ($\chi^2 = 6.99$, $p = .008$, $d = 0.43$), revealing more trips to the list in the *reliable*, as opposed to the *unreliable* condition (*reliable*: $M = 4.63$ times, $SD = 1.56$, *unreliable*: $M = 3.88$ times, $SD = 1.30$), suggesting that children used the external resource more often in the *reliable* condition (see Fig. 2. for all main results). For *Dwell Time*, there was also a significant effect of condition ($\chi^2 = 11.46$, $p < .001$, $d = 0.56$), showing a longer Dwell Time on the list in the *unreliable* condition (*reliable*: $M = 3.87$ s, $SD = 2.17$, *unreliable*: $M = 4.79$ s, $SD = 2.95$), indicating that children spent less time and effort memorizing the items on the list when the list was reliably available. There was also a significant difference in *Streak Correct* (*reliable*: $M = 1.52$, $SD = 0.56$, *unreliable*: $M = 1.78$, $SD = 0.61$, $\chi^2 = 13.70$, $p < .001$, $d = 0.62$), showing that children remembered fewer items per trip in the *reliable* condition.

[2] We preregistered *d*' (discriminability) and *C* (criterion/bias) as measures. Due to the low rate of false alarms (<6 %), they could not be properly calculated. For completeness, we provide these analyses in Supplementary Material Tables S1–5; they show the same overall pattern of results.

[3] We fit continuous data (*Dwell Time*, *Streak Correct*) with linear mixed-effect models. We inspected the residuals and, if necessary, used a Box-Cox procedure to transform the response variable to approximate normality easy to interpret lambda when reasonable (e.g., −1, 0, 1, 2). Model selection was based on the distribution of residuals. Count data (*Trips*), were fit with a generalized linear mixed-effect model with a Poisson distribution. We used *R* (R et al., 2023), *Rstudio* (Rstudio Team, 2015), *lattice* (Sarkar, 2008), and *tidyverse* (Wickham et al., 2019) for processing, analysis, and visualization. We ran mixed-effect models with *lme4* (Bates et al., 2015) and *lmerTest* (Kuznetsova et al., 2017), Box-Cox with *MASS* (Venables & Ripley, 2013), model comparison with *car* (Fox & Weisberg, 2018) and *MuMIn* (Bartoń, 2023), post-hoc with *emmeans* (Lenth, 2023), effect size with *effectsize* (Ben-Shachar et al., 2020), and confidence interval with *Hmisc* (Harrell & Dupont, 2023).

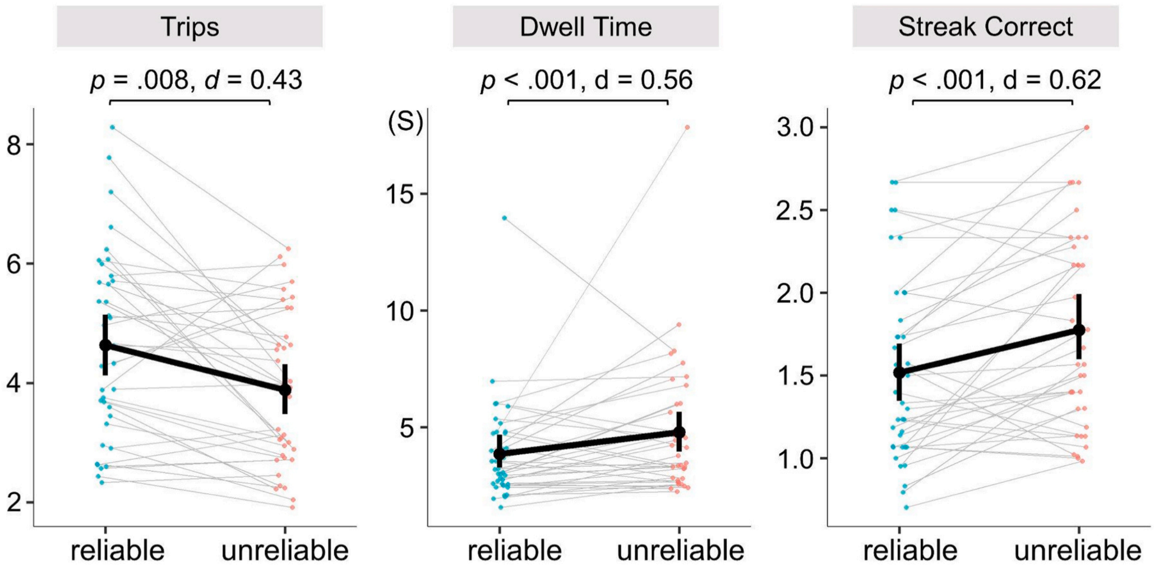

Fig. 2. Individual and group means for the three dependent measures in the two conditions. *Note*. Only *present* trials were included in the *unreliable* condition. Error bars reflect 95 % CIs.

4.2. Metacognition questions

Nearly all children chose the *reliable* condition as *easier* (89.2 %, $p < .001$) and *preferred* (94.6 %, $p < .001$). These results[4] make it clear that children recognized the challenge presented by unreliable external resources.

4.3. Age effects (non-preregistered analyses)

For *Trips,* we found a significant main effect of age ($\chi^2 = 5.86$, $p = .016$, $\eta_p^2 = 0.14$) with older children making fewer trips, but no interaction ($\chi^2 = 1.62$, $p = 0.204$, $\eta_p^2 = 0.04$; see Fig. 3. for all age effects). For *Dwell Time*, we found no evidence for a main effect of age ($\chi^2 = 0.35$, $p = .557$, $\eta_p^2 = 0.0004$), but we found an interaction between age and condition ($\chi^2 = 4.53$, $p = .033$, $\eta_p^2 = 0.11$), with the differences between the conditions increasing with age. As for *Streak Correct*, we found a main effect of age ($\chi^2 = 8.17$, $p = .004$, $\eta_p^2 = 0.14$) with older children remembering more, and an interaction effect ($\chi^2 = 4.05$, $p = .044$, $\eta_p^2 = 0.10$), with the differences between conditions increasing with age.

5. Discussion

Philosophers and psychologists have proposed various theories of how to understand the interaction between the external world (written language, tools) and our internal cognitive processes, such as embodied cognition, embedded cognition, and the extended mind (Clark & Chalmers, 1998; Glenberg, 2010; Hutchins, 1995). What these frameworks have in common is that all of them urge us to replace the traditional view of cognitive processes as entirely internal to the agent with interactive processes between the external world and the internal world, such as working memory (Van der Stigchel, 2020). To fully understand these interactive processes, we should not only study how people use external resources (Armitage et al., 2020; Armitage et al., 2023; Bulley et al., 2020) but also how the agent chooses to strike a balance between external resources versus internal processes in the pursuit of goals in naturalistic settings.

In the current study, we used our Shopping Game paradigm, where 5–6-year-old children searched for items based on a shopping list, to investigate how the reliability of external resources (here, the list itself) affected children's use of those resources versus their own working memory. Consistent with their conceptualization as part of the *Extended Mind* (Clark & Chalmers, 1998; Gallagher, 2018), one's perception of the *reliability* of these resources (will they be there when you need them?) should affect one's *use of* them – just as a weak battery or spotty internet might affect one's interaction with a set of navigation steps. Consistent with previous studies in adults (Kelly & Risko, 2022), we found that children used the list more – referring back to it more often and more briefly, and remembering fewer items – when they perceived the list as reliably available (and vice versa, minimizing trips to the list by studying it longer, and remembering more, when it was perceived as unreliable). An exploratory analysis of age effects showed an overall increase in memory use (fewer trips and more remembered in older children) and, more importantly, a significant interaction effect (in *Dwell*

[4] We had preregistered exploratory analyses on the interaction between conditions and responses to the metacognition questions. However, the near-ceiling performance on the questions meant that the assumptions for these analyses were not met (for completeness, results are presented in Supplementary Material Table S4).

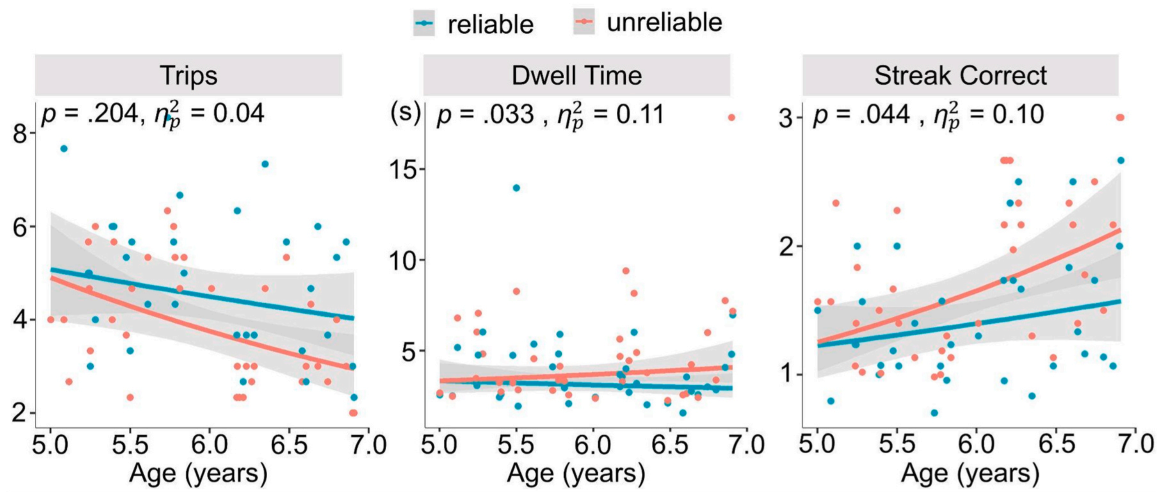

Fig. 3. Age trends for the three measures in the two conditions. Note. Only *present* trials were included in the *unreliable* condition. p values and effect sizes refer to the age x condition interactions. Gray bands reflect 95 % CIs.

time and *Streak Correct*). This provides evidence that children's ability to *adjust* the use of external resources depending on their perceived reliability increases from 5 to 6 years of age.

According to the study-effort hypothesis, maintaining information in working memory is valuable but costly. Therefore, using external resources, when they are reliably available, and access costs are relatively low (Liang et al., in press), is preferable (Kelly & Risko, 2022). To adaptively respond to differing conditions – how reliably available an external resource is, for example – means one needs to be able to assess both the demands of conditions as well as one's own effort. As we reviewed in our introduction, children's ability to opt for, or identify a less demanding task is only beginning to emerge at 5–7 years of age (Niebaum et al., 2019, 2021; Niebaum & Munakata, 2020; O'Leary & Sloutsky, 2017). And, indeed, children at this age put a limited value on products of their efforts (e.g., not willing to 'pay', say by agreeing to a waiting period, to receive a toy they built with their own effort, versus immediately receiving one built by someone else) (Kiefer et al., 2023). However, this is not to say that children are insensitive to demands, or their impact on performance. Young children will selectively seek hints when necessary (Geurten & Bastin, 2019), advantageously skip responses that have a greater likelihood of being incorrect (Balcomb & Gerken, 2008), and correctly anticipate receiving (or not) a performance-contingent reward (James et al., 2021). Even 18-month-olds will adjust their own efforts based on the likelihood of success, as garnered from observing an adult trying to solve a task (Lucca et al., 2020). These studies suggest that there are multiple factors that can facilitate children's monitoring of effort and cognitive demand.

Our study found robust evidence that children not only recognized the challenges posed by an unreliable external resource but also adjusted their cognitive strategies accordingly and almost universally identified the *reliable* condition as 'easier' and 'preferred' (89 % and 94 %, respectively). There are elements of our paradigm that likely facilitated this. In 5–6-year-olds, whether a sensitivity to task demands becomes explicit may depend on the available 'scaffolding'. Visual cues, leading prompts (e.g., "Choose the *easier* task"), and performance feedback can facilitate explicit metacognition (O'Leary, 2017; O'Leary & Sloutsky, 2019; Wang & Bonawitz, 2022). We used a rich set of visual cues (condition-relevant icons) and performance feedback (stars and tones) – all in the context of a simple, naturalistic task – to ensure that children could track what condition (i.e., reliable or unreliable) they were in throughout a trial and block. While the picture of children's metacognitive monitoring and control is still emerging, we speculate that our supportive cues and feedback helped children's implicit metacognition become explicit.

With digital devices literally at our fingertips, the effect of external resources on cognition is a concern for parents, teachers, and governments (CAMRA Act, 2021; Danet, 2020; McGarr, 2024; Sina et al., 2023; Woolford et al., 2023). Understanding how, and when, children use external resources can help educators guide children's use of these resources. While the reliable availability of external resources may diminish internal memory for the material, it does not necessarily mean that it is detrimental to cognition, per se. Instead, it might just decrease one's motivation to engage in effortful cognitive processes (Cecutti et al., 2021). As shown in our results and previous studies with adults (Kelly & Risko, 2022), poorer memory performance when external resources are available was, at least, partly due to a reduction in study time. In addition, while, for instance, saving a file diminished the memory for its content (in adults), it improved content memory for other materials (Storm & Stone, 2015). Moreover, longitudinal studies that followed undergraduates for two years showed that smartphone use is negatively associated with grades, but this association disappeared after controlling for contextually relevant variables (e.g., socioeconomic status, class size, course difficulty, etc.) (Bjerre-Nielsen et al., 2020). When children do store information externally, the memory of how to retrieve the information (i.e., the pointer to the information) remains, and researchers have suggested that critical learning material can be integrated into the pointer itself, such as visual representation or embodied metaphors (Skulmowski, 2023). Ultimately, the key may be to take advantage of the emergence of better and better external resources while avoiding developing an overreliance on them. In relation to education practices, based on our current and previous studies (Liang et al., in press), teachers should emphasize to children the potential negative consequences of an overreliance on external resources and encourage the use of internal memory where it is strategic or necessary to do so – for instance, when those resources might be hard to access, corrupted, or, as in the present study, potentially lost altogether.

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CRediT authorship contribution statement

Erik Blaser: Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Zsuzsa Kaldy:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Yibiao Liang:** Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.cogdev.2025.101542.

Data availability

I have share an link to the data/code in the main text

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