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Children's Darting (Not Diffuse) Attentional Spotlight Reduces Memory Selectivity for Relevant Content

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ABSTRACT

Why do children remember distracting details better than adults? This could be a silver lining—a benefit—of children's immature attention. The present work establishes this link between immature selective attention and children's broader learning. Furthermore, it adjudicates between two ways that immature attention could drive children's broad learning. One possibility is that children have a "diffuse" attentional spotlight, meaning irrelevant information "leaks" into long-term memory as children learn about relevant information. Alternatively, children's attention might dart *between* relevant and irrelevant information across time. While both mechanisms would broaden learning, only diffuse attention would facilitate memories for relevant and irrelevant information from the *same* event and associations between them. In a sample of children and adults ($n = 130$), we find clear evidence that immature attention underlies children's reduced memory selectivity for relevant content. Furthermore, relevant and irrelevant information from the *same* event were associated in adults' memory but not children's. We also observed that children learned about targets and distractors from *different* events, a pattern consistent with the idea that children's attention is more likely to dart than diffuse across items. Children's immature and darting attention may, therefore, explain why they remember "distracting" information better than adults.

1 | Introduction

Adults tend to learn selectively about relevant information, whereas children learn more equally about relevant and irrelevant information (Blanco et al. 2023; Blanco and Sloutsky 2019; Deng and Sloutsky 2016; Plebanek and Sloutsky 2017). This broader learning is widely thought to underlie children's learning advantages in diverse domains like statistical and language learning (Chrysikou et al. 2014; Deng and Sloutsky 2016; Gualtieri and Finn 2022). But why is children's learning so broad? One possibility is that immature selective attention produces paradoxical learning advantages. Indeed, it has been proposed that children have a more "diffuse" attentional spotlight, where attention spreads more evenly across relevant and irrelevant information (Blanco et al. 2023; Deng and Sloutsky 2016; Gopnik et al. 2017; Gualtieri and Finn 2022; Plebanek and Sloutsky 2017). Despite the explanatory power of this possibility, there are gaps in evidence supporting it. Moreover, and equally surprising, only one study has linked selective attention to developmental differences in memory selectivity (Blanco et al. 2023). Further, none have tested

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Summary

- Children have broader learning than adults because their immature selective attention enhances memory for irrelevant information.
- Patterns in memory data suggest children's attention darts between relevant and irrelevant information over time rather than diffuses across items in an event.
- Children learn about targets and distractors from different events.
- Unlike adults, children do not form associative memories between relevant and irrelevant information within the same event.

key predictions emblematic of having a more diffuse attentional spotlight–namely, that children will form memories for relevant and irrelevant information presented in the same event and even form associative links between them.

While children have less selective attention (Hanania and Smith 2010; Plude et al. 1994) and reduced memory selectivity compared to adults (Blanco and Sloutsky 2019; Deng and Sloutsky 2016; Plebanek and Sloutsky 2017), these aspects of cognition tend to be examined in separate studies, leaving open questions about how they relate. Regarding selective attention, children display greater distractor interference in visual (Enns and Girgus 1985; Plude et al. 1994) and auditory domains (Doyle 1973; Geffen and Sexton 1978). This greater interference is thought to be linked to reduced inhibitory control in children than adults (Aslan and Bäuml 2010; Pritchard and Neumann 2011; Tipper et al. 1989). Children also learn more about irrelevant features of items (Plebanek and Sloutsky 2017) and contexts (Frank et al. 2021) and rely more on irrelevant information during categorization (Blanco and Sloutsky 2019; Deng and Sloutsky 2016). One study aimed to link this literature, showing that children fixated on irrelevant cues more than adults, which boosted their category learning performance relative to adults when previously irrelevant information became relevant (Blanco et al. 2023). However, in this study, children had to learn through trial and error where to look for relevant information, making it unclear whether less selective attention or a lack of knowledge about where to find relevant information broadened learning. Linking children's broader learning with measures of attention in a task where children are explicitly informed about which information is relevant would more strongly test whether less selective attention broadens learning.

Furthermore, the dynamics through which selective attention might broaden learning remain unexamined. One possibility is that children have a "diffuse attentional spotlight," implying that attention is spread across relevant and irrelevant information within a single event (Blanco et al. 2023; Deng and Sloutsky 2016; Gopnik et al. 2017; Gualtieri and Finn 2022; Plebanek and Sloutsky 2017). However, an alternative is that children's attention is every bit as narrow as adults', but darts more indiscriminately between relevant and irrelevant information across time. This darting could occur because children are more exploratory (Gopnik et al. 2017), or lack the cognitive control to keep focused (Bunge et al. 2002). Because these dynamics would lead to very different memories, one strategy to disentangle them is to examine the content of memory for individual events. With a narrow attentional spotlight that darts across time, children would learn about irrelevant details at the expense of relevant details from the same event. Conversely, with a diffuse attentional spotlight, irrelevant information would "leak" into memory while children learn relevant information, resulting in no trade-off between memories for relevant and irrelevant information from the same event. Additionally, diffuse attention could allow relevant and irrelevant information from the same event to be linked in memory.

While these possibilities have not been teased apart in children, strategies used to study older adults' memory provide a roadmap. Like children, older adults excel at learning task-irrelevant content (Amer et al. 2020; Campbell et al. 2010; Rowe et al. 2006; Weeks and Hasher 2018). This phenomenon has been linked to diffuse attention by leveraging patterns in event-specific memory. For example, older adults more often recall irrelevant content from events from which they also learn relevant content (James et al. 2016). These distinct event features can become bound in memory: when older adults see relevant information, it hastens the recall of previously related irrelevant information (Amer et al. 2020; Campbell et al. 2010; Rowe et al. 2006; Weeks and Hasher 2018). Similar insights have not been possible in children as most relevant studies focus on the cumulative learning of category structure across many experiences (Blanco et al. 2023; Blanco and Sloutsky 2019; Deng and Sloutsky 2016), masking which content was learned at which moment.

Here, we tested whether reduced selective attention in children explained developmental differences in memory selectivity. We then leveraged children's individual memories to examine whether patterns were most consistent with the diffuse or darting spotlight account. We focused on 7–9-year-old children because selective attention is still developing in this age range (Di Chiaro and Holmes 2024; Hugdahl and Andersson 1986; Jung et al. 2023; Plebanek and Sloutsky 2019; Plude et al. 1994; Reuter et al. 2019; Reynard et al. 2023). Furthermore, research on children's memory selectivity focuses on 4–5-year-olds (Deng and Sloutsky 2016; Plebanek and Sloutsky 2017). Therefore, this study will provide novel insights into older children's memory.

Children and adults performed an n-back task—calibrated to their working memory abilities—to detect repeats in the attended target category while ignoring superimposed images from a distractor category (Figure 1). To measure individual differences in selective attention, we assessed how (to-be-ignored) repeats of distractor images influenced accuracy and response times (RT) on the n-back task. After the n-back, participants completed a surprise recognition memory test for targets and distractors. We probed memory selectivity by assessing how much better later recognition memory was for n-back targets than distractors. Furthermore, to adjudicate between a narrow darting versus diffuse attentional spotlight, we examined recognition memory trade-offs between targets and distractors from the same n-back trials. With a narrow and darting spotlight, children should show broad learning of targets and distractors across the task, but trade-offs on individual trials, such that recognition memory for

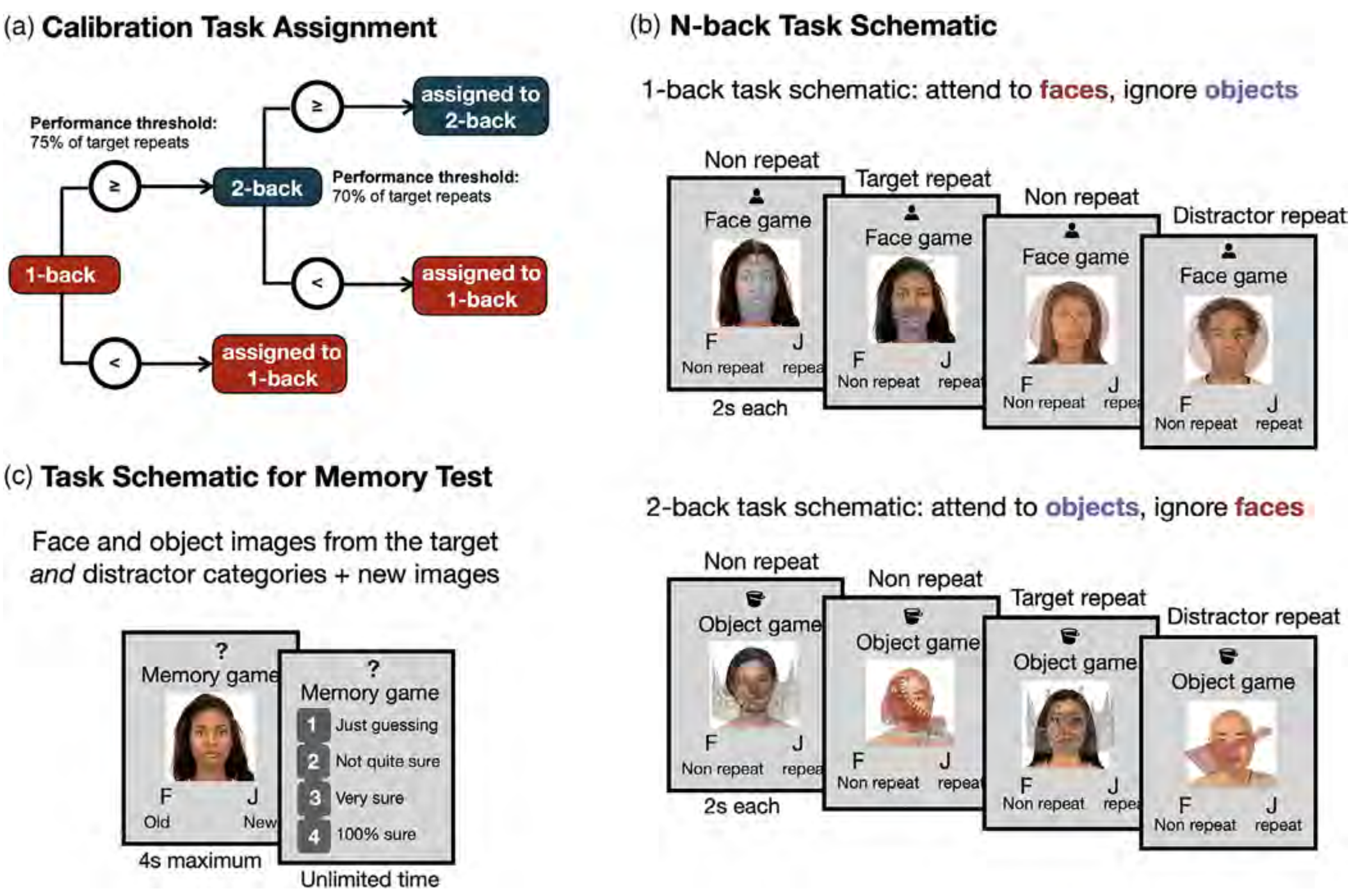

FIGURE 1 | Experimental design. (A) A schematic depicting calibration task assignment to the 1- and 2-back levels. (B) After the calibration n-back task, participants completed the primary n-back task. They viewed an image of an object superimposed on an image of a face and tried to detect when images from the relevant category repeated while ignoring images from the irrelevant category. Participants completed one block in which faces were the relevant category and another in which objects were the relevant category. For illustration purposes, we depicted a 1-back in which faces are the target (top panel) and a 2-back in which objects are the target (bottom panel). (C) After the primary n-back task, participants completed a surprise recognition memory test, in which we probed memory for target and distractor images from the primary n-back task. Participants indicated whether each image was old or new and rated their confidence on a 4-point scale.

distractors is better from n-back trials where targets were not learned. By contrast, a diffuse spotlight predicts broad learning, with little or no trade-off in learning targets and distractors from the same n-back trial; that is, recognition memory for targets and distractors from the same n-back trial would be unrelated, or even positively correlated, reflecting diffuse attention. We also examined if participants formed associative memories for target-distractor pairs from the same event—a phenomenon that could be facilitated by diffuse attention.

2 | Methods

2.1 | Participants

Ninety-five children aged 7–9 years and 80 adults aged 18–35 years participated in this online experiment. Adult participants were undergraduates, while children were recruited through the university's Child Study Centre, Facebook ads, and outreach activities. Undergraduates received course credit. Children and their parents were compensated with $10 CAD via PayPal or a gift card. All participants had normal or corrected-to-normal vision, and participants or parents provided written informed consent/assent. The local ethics committee approved all experimental procedures. Before analyzing the data, we excluded 34 children and 11 adults who met one or more pre-registered exclusion criteria: missed more than 25% of trials during the n-back task or recognition memory test, detected fewer than half of target repeats in *both* n-back blocks, low memory performance (i.e., d prime [d'] scores < 0), and/or technical errors that led to unsaved data. The percentage of the sample excluded is similar to what has been reported in prior online studies (Scott and Schulz 2017).

Prior to collecting data, we performed a power analysis on data from several pilot studies (total $n = 37$ children, 39 adults). These pilot studies are described separately (Decker 2022). We simulated power by resampling data across 5000 iterations using the *simr* package in R (R Development Core Team 2011). These simulations revealed that 55 participants per age group would provide 90% power to detect developmental differences in memory selectivity ($p < 0.05$, two-tailed). As pre-registered, however, we over-recruited beyond our target sample in anticipation of having to exclude a higher number of children based on performance in our pilots and previously published online developmental studies (Scott and Schulz 2017). The final sample included 61 children and 69 adults. Data was not analyzed until the final sample size was achieved.

2.2 | Stimuli

Stimuli can be found on the Open Science Framework(OSF) and were images of faces (n = 191), animals (n = 75), and objects (n = 116). All the animal images and a subset of face images were included in the practice and calibration n-back task (*practice:* n = 4 faces, n = 4 animals*; calibration*: n = 71 faces, n = 71 animals). The remaining faces (n = 116) and all the objects were included in the primary n-back task and recognition memory test. Stimuli in the primary n-back and recognition memory tasks were counterbalanced across participants such that each image had an equal likelihood of being an n-back target or distracter or being an old or new image in the memory test. We generated eight different stimulus presentation orders for each task (calibration, primary n-back, and memory test) and each participant was assigned to one of these eight stimulus orders. Images of animals and objects were presented at 50% opacity and superimposed on images of faces. Faces were presented at full opacity because, in pilot studies, they were more challenging to categorize. Images were tinted using built-in warming and cooling photo filters in Photoshop. A warming Filter (85) was used on the face images using a density of 70% (images appear more orange). A cooling filter (80) was applied to images of objects using a density of 70% (images appear bluer).

2.3 | Procedure

Participants performed the experiment at home on their personal computers. Before participation, they were sent a link to the experiment. The experiment was created in PsychoPy (Peirce 2007) and was hosted on Pavlovia (https://pavlovia.org/finnlandlab/nsynch). A trained experimenter met participants over Zoom to explain the task. The experimenter remained on Zoom throughout the experiment to ensure continued task engagement.

Participants first completed a calibration n-back task designed to determine each participant's working memory ability (Figure 1A). Then, based on calibration performance, participants completed either a 1- or 2-back in the primary n-back task (Figure 1B). The calibration task helped ensure developmental differences in task difficulty were minimized during the primary n-back task. Both n-back tasks required participants to detect repeat images from a target category while ignoring images from a distractor category (Figure 1B). After the primary n-back task, participants completed a surprise recognition memory test in which memory was tested for both targets and distractors from the primary n-back task (Figure 1C).

2.3.1 | Calibration and Primary N-Back Tasks

Participants completed a calibration n-back followed by a primary n-back task. In both tasks, participants were shown two superimposed images from a target and a distractor category on each trial. A category instruction cue was presented onscreen throughout to remind participants which category was relevant. In the 1-back block, participants pressed "J" to indicate a target had repeated from the preceding trial (a *target repeat trial*) and "F" to indicate it had not repeated (a *non-target repeat trial*). Distractor images were repeated on a subset of trials (*distractor repeat trials*), but participants were instructed to ignore these trials entirely. In the 2-back block, participants were instructed to indicate when a target was the same as the image seen *two* trials back. Furthermore, both targets and distractors were repeated in 1- and 3-back increments. This made the 2-back blocks harder, requiring individuals to differentiate 2-back repeats from 1- and 3-back repeats. In both the calibration and primary n-back task, images were displayed for 2 s, interspersed with a half-second inter-stimulus interval (ITI; Figure 1B).

2.3.2 | Calibration N-Back Task

Images of faces and animals alternated as targets and distractors across blocks. Participants completed two blocks of a 1-back task (Figure 1A) that included 20 trials in each block (six target repeats; six distractor repeats per block). Participants who identified ≥75% of target repeats completed two more blocks of a 2-back task. The 2-back blocks included 30 trials each (five target repeats, five distractor repeats, four 1-back lures per category, and four 3-back lures per category). If participants identified ≥70% of target repeats in the 2-back blocks, they were assigned to a 2-back during the primary n-back task (15 children [25%] and 42 adults [61%]). The remaining participants were assigned to complete a 1-back during the primary n-back task (46 children [75%] and 27 adults [39%]).

2.3.3 | Primary N-Back Task

Images of objects and faces alternated as targets and distractors across blocks (Figure 1B). Face images were used in both the calibration and primary n-back task because pilot testing revealed that n-back performance on non-face stimuli did not reliably predict n-back performance on face stimuli. Using face stimuli during the calibration task, therefore, ensured accurate assignment to the appropriate n-back level in the primary n-back task. The primary n-back task comprised two blocks of 64 trials each. In the 1-back condition, there were 19 target repeats and 19 distractor repeats per block. In the 2-back condition, there were 11 target repeats and 11 distractor repeats per block, plus four 1-back and four 3-back repeats of both target and distractor types (26 trial unique images per block per category).

2.3.4 | Surprise Recognition Memory Test

After the primary n-back task, participants completed a surprise recognition memory test to test memory for images of targets and distractors from the primary n-back task (Figure 1C). The test included 104 old images (26 object targets from the n-back, 26 object distractors, 26 face targets, 26 face distractors) and 52 new images (26 faces, 26 objects). Images that had been repeated during the n-back task were not included in the memory test ($n = 38$ from each category) to avoid bias from repeated viewing. Participants were instructed to press "F" if they thought the image was shown during the n-back ("old") and "J" for images they thought were new. After each memory decision, they rated their confidence on a 4-point scale (just guessing = 1; not quite sure = 2; pretty sure = 3; sure = 4). These confidence ratings were not incorporated into the analysis. Trials progressed after each memory decision. Participants had a maximum of 4 s to respond to whether an image was old or new and unlimited time to report confidence. The choice to impose modest time pressure for the memory judgement ensured that recognition memory RT data would be a valid measure of decision time and to keep the task progressing smoothly. Note that the mean RT to make a recognition memory judgement was well within the 4-s time limit for both children and adults (Figure S4 shows the RT distribution and Supplementary Analysis 6 provides descriptive statistics). Image presentation was pseudo-randomized: 1/3 of distractors appeared immediately after their corresponding target from the 1-back task ("correctly paired"), 1/3 appeared following a different target ("incorrectly paired"), and 1/3 appeared after a new image ("unpaired"). Eight different stimulus presentation sequences ensured that every distractor image had an equal chance of being correctly paired, incorrectly paired, or unpaired. This ordering allowed us to explore whether participants formed associative memories for targets and distractors from the same trial. The presence of associative memories would be expected to lead to faster recognition memory for correctly paired than incorrectly paired distractors. Participants had the option of a brief break midway through the memory test.

2.4 | Statistical Analysis

Unless otherwise noted, statistical models and indices were pre-registered on the Open Science Framework, which contains data and analysis scripts for this study. Pearson's or Spearman's correlations were fit to examine relationships between individual differences metrics. Mixed effects regression models were fit to data that repeated within participants. Mixed effects models included random intercepts for each participant and random slopes for fixed effects variables that repeated within participants. For models that included fixed effects with only one observation per level (as is the case when modeling d'), we modeled random intercepts per participant. Models that did not converge were reduced in complexity until they converged (Barr et al. 2013). As pre-registered, n-back blocks in which participants detected fewer than half of n-back target repeats were excluded (blocks from 19 children and 9 adults), and the memory test data from these n-back blocks were not analyzed. In the case of significant interactions, we performed follow-up contrasts to extract simple effects by changing the base level of the model. Before fitting models or calculating individual differences metrics, trial-level responses from the n-back and recognition tasks that were <300 ms were excluded. From the remaining data, we removed RTs that were three standard deviations from a participant's own raw mean RT. Thus, outlier RTs did not influence individual difference metrics or bias results from models of RTs. Before fitting models or calculating RT indices, we log-transformed RT data. Variables were effect coded before fitting models: age group (children = –1, adults = 1), n-back level (1-back = –1, 2-back = 1), stimulus type (distractor = –1, target = 1), image category (faces = –1, objects = 1), distractor repetition type (distractor repeat = –1, non-distractor repeat = 1).

2.4.1 | Examining Developmental Differences in N-Back and Episodic Memory Performance

We used a chi-squared test to examine whether a greater proportion of children than adults had been assigned to the 1-back task. We used d' to operationalize n-back and recognition memory performance. For the n-back task, a hit was considered a repeat response to a target repeat trial, and a false alarm was considered a repeat response to a non-target repeat trial. For the recognition memory task, a hit was considered an old response to an old image, and a false alarm was an old response to a new image. We calculated n-back d' separately for each n-back block, and we calculated memory d' separately for images of faces and objects. By convention (Stanislaw and Todorov 1999), false alarm rates of 0 were adjusted to $0.5/N+1$, where N equals the total number of trials used in the calculation. Hit rates of 100% were adjusted to $N+0.5/N+1$. To examine age differences in n-back performance, we fit a linear mixed effects model predicting d' from age group, block type (attending to faces vs. objects) and their interaction (i.e., *d' ~ age group × block type + (1|participant*). To examine age differences in memory performance, we fit a linear mixed effects model predicting d' from age group, image category (faces, objects) and their interaction (i.e., *d' ~ age group × image category + (1|participant*). Although not pre-registered, we included n-back d' (collapsed across blocks) as a covariate in analyses. This step allowed us to isolate the effects of age group from that of n-back performance. This deviation from the pre-registration did not change the pattern of results.

2.4.2 | Testing for Developmental Differences in Selective Attention

Using a binomial mixed-effects regression and a linear mixed-effects regression, we examined developmental differences in distractor interference. We compared differences in RT and accuracy on the n-back on trials where distractors repeated versus on trials where neither distractors nor targets repeated. The difference in RTs and accuracy between these two trial types provides a measure of interference from distractor repeats during n-back task performance. The key insight is that if distractors are truly ignored, distractor repetition should not affect task performance (i.e., there should be no differences between these trial types). We therefore fit a model to test how much distractor repeats interfered with n-back performance and whether this differed by age group. In this model, age group, distractor repetition trial type (distractor repeat vs. non-repeat), and their interaction were regressed onto accuracy or log RT (e.g., *accuracy ~ age group × distractor repetition type + (distractor repetition type|participant))*. Trials where targets were repeated were excluded from analyses. Exploratory (non-pre-registered) models were fit to probe whether age group differences in distractor interference were modulated by distractor image category (i.e., whether distractor interference was stronger when distractors were objects vs. faces). This was probed by adding image category as a covariate and interaction term to the model. The simple effects from these exploratory interaction models are reported in the Supporting Information (See Supporting Information Analysis 1 and 2). Only accurate responses were included in models where RT was the dependent variable. We included n-back d' as a covariate, which did not change the pattern of results.

2.4.3 | Assessing Developmental Differences in Memory Selectivity

We fit a linear mixed effects model to examine age group differences in memory selectivity. In this model, d' served as the dependent variable and stimulus type (distractors, targets) and age group (children, adults) served as fixed effects and interaction terms (i.e., $d \sim group \times stimulus\ type + (1|participant)$). The same false alarm rate (old responses to new images) was used to compute d' for distractors and targets. To determine whether age group differences in memory selectivity differed by category, we fit a linear mixed effects model, adding category as a fixed effect and interaction term (i.e., $d' \sim age\ group \times stimulus\ type \times category + (1|participant)$). Here, d' was calculated separately for faces and objects and for targets and distractors. Hits and false alarms, therefore, were calculated separately by image category (faces, objects), and false alarm rates were calculated as the proportion of old responses to new images of the same category. We included d' from the n-back task as a covariate in all models to ensure effects were unrelated to n-back performance.

2.4.4 | Testing Whether Distractor Interference Mediates Developmental Differences in Episodic Memory Selectivity

We calculated an individual difference metric of distractor interference, our measure of selective attention. We subtracted mean RT on non-repeat trials (in which neither targets nor distractors repeated) from mean RT on distractor repeat trials (in which only distractors repeated). We also calculated a *memory selectivity score*, equivalent to d' for targets minus d' for distractors. Using a linear regression, we first tested whether there was a relationship between distractor interference and memory selectivity. Memory selectivity served as the DV, and distractor interference scores served as the IV (i.e., $memory\ selectivity \sim distractor\ interference$). We fit a second exploratory model to test for age group interactions by adding age group as a covariate and interaction term. N-back d' was included as a covariate in both models.

Next, we fit two mediation models to test whether distractor interference mediated lower memory selectivity using the mediation package in R. In one model, we examined how n-back interference from face and object distractors shaped memory selectivity. In another model, we examined how n-back interference from object distractors shaped memory selectivity for the object category. N-back d' was included as a covariate in both models. We fit 5000 bootstrap iterations to provide stable estimates of the direct, indirect, and total effects and reported the 95% confidence intervals. Intervals that did not include zero were considered statistically significant.

2.4.5 | Testing Evidence in Favor of a Diffuse or Darting Attentional Spotlight

To distinguish between a diffuse and darting attentional spotlight, we tested whether memory for distractors from a given n-back trial depended on whether the target from the same trial was learned. Note that the key signature of narrow darting attention is broad learning across the task, but a trade-off within individual trials—a pattern incompatible with diffuse attention, which predicts no trade-off in memory between targets and distractors from the same trial. Therefore, for each participant, we calculated the average memory hit rate for distractors when paired targets were remembered versus not remembered. We then fit a linear mixed-effects regression predicting memory hits by whether a paired target was remembered or not (i.e., $distractor\ hits \sim target\ remembered\ vs.\ forgotten \times age\ group + (1|participant)$). Age group was included as a fixed effect and interaction term and n-back d' as a covariate. To assess the influence of image category on memory, we re-fit the model after incorporating category (faces, objects) as a covariate and interaction term. These analyses were included in our pre-registration but specified as exploratory.

2.4.6 | Examining Associative Memories for Targets and Distractors From the Same n-Back Trial

To investigate whether participants formed associative memories between targets and distractors from the same n-back trial, we examined whether seeing a target during the recognition memory task hastened recall of a paired distractor. We focused on RTs rather than accuracy because we expected that seeing a target would hasten the recall of an associated distractor but not necessarily enhance memory, consistent with prior research in adults (Davis et al. 2024). Using a linear mixed effects model, we compared correct recognition memory RTs to distractors that appeared after their originally paired target versus a different target. RTs were the dependent variable, and pairing type (paired vs. unpaired), age group, and category were fixed effects, and interaction terms (i.e., $RT\ for\ distractor \sim pairing\ type \times group \times category + (category|participant)$). N-back d' was included as a covariate. These analyses were pre-registered but were specified as exploratory.

3 | Results

We first describe developmental differences in n-back performance, distractor interference, and memory selectivity. We then test whether distractor interference mediates developmental differences in memory selectivity. Finally, we adjudicate between the diffuse and darting models of attention by examining the learning of distractors and targets from the same n-back trial.

3.1 | Children Displayed Worse n-Back Performance than Adults

A higher percentage of children than adults were assigned to the simpler 1-back task ($X^2 = 15.87$, $df = 1$, $p = <0.001$). However, children's n-back performance was still worse than adults' ($b = 0.25$, SE $= 0.06$, $t(128) = 3.84$, $p < 0.001$; Figure 2A).

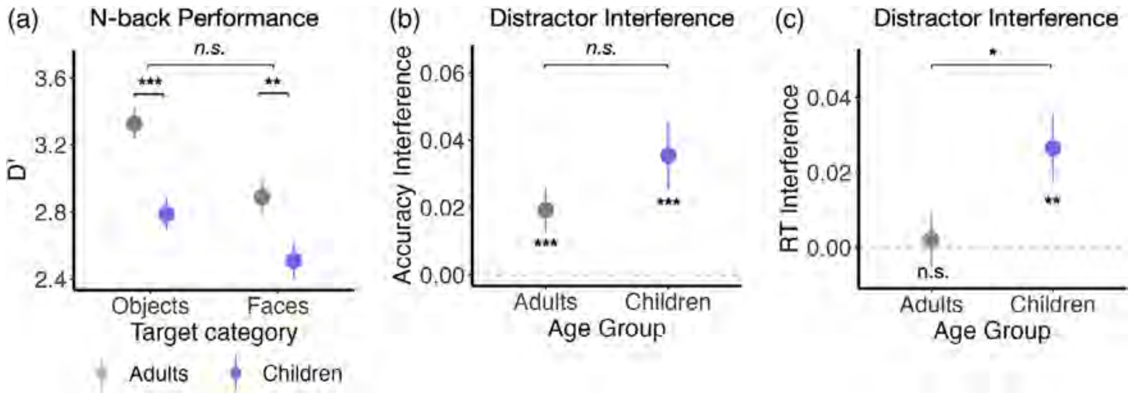

FIGURE 2 | Developmental differences in n-back performance and distractor interference. (A) Children performed worse than adults on the n-back task regardless of the target category. (B) Children and adults showed similar interference in their accuracy when distractor images repeated. (C) Children, but not adults, slowed down to correctly reject distractor repeats. In B and C, models were conducted at the individual trial level, but here, we depict difference scores on the y-axes (B: mean accuracy on non-repeat trials minus mean accuracy on distractor repeat trials; C: mean RTs on distractor repeat trials minus mean RT on non-repeat trials). Higher scores, therefore, reflect greater distractor interference. Stars denote the statistical significance level of the reported trial-level statistics (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). Mean and standard errors are shown.

This difference did not interact with the target image category (*age group* × *category*: $b = 0.04$, SE $= 0.04$, $t(111) = 0.92$, $p = 0.357$; Figure 1A) or the n-back level participants completed (*age group* × *n-back level*: $b = 0.007$, SE $= 0.07$, $t(126) = 0.10$, $p = 0.922$). Thus, the calibration likely mitigated some age group differences in task difficulty but did not eliminate them entirely.

3.2 | Children Displayed Greater Distractor Interference on the n-Back Than Adults

Across the sample, accuracy was worse ($b = -0.39$, SE $= 0.08$, $z = -5.21$, $p < 0.001$) and RT was slower when distractors repeated ($b = 0.008$, SE $= 0.003$, $t(135) = 2.54$, $p = 0.012$; Figure 2B,C). Participants, therefore, did not perfectly "tune out" distractors. Distractor repeat trials impaired accuracy to a similar degree in children and adults (*age* × *distractor repetition type*: $b = -0.04$, SE $= 0.07$, $z = -0.60$, $p = 0.549$; Figure 2B). However, children's RT slowed down significantly more than adults' when rejecting distractor repeats (*age* × *distractor repetition type*: $b = -0.006$, SE $= 0.003$, $t(135) = -2.04$, $p = 0.043$; Figure 2C). In fact, children slowed down to reject distractor repeats ($b = 0.01$, SE $= 0.005$, $t(155) = 3.01$, $p = 0.003$), but adults did not ($b = 0.002$, SE $= 0.004$, $t(113) = 0.38$, $p = 0.703$; Figure 2C). Exploratory (non-preregistered) analyses revealed a significant interaction, showing that these age group differences were marginally larger when distractors were objects than faces *(age* × *distractor repetition type* × *category*: $b = 0.006$, SE $= 0.003$, $t(6880) = 1.82$, $p = 0.068$). Object images were, therefore, particularly difficult for children to ignore (Supporting Information Analysis 1 and 2 detail distractor interference effects separately for objects and faces).

3.3 | Children's Memories Contained Proportionately More Goal-Irrelevant Information

We next tested whether we could replicate prior findings that children's memories were less selective than adults' using an episodic memory test. When examining memories across both targets and distractors, memory performance did not differ between children and adults ($b = 0.04$, SE $= 0.03$, $t(255) = 1.12$, $p = 0.266$; Figure 3A). Moreover, across the sample, participants were better at remembering targets than distractors, indicative of memory selectivity ($b = 0.28$, SE $= 0.03$, $t(255) = 10.64$, $p < 0.001$). However, memory selectivity for targets was reduced in children compared to adults (*age group* × *stimulus type*: $b = 0.11$, SE $= 0.03$, $t(255) = 4.16$, $p < 0.001$; Figure 3B). Furthermore, adults had better target memory than children ($b = 0.15$, SE $= 0.04$, $t(255) = 3.95$, $p < 0.001$), but children had marginally better distractor memory than adults ($b = -0.07$, SE $= 0.04$, $t(255) = -1.77$, $p = 0.079$). These developmental differences did not differ by n-back level (See Supporting Information Analysis 3).

Next, we performed exploratory analyses to test whether memory performance or memory selectivity differed by target category. Across the sample, participants were better at remembering objects than faces ($b = 0.50$, SE $= 0.02$, $t(335) = 20.30$, $p < 0.001$). In fact, memory for faces was low across the sample, with a mean d' of 0.38 for targets and 0.08 for distractors. In fact, over a third of participants had d' scores below chance (d' = 0) for face distractors (42% of children, 37% of adults). Moreover, almost 20% had memory that was below chance for face targets (31% of children, 8% of adults). Given these floor effects, we anticipated that developmental differences in memory selectivity would be more robustly estimated for the object category.

Consistent with this prediction, developmental differences in memory selectivity were strongest for object images (*age group* × *stimulus type* × *category*: $b = 0.06$, SE $= 0.03$, $t(380) = 2.53$, $p = 0.012$). While participants remembered object targets better than distractors regardless of age (*children*: $b = 0.23$, SE $= 0.05$, $t(367) = 4.43$, $p < 0.001$; *adults*: $b = 0.59$, SE $= 0.05$, $t(346) = 12.81$, $p < 0.001$; Figure 3C), this memory selectivity effect was reduced in children (*age group* × *stimulus type*: $b = 0.12$, SE $= 0.02$, $t(335) = 4.73$, $p < 0.001$; Figure 3C). Furthermore, adults recognized target objects more accurately than children ($b = 0.16$, SE $= 0.05$, $t(424) = 3.16$, $p = 0.002$), whereas children recognized distractor objects more accurately than adults ($b = -0.20$,

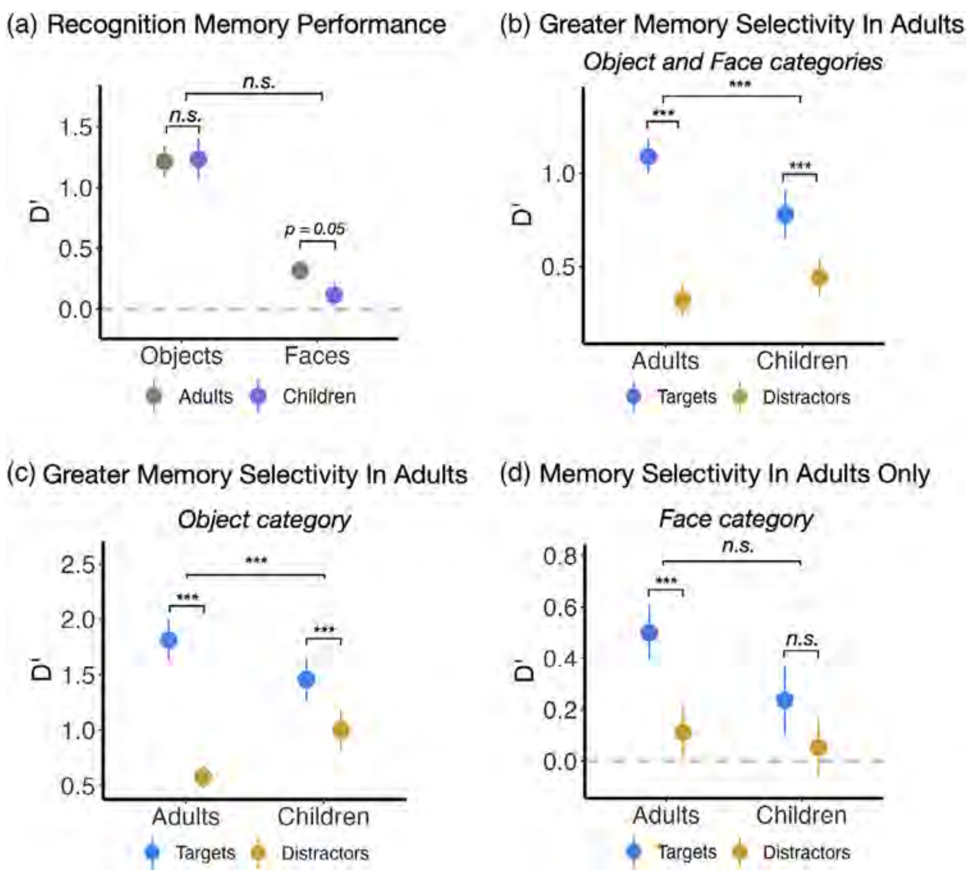

FIGURE 3 | Children's memories contain a greater proportion of goal-irrelevant information. (A) Memory performance did not differ between children and adults. (B) Both children and adults were more likely to remember targets than distractors. However, memory selectivity for targets was reduced in children. (C) For images of objects, memory selectivity was lower in children compared to adults. (D) For images of faces, only adults displayed better memory for targets than distractors. However, developmental differences in memory selectivity for faces did not reach statistical significance. Plots depict means and 95% confidence intervals. Stars denote statistical significance (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).

SE = 0.06, $t(434) = -3.51$, $p < 0.001$; Figure 3C). These effects did not differ by n-back level (Supporting Information Analysis 3).

For face images, adults remembered targets better than distractors ($b = 0.19$, SE = 0.05, $t(346) = 4.17$, $p < 0.001$). In contrast, children did not ($b = 0.09$, SE = 0.05, $t(367) = 1.64$, $p = 0.101$; Figure 3D). However, even though only adults demonstrated memory selectivity for faces, age group differences in memory selectivity for faces did not reach statistical significance (*age group* × *stimulus type*: $b = 0.05$, SE = 0.04, $t(358) = 1.52$, $p = 0.130$; Figure 3D). Despite floor effects in face memory reducing age group differences (as well as possibly lowering statistical power), the full pattern of results (collapsed across category) shows that children's memories are less selective than adults'.

3.4 | Distractor Interference Mediates Developmental Differences in Memory Selectivity

We next asked whether distractor interference during the n-back task mediated developmental differences in memory selectivity. Across the sample, accuracy interference during the n-back did not correlate with memory selectivity ($b = -1.00$, SE = 0.73, $t(127) = -1.37$, $p = 0.174$). However, greater RT interference was associated with reduced memory selectivity ($b = -2.38$, SE = 0.69, $t(127) = -3.45$, $p < 0.001$; Figure 4A). We also explored these relationships for the object images—where differences in selective attention and memory selectivity were observed between age groups. We found that RT interference from distractor objects correlated with reduced memory selectivity for objects ($b = -2.18$, SE = 0.66, $t(98) = -3.29$, $p = 0.001$; Figure 4B). Altogether, these findings suggest that poorer filtering of distractors broadens the scope of learning to more equally incorporate relevant and irrelevant information.

After establishing a relationship between selective attention and memory selectivity, we investigated whether individual differences in selective attention mediated developmental differences in memory selectivity. In these mediation models, the path from age group to RT interference scores—reflecting how much individuals slowed down for distractor repeat trials—did not reach statistical significance ($b = -0.01$, SE = 0.006, $t(127) = -1.68$, $p = 0.096$). This non-significant result likely reflected the lower statistical power of this individual difference analysis compared to the trial-level analysis investigating age-group differences in distractor interference (reported above). Despite this path's non-significance, we proceeded to fit a mediation model examining whether these marginal developmental differences in RT interference scores explained developmental differences in memory selectivity. We found that these marginal age group differences in

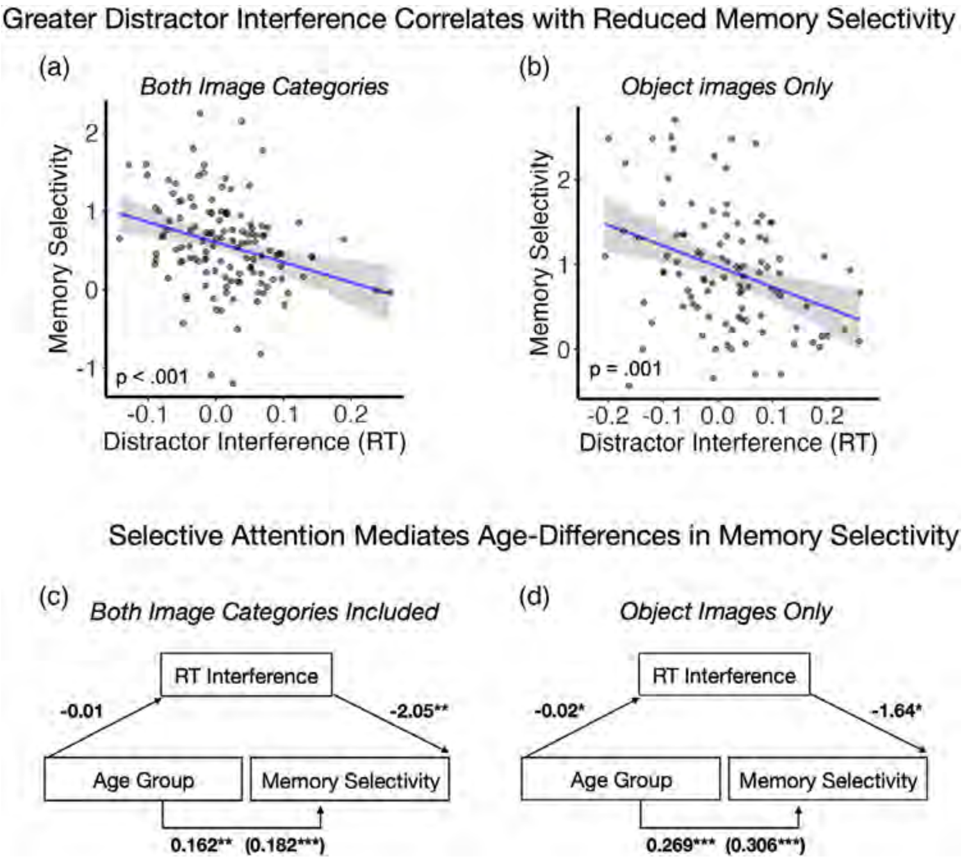

FIGURE 4 | Individuals who showed greater distractor interference tended to have reduced memory selectivity. (A) Across the sample, individuals who exhibited more slowing on the n-back distractor repeat trials showed reduced recognition memory selectivity. (B) Similarly, individuals who exhibited more slowing on trials where distractor objects repeated tended to exhibit reduced memory selectivity for object images. (C) RT interference from distractor repeats (collapsed across categories) marginally mediated age group differences in memory selectivity. (D) RT interference from distractor objects significantly mediated age group differences in object memory selectivity. In A and B, the grey shading reflects 95% confidence intervals around the line of best fit. In C and D, the values in parentheses are the beta coefficients reflecting the relationship between age group and memory selectivity *before* accounting for RT interference (i.e., the total effect), whereas the values in front of the parentheses reflect the relationship *after* accounting for RT interference (i.e., the direct effect). Stars denote significance ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$).

RT interference marginally mediated children's reduced memory selectivity ($ab = 0.021$, 95% CI [−0.003, 0.05], $p = 0.091$; Figure 4C). The total effect of age group on memory selectivity ($c = 0.182$, 95% CI [0.083, 0.280], $p < 0.001$) was reduced when taking into account distractor interference scores ($c' = 0.162$, 95% CI [0.062, 0.26], $p = 0.001$).

We then proceeded to fit a mediation model that focused exclusively on the object images, where developmental differences in memory selectivity were strongest. In these models, the path from age group to RT distractor interference scores (reflecting the degree to which individuals slowed down for object distractor repeats) was significant ($b = -0.02$, SE = 0.01, $t(98) = -2.17$, $p = 0.032$). Furthermore, higher RT interference from object distractors partially mediated age group differences in memory selectivity for objects ($ab = 0.37$, 95% CI [0.002, 0.09], $p = 0.029$; Figure 4D). Indeed, the total effect of age group on memory selectivity ($c = 0.306$, 95% CI [0.179, 0.43], $p < 0.001$) was significantly reduced after accounting for RT interference from objects ($c' = 0.269$, 95% CI [0.145, 0.390], $p < 0.001$). Similar patterns were observed when we did not include n-back performance as a covariate (Supporting Information Analysis 4). These findings suggest that immature selective attention underlies children's advantages for learning about goal-irrelevant information. This finding sets the stage for testing whether children's attentional spotlight is more rapidly shifting or diffuse, which we address in the subsequent section.

3.5 | Children's Attention Darts Across Time

We next probed the mechanisms by which reduced selective attention in children produces broader learning. One account is that children's attentional spotlight is diffuse, spreading across both relevant (target) and irrelevant (distractor) information within each trial. Alternatively, children might still learn broadly even if their attentional spotlight is narrow—by darting focus between targets and distractors across different events. To distinguish these possibilities, we examined attentional breadth by looking at trial-level trade-offs between targets and distractors. We asked whether children were more likely to remember distractors from n-back trials in which they did not remember targets—a pattern consistent with narrow attention. Conversely, if children's attention diffused across items, remembering a distractor should

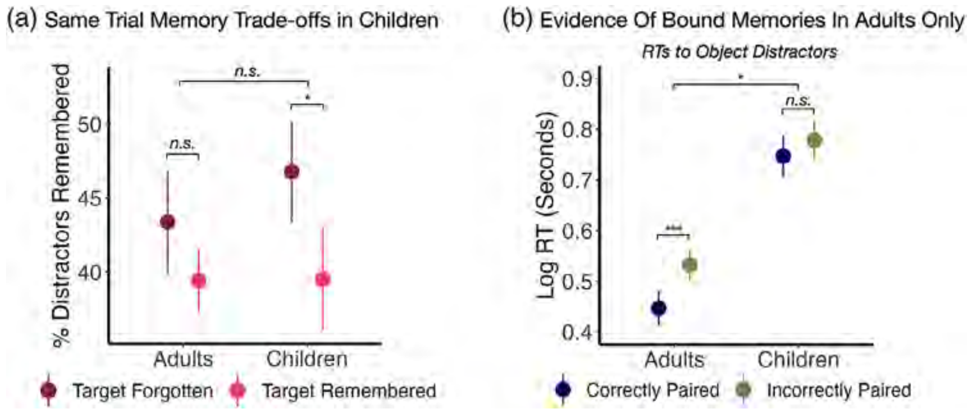

FIGURE 5 | Adjudicating between the diffuse and darting spotlight models of attention. (A) In contrast to predictions of the diffuse attentional spotlight account, children were more likely to remember distractors from trials where they had neglected to learn about targets. In contrast, for adults, there was no trade-off between memory for targets and distractors from the same trial, though the effect for adults was in the same direction. (B) During the recognition memory test, face targets led to faster recognition of paired object distractors in adults only. Mean and standard errors are plotted. Stars denote significance ($*p < 0.05$, $**p < 0.01$, $***p < 0.001$).

be unrelated or even positively related to remembering a target from the same trial (as both would fall within a diffuse spotlight).

Consistent with narrow attention, we found that across the sample, participants were more likely to remember a distractor if they did *not* remember the target from the same trial ($b = -0.03$, SE = 0.01, $t(124) = -2.21$, $p = 0.029$; Figure 5A). This pattern did not differ by distractor category (*category* × *target memory*: $b = -0.006$, SE = 0.01, $t(315) = -0.46$, $p = 0.649$) or age group (*age group* × *target memory*: $b = 0.009$, SE = 0.01, $t(124) = 0.70$, $p = 0.487$). This suggests that the *breadth* of attention on any given trial does not differ in children and adults.

Exploratory analyses examining age groups separately showed that children exhibited memory trade-offs between targets and distractors from the same trial ($b = -0.04$, SE = 0.02, $t(125) = -1.99$, $p = 0.049$; Figure 5A). This trade-off was non-significant but in the same direction in adults ($b = -0.02$, SE = 0.02, $t(124) = -1.11$, $p = 0.270$). These findings suggest that children's attention is narrow—prioritizing either a target or a distractor on a given trial. Thus, broad learning appears to be best explained not by diffuse attention within each event, but by narrow attention that learns broadly by shifting between relevant and irrelevant information across trials.

3.6 | Adults, but Not Children, Show Priming of Target-Distractor Pairs

After establishing that children tended to remember *either* targets or distractors from each trial—indicating that attention darts—we tested whether participants formed associative memories of targets and distractors from the same n-back trial. Across the sample, seeing a target led to faster subsequent recognition of paired distractors (paired vs. unpaired RT: $b = -0.02$, SE = 0.007, $t(1692) = -2.31$, $p = 0.021$). Exploratory analyses showed that this effect was marginally stronger when considering distractors from the object category (*category* × *pairing type*: $b = -0.01$, SE = 0.007, $t(1688) = -1.87$, $p = 0.062$): That is, target faces hastened subsequent recognition of paired object distractors (paired vs. unpaired RT: $b = -0.03$, SE = 0.01, $t(1691) = -2.79$, $p = 0.005$). In contrast, target objects did not lead to faster recognition of paired face distractors (paired vs. unpaired RT: $b = -0.003$, SE = 0.01, $t(1673) = -0.33$, $p = 0.743$). These findings suggest that participants formed associations between target faces and object distractors from the same n-back trial.

While our pre-registration sought to examine associative memory for all items, given the lack of priming for face distractors, we focused developmental difference analyses on associations between target face and distractor object pairs. We found that face targets led to faster recognition of object distractors more in adults than children (*pairing type* × *age group*: $b = -0.02$, SE = 0.01, $t(1691) = -2.07$, $p = 0.038$). For adults, face targets led to faster recognition memory of paired object distractors ($b = -0.05$, SE = 0.01, $t(1691) = -3.63$, $p < 0.001$). In contrast, for children, there was no evidence that face targets led to faster recognition of paired object distractors ($b = -0.008$, SE = 0.02, $t(1682) = -0.48$, $p = 0.630$). Thus, only adults formed associative memories for targets and distractors from the same trial (Supporting Information Analysis 7 shows that priming did not depend on explicit memory for face targets). These findings are consistent with the idea that children's attention darted *between* relevant and irrelevant information across trials, which may have prevented associative memories between items. Supporting Information Analysis 5 details how priming influenced recognition memory accuracy for distractors.

4 | Discussion

We examined the role of selective attention in children's tendency to learn more equally about relevant and irrelevant information than adults. We found that 7–9-year-olds were less likely than adults to prioritize relevant information in memory and had marginally better memory for distractors—a difference that reached significance when focusing on images of objects. Selective attention also partially mediated developmental differences in memory selectivity for objects, establishing a link between immature attention and children's broader learning. We also examined evidence emblematic of children having a "diffuse attentional spotlight" by examining children's individual memories for targets and distractors from the same trial. In contrast to the idea that children diffused attention, we found that children were more likely to form "distractor" memories in the very moments when they did *not* form target memories. The combination of children's broad learning at the aggregate level, and these trial-level trade-offs align more closely with a narrow attentional spotlight that darts across time rather than one that diffuses on each trial. Additionally, unlike adults, children did not form memory associations between targets and distractors from the same event. These data suggest that when children focus attention on targets, distractors are unlikely to "leak" in.

Our study provides evidence that children's broader learning, particularly for images of objects, stems from immature selective attention with a design that safeguards against alternate explanations. In prior work, selective attention and learning were confounded because participants had to learn about relevance through trial and error before they could selectively focus on relevant content (Blanco et al. 2023; Blanco and Sloutsky 2019; Deng and Sloutsky 2016). Our study explicitly informed and reminded participants which images were relevant. Furthermore, in prior studies, participants who took longer to make decisions (which likely included more children) had more time to view relevant and irrelevant content (Plebanek and Sloutsky 2017). This may have inadvertently boosted learning for irrelevant information. We addressed this issue by presenting images for fixed times during learning across participants. Last, prior research did not control for task difficulty (Blanco et al. 2023; Plebanek and Sloutsky 2017), which may have led to greater fatigue in children, contributing to broader learning. We calibrated n-back task difficulty to participants' working memory abilities and controlled for n-back performance in statistical models. Together with this prior work, our findings show that children's learning is less selective than adults'.

We tested two possible dynamics of children's attention: darting versus diffuse. Supporting the darting account, exploratory analyses revealed that children's memory for targets and distractors from the same event traded off: Children were more likely to remember a distractor if they could not recognize a target from the same event. When considered alongside children's broad learning overall, this pattern aligns with the idea that children "dart" attention between targets and distractors—rather than diffuse it within an event. By contrast, the "diffuse" model predicts that memories of relevant and irrelevant content should be independently stored, yielding null retrieval contingencies. However, positive contingencies might also be emblematic of a diffuse spotlight. For example, when adults are instructed to broadly attend to multiple event features, they show positive retrieval dependencies in memory (Horner and Burgess 2013, 2014). Fluctuations in sustained attention may be the extra ingredient through which diffuse spotlights yield positive contingencies. For example, children and adults are more likely to remember individual images learned in good attentional states (deBettencourt et al. 2018; Decker, Duncan, et al. 2023; Decker and Duncan 2020) and sustained attention synchronously enhances and diminishes memories for relevant and irrelevant content over time (Corriveau et al. 2024). This adds to recent demonstrations that sustained attention shapes learning of irrelevant content (Decker, Dubois, et al. 2023).

Importantly the negative retrieval contingency that we observed did not differ between children and adults. This pattern indicates that the breadth of attentional focus within a single event is similarly narrow across age groups, indicating developmental continuity in the breadth of attentional focus. Notably, adults' attention has been shown to rapidly dart between relevant and irrelevant content several times per second (Landau and Fries 2012). Perhaps, then, adults' attention darts so rapidly within a trial that it gives the illusion of diffuse attention. If true, then what might change across development may be the speed at which attention darts rather than the breadth of focus. If children's attention simply darts slower than adults' across trials, then with longer encoding durations, children's attention might shift between targets and distractors within a trial, giving the illusion of diffuse attention in aggregate memory measures. Given the indirect and exploratory nature of the findings on darting attention, future studies should replicate and extend the findings using other paradigms and incorporate additional measures like neuroimaging and eye-tracking to further investigate children's attentional scope and dynamics and their impact on learning.

By contrast, there is evidence that attention's spotlight broadens in older adults, in stark contrast to what we see in children. For instance, older adults hyper-bind targets and distractors from the same event in memory (Amer et al. 2020; Campbell et al. 2010; Rowe et al. 2006; Weeks and Hasher 2018). We also observed evidence of hyper-binding in young adults, consistent with demonstrations that this phenomenon is not restricted to aging (Davis et al. 2024). Children, however, showed no evidence of hyper-binding. This developmental difference could reflect the slow maturation of associative memory (Ofen et al. 2007; Shing et al. 2010)—though children are clearly capable of forming basic associations (Ngo et al. 2019). Alternatively, children's low explicit memory for faces may have constrained their associated memory formation. Our data in adults, however, suggests that explicit memory for faces was not required for hyper-binding. Thus, the findings more parsimoniously suggest that attentional darting explains children's lack of hyper-binding, which appeared to isolate *either* a target or a distractor within each trial. That is, children's darting spotlight may have facilitated separate memories for targets and distractors.

But what might cause children's attention to dart between targets and distractors across trials? This darting could be caused by multiple cognitive and attentional mechanisms. For example, failures of working memory maintenance for targets or task goals (Gathercole et al. 2004) or lapses in distractor inhibition (Bunge et al. 2002) could cause attention (and memory formation) to dart from targets toward distractors across trials. Alternatively, children's exploratory tendencies (Blanco and Sloutsky 2021, 2024; Schulz et al. 2019) may manifest in a desire to periodically shift focus toward novelty. Thus, the development of selective attention may be less about the efficiency of focus and more about how children's attention darts across time.

In conclusion, we found that children and adults take away very different information in memory—a phenomenon we linked to selective attention. Furthermore, by examining the content of children's individual memories, we inferred that children's attention darts (rather than diffuses), contributing to a long-standing theory of what underlies distributed attention in childhood. These findings highlight the power of considering the temporal dynamics of children's cognition: What might appear as a diffuse spotlight, when averaged across time, may, in fact, reflect a spotlight that is just as narrow—but that spends more time laser-focused on irrelevant information. Darting attention may, therefore, explain children's unique learning advantages.

Author Contributions

Alexandra Decker: conceptualization, data curation, formal analysis & visualization, methodology, software, writing. **Marlie Tandoc**: conceptualization, investigation, methodology, project administration, software. **Hyuna Cho**: investigation, methodology, project administration, software. **Gloria Rebello**: investigation, project administration. **Donald J. Mabbott**: conceptualization. **Katherine Duncan**: conceptualization, funding acquisition, methodology, supervision, writing. **Amy S. Finn**: conceptualization, funding acquisition, methodology, project administration, supervision, writing with input from all authors.

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Ethics Statement

This research received approval from the local ethics board at the University of Toronto.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The materials, data and analysis scripts have been uploaded to the Open Science Framework (https://osf.io/srbpn/). The hypotheses and methods were pre-registered (https://osf.io/vjwcn).

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supporting File 1: desc70118-sup-0001-SupMat.docx