The Role of Object Attention in Relational Mapping Changes Over Development

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Abstract

Relational reasoning develops slowly. Children's difficulty may stem from the difficulty of inhibiting object attention, but the role of object attention in relational reasoning remains unclear. Experiment 1 tested the hypothesized trade-off between processing relational and object information using a novel *match-then-recognize* paradigm. The relational-mapping task required participants to match ordinal positions of objects, followed by an object memory test. In adults, there was a clear trade-off: object recognition was *negatively* correlated with relational mapping. Children's object recognition was lower than adults' but *positively* correlated with relational matching. Experiment 2 further tested the role of inhibition by occluding object matches. Surprisingly, older children and adults actively removed occluders, to their own detriment, whereas the youngest children neither removed occluders nor were helped by them. Findings suggest that selective attention can be crucial for relational reasoning, but ignoring object information may be less important for success than total allocated attention.

Keywords: cognitive development; relational reasoning; object attention; analogy

Introduction

Relational reasoning requires understanding how elements relate to one another rather than focusing on individual elements. Such reasoning is essential for learning and problem-solving. An ordered series of elements, such as numbers on a number line organizes spatial search in ordinary life. For example, when navigating to the address of a library down the street, the remaining blocks to walk can be related to the difference in location between two numbers on the number line. When navigating to a book by its call number, the location of the book on its shelf can again be related to the difference between two numbers on the number line. When finding a specific page in that book, the number of pages to flip can be approximated by mapping the thickness of the book to the total number of pages. In all these cases, mapping numerical to spatial relations involves ignoring many individual elements. If a specific building, book, or sentence captures one's attention along the way, progress toward the goal will be delayed.

Identifying relational similarities across superficially different domains is also crucial for analogy. Structure-mapping theory explains that transfer across domains relies on identifying and aligning relational similarities, not shared features of individual objects or superficial resemblances (Gentner, 1983).

Young children often struggle with relational reasoning. Rather than concentrating on relations, they are often distracted by the features of individual items. For example, three-year-old children can typically retrieve a full-sized toy from the corresponding location in a full-sized room after observing a miniature toy hidden in a scale-model room (DeLoache, 1987, 1991). But if the corresponding objects differ perceptually (e.g., mapping a gray miniature chair to a blue full-sized chair), they struggle and fail to match them during retrieval (Marzolf & DeLoache, 1994). Similarly, in a relational mapping task where the to-be-mapped locations had different features, five-year-olds struggled, showing a bias toward choosing visually matching objects instead of relationally matching objects (e.g., [green card] *at the top* - [red card] *at the top*; Loewenstein & Gentner, 2005).

Therefore, analogical reasoning ability in young children is thought to improve through a perceptual-to-relational shift, wherein children gradually move from focusing on surface similarities to attending to deeper relational structures (Gentner, 1988; Rattermann & Gentner, 1998). Several accounts have been proposed to jointly contribute to this developmental shift, including the accumulation of relational knowledge and improvements in executive functions—specifically, enhancements in working memory and inhibitory control (Richland, Morrison, & Holyoak, 2006; Gentner & Smith, 2013; Richland & Burchinal, 2013). When perceptually similar but relationally irrelevant distractors are present, the ability to inhibit object matches becomes critical. From this perspective, as children's inhibitory control strengthens, their tendency to rely on object-matching should diminish, giving way to increased reliance on relation-based reasoning.

Although structure-mapping theory and the perceptual-to-relational shift hypothesis are surely right to emphasize the importance of relational similarities, it seems unlikely that development consists merely of learning the right allocation of the same amount of total attentional resources. Rather, the total attentional resources of an adult is likely to be greater than that of a child. While the typical relational-match-to-sample paradigm can assess *selective* attention to relations, it cannot assess the *total* amount of attention. What is required is a direct, independent measure of object attention. Further, removing any need for inhibition would provide an especially robust test of the theory, as one would expect such manipulation to improve children's relational mapping.

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The present study

To address these issues, a novel *match-then-recognize* paradigm was designed to measure processing of relational and object information independently. Participants first matched elements in two cross-mapped arrays based on their ordinal positions. This relational matching task was followed by an object recognition task that tested memory for the objects from the relational matching task. If objects were unattended, it is highly unlikely they could be remembered. This paradigm is adapted from Sloutsky and Fisher's (2004) induction-then-recognition paradigm, which examined developmental changes in categorization.

This paradigm has separate measures of relational and object processing, enabling assessments of whether neither, either, or both types of information were processed. From structure-mapping theory, we would expect a negative association between correct relational matching and correct object recognition. From the perceptual-to-relational shift account, we would expect developmental change. Adults would be expected to succeed in matching the elements by ordinal relations while not remembering which items appeared. In contrast, young children would be expected to struggle with matching but recognize the objects. Overall, a negative association between relational mapping and object recognition would be expected.

Experiment 2 examined whether inhibiting perceptual commonalities is necessary to extract relational commonalities. Items in the matching array were hidden behind occluders ("boxes"), thereby presenting no object matches to inhibit. Without the need for inhibition, participants, especially young children, would be expected to improve their relational reasoning. Our task provided participants the option to reveal objects by removing occluders; the number of taps measured their active search for object information and, conversely, avoidance of distraction. Greater tapping was expected to correlate with better object memory but lower matching accuracy, reflecting a trade-off between processing object details and extracting relational structure. This test is similar to one used by Wan and Sloutsky (2024) to examine the distribution of attention during categorization. A cost/no-cost manipulation was also introduced; the cost condition discouraged tapping. By offering no object matches to inhibit and discouraging active exploration, the cost condition of Experiment 2 was expected to yield the highest levels of successful relational matching.

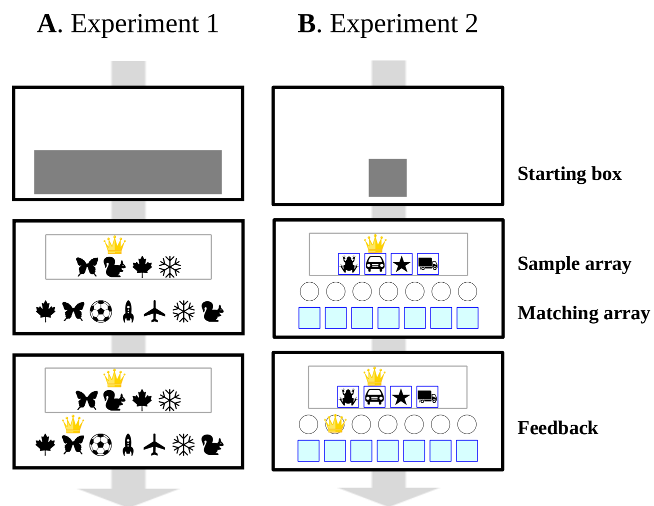

Figure 1: Procedure for the relational mapping task in Experiments 1 and 2. Participants matched elements in two arrays based on their ordinal locations. In Experiment 2, the matching array was initially hidden behind boxes. Participants could reveal one or more boxes by tapping, although this was not necessary. A cost/no-cost manipulation was implemented: in the cost condition, a progress bar at the bottom of the screen displayed the participant's current points, with each tap deducting one point. In the no-cost condition, participants could tap freely.

Experiment 1

Participants

Participants included 112 3- to 12-year-olds (age range: 3.14 – 12.50, $M = 6.84$, $SD = 2.12$; 57 male, 54 female) and 46 adults ($M = 19.07$, $SD = 0.68$; 17 male, 28 female). Seven additional children were discarded (four for incompletion and three for not being fluent in English). The sample size was determined by power analysis of a pilot test of 28 children.

Children were recruited at a local museum (Center of Science and Industry, Columbus, Ohio). Immediately after parental consent, they were tested individually in a quiet corner. Adults were college students enrolled in an introductory psychology course. They were tested individually in the laboratory. The study was approved by The Ohio State University Institutional Review Board (2005B0192, 2022B0344).

Stimuli and Procedure

A *match-then-recognize* paradigm was administered, with a relational mapping task followed by an object recognition task. Tasks were presented using a 13.5-inch laptop with a touch screen (Surface Laptop; 2256 × 1504 pixels) with PsychoPy3 (version 2022.1.2). Stimuli were 24 black-and-white pictures of different objects (e.g., apple, duck, squirrel).

Relational mapping task The task was adapted from a previous relational matching paradigm (Loewenstein & Gentner, 2005; Opfer, Thompson, & Furlong, 2010). In the current task, given a "winner" in the sample array, participants needed to find the "winner" in the matching array. Winners always had the same ordinal position from left to right. The matching rule was not explicitly revealed to participants; the rule had to be learned through trial and error, with an ordinal label provided to aid learning.

At the beginning of a trial, a gray box was presented at the center of the screen (Figure 1A). After being touched, a

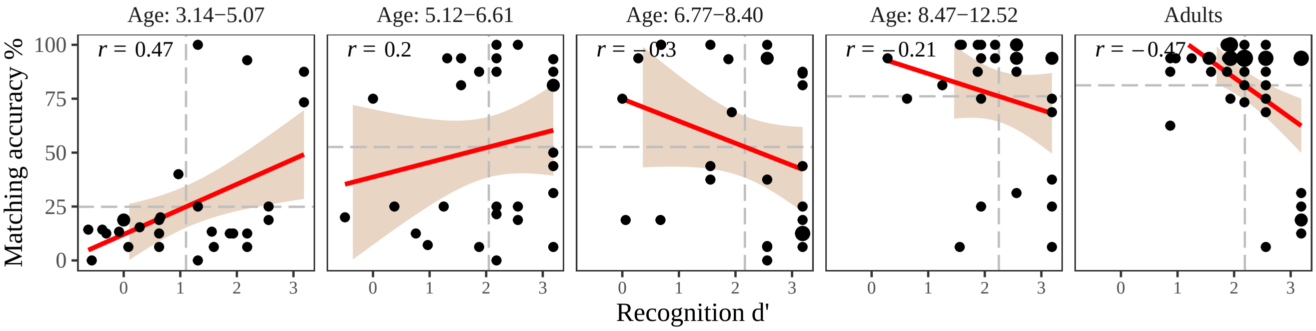

Figure 2: Experiment 1. In children, recognition sensitivity positively predicted matching accuracy, with the relationship shifting to negative as age increased. However, in adults, recognition sensitivity negatively predicted matching accuracy. Children were grouped by age quantiles for plotting purposes. The dot size indicates the number of observations, and gray dashed lines represent the group average of matching accuracy or recognition sensitivity.

sample array and a matching array appeared simultaneously. One of the objects in the sample array was marked by a crown to indicate the winner, accompanied by auditory instructions, e.g., "The second is the winner. Which is the new winner?". Then, participants were required to choose one object in the matching array. After they chose, another crown appeared for two seconds at the correct location with sound as feedback (if correct: high pitch beep; if wrong: low pitch beep; lasting 500 milliseconds).

Sixteen pictures were randomly chosen from the repertoire for each participant, composing 16 trials in total. In each trial, the sample array consisted of four different pictures, with one marked as the winner by a yellow crown. The winner (i.e., crown) appeared at each place (first, second, third, and fourth) four times in random order across trials. The matching array consisted of seven different figures, four identical to those in the sample array but in a different order. A conflict between the number-matching and object-matching items in the matching array was ensured so that the correct option in the matching array always differed from the "winner" picture in the sample array (e.g., squirrel vs butterfly).

Recognition task Immediately after the relational matching task, a recognition test was conducted. Eight out of 16 pictures that appeared in the matching task and eight novel pictures were presented one by one in random order. Participants were asked if they saw it in the matching task. No feedback was given in this test.

Results

All analyses were performed in R (version 4.3.1). Trials with extremely fast response time (RT) were removed from the analysis (Relational Matching: RT $<$ 1 second, children, 1.59%, adults, 0.14% of the trials; Object Recognition: RT $<$ 650 millisecond, children, 1.37%, adults, 0%, of the trials).

Children Relational matching performance was first analyzed using trial-by-trial data from the matching task through logistic regression analyses. Children's matching accuracy increased with trial number and age (both treated as continuous variables; age in years), with participant as a random factor (Trial number: odds ratio (OR) = 1.16, 95% CI: [1.12, 1.20], $p < 0.001$; Age: OR = 1.92, 95% CI: [1.55, 2.41], $p < 0.001$). Trial number and age also interacted (OR = 1.04, 95% CI: [1.03, 1.06], $p < 0.001$). Thus, children learned the matching rule with experience, and relational matching performance and learning efficiency increased with age.

To investigate the role of object attention in relational mapping, we regressed subject's matching accuracy on their recognition sensitivity (d' in signal detection theory; 0 indicates no discriminability between old and new items) and age. Overall, there was a positive association between age and matching accuracy ($b = 8.89$, $t = 6.08$, $p < 0.001$, $r = 0.50$) and a positive association between recognition and matching accuracy ($b = 7.23$, $t = 2.29$, $p = 0.024$, $r = 0.21$). But when considering both, only age accounted for a significant amount of variation. Moreover, there was an interaction between age and recognition in predicting matching accuracy ($b = -3.25$, $t = -2.29$, $p = 0.024$; Figure 2)—With the increase of age, the positive correlation between matching and recognition in young children shifted toward a negative correlation.

To examine whether children's performance differed from chance and to assess developmental trends, children were divided into four age quantiles. Results showed that children in the youngest age group performed at chance level on the matching task, whereas children in the remaining three age groups demonstrated above-chance performance (accuracy in percentage; chance = $1/7 \times 100$; 1st quantile: $M = 24.89$, $t_{27} = 2.02$, $p = 0.054$, Cohen's $d = 0.38$; 2nd-4th quantile: $ps < 0.001$, Cohen's $ds > 1$; Figure 2). Average object matching was also examined, showing that children in the youngest quantile chose the object-matching items above chance while the rest of the children were at or significantly below chance level (1st Qu.: $M = 22.39$, $t_{27} = 2.21$, $p = 0.036$, Cohen's $d = 0.42$; 2nd Qu.: $M = 10.58$, $t_{27} = -1.83$, $p = 0.079$, Cohen's $d = 0.35$; 3rd Qu.: $M = 4.32$, $t_{27} = -11.26$, $p < 0.001$, Cohen's $d = 2.13$; 4th Qu.: $M = 5.13$, $t_{27} = -8.20$, $p < 0.001$, Cohen's $d = 1.55$).

In addition to learning the ordinal matching rule, we also examined the first trial when no feedback was provided. None of the subgroups chose the correct number-matching item above chance (ps > 0.05). Although they have heard ordinal numbers, older but not younger children chose the object-matching items above chance on the very first trial (1st Qu.: $M = 30.77$, $t_{27} = 1.79$, $p = 0.086$, Cohen's $d = 0.35$; 2nd Qu.: $M = 32.14$, $t_{27} = 1.99$, $p = 0.057$, Cohen's $d = 0.38$; 3rd Qu.: $M = 40.74$, $t_{27} = 2.75$, $p = 0.011$, Cohen's $d = 0.53$; 4th Qu.: $M = 46.43$, $t_{27} = 3.35$, $p = 0.002$, Cohen's $d = 0.63$). This suggested that younger children did not have prior beliefs to form hypotheses to test at the beginning, whereas older children, shaped by greater everyday experiences, were able to test the hypothesis of object matching (Landau, Smith, & Jones, 1988).

Adults In adults, trial-by-trial matching accuracy was also predicted by trial number (OR = 1.45, 95% CI: [1.33, 1.59], $p < 0.001$), suggesting they were learning the matching rule. On average, they succeeded in the matching task ($M = 81.21$, $SD = 26.00$, $t_{45} = 17.46$, $p < 0.001$, Cohen's $d = 2.57$) while avoided choosing object-matching items (object-matching %: $M = 5.72$, $SD = 3.92$, $t_{45} = -14.84$, $p < 0.001$, Cohen's $d = 2.19$).

Regarding the relationship between relational matching and object recognition, adults showed a significant negative association ($b = -18.80$, $t = -3.57$, $p = 0.001$, $r = -0.47$; Figure 2), suggesting that the mature capacity of relational matching does involve selectively attending to relational information and ignoring irrelevant object information.

In terms of the initial choices in the first trial, adults' responses were aligned with older children—Most of them preferred the object-matching item instead of the number-matching item, though both were above chance and together comprised almost all the responses (object-matching %: $M = 63.04$, $SD = 48.80$, $t_{45} = 6.78$, $p < 0.001$, Cohen's $d = 1.00$; number-matching %: $M = 28.26$, $SD = 45.52$, $t_{45} = 2.08$, $p = 0.043$, Cohen's $d = 0.31$).

Discussion

In a paradigm combining relational matching and object recognition, children learned to match two arrays based on ordinal position through corrective feedback. Learning accuracy and speed increased with age. More importantly, 3- to 6-year-olds' memory of objects, which were irrelevant to matching, was positively correlated with matching accuracy. This positive association turned negative as age increased. Adults, who performed the matching task near ceiling levels, showed a robust negative association between matching and recognition.

Moreover, the role of object attention in relational mapping does not simply reflect differences in overall task performance. When data were collapsed across age, object recognition did not significantly predict matching accuracy at either end of the performance spectrum (with a cut-off around 50%, given the bimodal distribution of matching accuracy; for participants with matching accuracy $> 50\%$, $r = -0.025$, $p = .811$; for those $\leq 50\%$, $r = 0.224$, $p = .071$). These results suggest that high- and low-performing participants did not differ systematically in how they attended to object features; instead, developmental factors seem to underlie the observed shift—from leveraging object information to effectively suppressing it during relational mapping.

These results demonstrate a continuous developmental trajectory in relational reasoning, from children as young as three years old to college-aged adults. On one hand, mastering relational reasoning requires focusing on relational information while ignoring object information, as suggested by the perceptual-to-relational shift hypothesis. On the other hand, processing object information—typically viewed as the main cause of children's failure in relational reasoning tasks—appeared to facilitate relational reasoning in young children. The results suggest that when relational reasoning is most challenging to children, increasing total attention (not just attention to relations) may be necessary. In Experiment 2, we further tested this account for a situation in which irrelevant information did not need to be inhibited.

Experiment 2

Participants

Fifty-three children (age range: $2.89 - 10.40$, $M = 7.09$, $SD = 2.02$; 27 male, 26 female) and 33 adults ($M = 19.65$, $SD = 2.47$; 5 male, 27 female) were included in Experiment 2. They were recruited from the same pool of participants and followed the same procedure as in Experiment 1.

Stimuli and Procedure

The stimuli and the procedure were the same as those in Experiment 1, except for the additional hidden box manipulation. Unlike Experiment 1, where all items were visible, in Experiment 2, items in the matching array were occluded (Figure 1B). Participants were told that the blue boxes were hiding some toys, and one of them was the winner. They were allowed to tap the boxes to remove the occluder. The untapped boxes would not be revealed in the feedback phase.

We additionally included a cost condition, where removing occluders cost one point and selecting the correct option rewarded five points. Thus, the no-cost group could explore freely and reveal boxes without restriction, whereas the cost group would be unable to reveal more boxes once their points reached zero. Participants in the no-cost group started with 15 points. If they tapped every box without selecting the correct winner, they were forced to choose the winner with the boxes covered starting at the third trial.

Results

Trials with extremely fast RTs were removed from the analysis (Object Recognition: RT < 650 millisecond, children, 1.53%, adults, 0.38%, of the trials).

The findings in Experiment 1 was replicated—there was a significant interaction between age and recognition sensi-

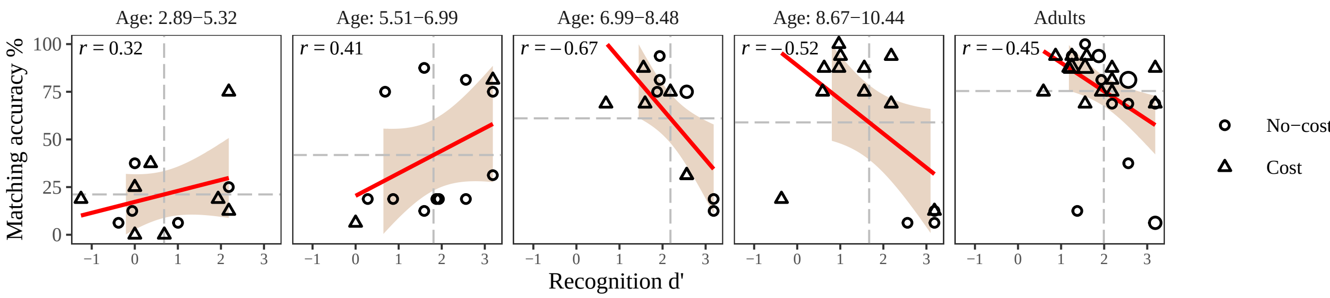

Figure 3: Experiment 2. Among young children, better recognition was associated with better relational matching, whereas in older children and adults, better recognition was associated with worse relational matching. Children were grouped by age quantiles for plotting purposes. The dot size represents the number of observations. Gray dashed lines indicate the group's average measures.

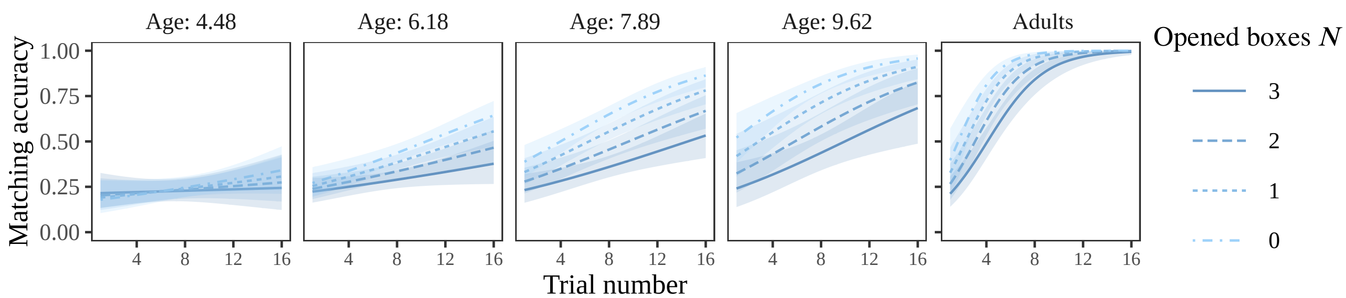

Figure 4: Experiment 2. Estimated matching accuracy as a function of age, trial number, and the number of revealed boxes—matching accuracy and learning speed declined as participants tapped more boxes to reveal irrelevant object information, with this effect strengthening with age.

tivity in predicting matching accuracy. Specifically, the relationship between recognition sensitivity and matching accuracy shifted from positive to negative as children's age increased (interaction: $b = -3.84$, $t = -2.24$, $p = 0.030$; Figure 3). The negative association persisted into adulthood ($b = -14.90$, $t = -2.77$, $p = 0.009$, $r = -0.45$; Figure 3).

To investigate information-seeking actions and the amount of distracted information resulting from these actions, we calculated the average number of boxes opened per trial for each participant. In children, there was a main effect of the cost condition on the number of boxes opened, with the cost group uncovering fewer boxes than the no-cost group (cost: $M = 0.78$, $SD = 0.66$; no-cost: $M = 2.04$, $SD = 2.20$; $t = -2.88$, $p = 0.006$). An interaction between condition and age was also observed ($b = -0.72$, $t = -3.24$, $p = 0.002$)—as age increased, the cost group sought less irrelevant information, while the no-cost group sought more irrelevant information. In adults, the cost group also opened fewer boxes than the no-cost group (cost: $M = 0.73$, $SD = 0.65$; no-cost: $M = 2.77$, $SD = 2.41$; $b = -2.04$, $t = -3.27$, $p = 0.003$), and the number of boxes opened in the no-cost condition was comparable to that of 8-year-old children. Thus, participants were quite sensitive to the cost of seeking information. Surprisingly, without restrictions, older children and adults explored object information, even though it was irrelevant to the task.

Crucially, we examined whether the demand for inhibition interferes with relational matching. When controlling for age, children in the cost group showed worse object recognition than those in the no-cost group ($b = -0.77$, $t = -2.68$, $p = 0.010$). Although matching accuracy was higher in the cost group, it did not significantly differ from the no-cost group ($b = 8.93$, $t = 1.07$, $p = 0.288$). Similar results were observed in adults (cost effect on Recognition: $b = -0.53$, $t = -2.19$, $p = 0.036$; on Matching: $b = 15.95$, $t = 1.94$, $p = 0.062$).

In addition, the more boxes participants opened, the better they remembered the objects (Children: $b = 0.23$, $t = 2.79$, $p = 0.007$; Adults: $b = 0.18$, $t = 3.32$, $p = 0.002$); the more boxes they opened, the worse they performed on the relational matching task (Children: $b = -9.04$, $t = -4.39$, $p < 0.001$; Adults: $b = -9.73$, $t = -7.63$, $p < 0.001$, $r = -0.81$). However, in children, the effect of having more irrelevant information on decreasing matching accuracy was absent in younger children but became more pronounced with increasing age (box×age interaction: OR = 0.89, 95% CI: [0.85, 0.93], $p < 0.001$; 1st quantile by age: $r = 0.09$, $p = 0.761$; 2nd Qu., $r = -0.39$, $p = 0.194$; 3rd Qu., $r = -0.80$, $p = 0.001$; 4th Qu., $r = -0.72$, $p = 0.004$; Figure 4).

The number of tapped boxes and trial number also interacted in predicting matching accuracy (Children: OR = 0.98, 95% CI: [0.96, 0.99], $p = 0.010$; Adults: OR = 0.94, 95% CI: [0.90, 0.96], $p < 0.001$), indicating that revealing boxes not only decreased accuracy but also slowed down the learning of the matching rule.

Discussion

Experiment 2 replicated the major findings of Experiment 1 and further tested whether difficulties in relational reasoning are tied to challenges in inhibition. Despite reduced irrelevant object information in Experiment 2, matching accuracy did not improve compared to Experiment 1; performance in the no-cost condition was even marginally worse (Children: $b_{cost-exp1} = -3.67$, $t = -0.54$, $p = 0.592$; $b_{noCost-exp1} = -11.84$, $t = -1.71$, $p = 0.088$. No interaction with age. Adults: $b_{cost-exp1} = 2.38$, $t = 0.33$, $p = 0.744$; $b_{noCost-exp1} = -13.57$, $t = -1.91$, $p = 0.060$). However, a strong negative association emerged between revealed irrelevant information and matching accuracy, absent in young children but pronounced in older children and adults.

If inhibiting irrelevant information were crucial for extracting relational structures, younger children with developing inhibitory control should have benefited most from the simplified environment. This was not observed. The positive association between object recognition and relational matching in young children again suggests that extracting relational similarities is aided by processing some perceptual information. Conversely, for older children and adults, redundant, task-irrelevant information hinders ordinal relation processing and relational mapping. Yet, they still sought irrelevant information in the no-cost condition. This suggests that the role of inhibition may shift with age: younger children rely more on perceptual exploration, while older individuals refine their ability to ignore distractions for efficient relational reasoning.

General Discussion

Two experiments employed a relational mapping task followed by an object recognition task to investigate how children and adults process task-relevant relational information and task-irrelevant object information during relational matching. A novel feature of our test is that these measures were independent, unlike previous relational matching tasks, which infer object attention from choices of critical lures (Loewenstein & Gentner, 2005; Richland et al., 2006).

Consistent with the relational shift account and the competition hypothesis, a negative association between correct relational matching and object recognition was observed in older children and adults. The strength of this negative association was similar between Experiment 1, where object matches could have been inhibited, and in Experiment 2, where object matches were actively sought out during exploration. The finding highlights the importance of prioritizing relational information, a key predictor of children's proficiency in analogical reasoning (Starr, Vendetti, & Bunge, 2018).

Contrary to the predictions of the perceptual-to-relational shift account, however, we observed a positive association between object recognition and matching in younger children—roughly under 6.45 years old in Experiment 1 and 6.34 years old in Experiment 2. Results suggest that when selective attention is not yet sufficiently developed to filter out task-irrelevant information, young children benefit from processing a broader range of information. Not only that, in Experiment 2, when the amount of task-irrelevant information was manipulated, young children's relational matching did not improve with less distraction.

Findings contradict the idea that ignoring irrelevant information is the mechanism by which young children achieve relational reasoning. Instead, with limited prior knowledge and an ambiguous problem solution, gathering more information—regardless of relevance—seems the only viable way to approach the solution, especially when it is uncertain which type of information is critical. Strategically avoiding irrelevant information, a skill that adults do not always perfect, would be effortful for children to learn. Consequently, at an early age, inhibition may be less important than an active, distributed search that can update a limited working memory (Simms, Frausel, & Richland, 2018; Starr et al., 2023)—even if it involves attention to the irrelevant.

Our findings are also broadly supportive of the idea that close literal matches can serve as stepping stones to achieving abstract relational matching. In work on "progressive alignment", surface similarities between corresponding elements are found to encourage comparison and thus help extract relational structures (Gentner & Smith, 2013). This finding has important theoretical and educational implications, especially in mathematics which attempts to teach children novel relational structures (Kotovsky & Gentner, 1996; Thompson & Opfer, 2010; Yu et al., 2022). Our finding that young children's attention to task-irrelevant details can be beneficial supports this key idea about why progressive alignment promotes relational reasoning.

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