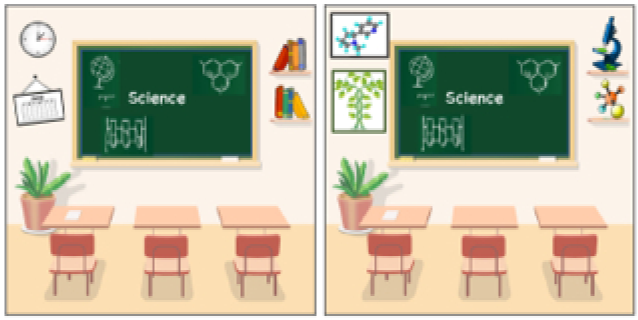
WIREs
COGNITIVE SCIENCE

WILEY

# Context and Attention Control Determine Whether Attending to Competing Information Helps or Hinders Learning in School-Aged Children



| | |
|---|---|
| Journal: | *WIREs Cognitive Science* |
| Manuscript ID | COGSCI-776.R2 |
| Wiley - Manuscript type: | Advanced Review |
| Date Submitted by the Author: | n/a |
| Complete List of Authors: | Markant, Julie; Tulane University, Department of Psychology<br>Amso, Dima; Columbia University, Psychology |
| Keywords: | attention control, executive attention, attention flexibility, Context, learning |
| Choose 1-3 topics to categorize your article: | Attention (BEAB) < Psychology (BEAA), Learning (BEAN) < Psychology (BEAA), Development and Aging (BEAF) < Psychology (BEAA) |




Attending to competing contextual information during a science lesson can be detrimental to learning when this information is unrelated to lesson goals, but may instead benefit learning when the information is goal-relevant.

23x12mm (350 x 350 DPI)

# Context and Attention Control Determine Whether Attending to Competing Information Helps or Hinders Learning in School-Aged Children

Julie Markant[1,2] and Dima Amso[3]

[1]Department of Psychology, Tulane University

[2]Tulane Brain Institute, Tulane University

[3]Department of Psychology, Columbia University



Article type: Advanced Review

**Corresponding Author**
Julie Markant
Department of Psychology
Tulane University
2007 Percival Stern Hall #52
6400 Freret St.
New Orleans, LA 70118
jmarkant@tulane.edu

The authors report no conflicts of interest.

Funding information: This work was supported by funding from the National Science Foundation (NSF 2051819 to DA).

Data availability statement: Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Abstract

Attention control regulates efficient processing of goal-relevant information by suppressing interference from irrelevant competing inputs while also flexibly allocating attention across relevant inputs according to task demands. Research has established that developing attention control skills promote effective learning by minimizing distractions from task-irrelevant competing information. Additional research also suggests that competing contextual information can provide meaningful input for learning and should not always be ignored. Instead, attending to competing information that is relevant to task goals can facilitate and broaden the scope of children's learning. We review this past research examining effects of attending to task-relevant and task-irrelevant competing information on learning outcomes, focusing on relations between visual attention and learning in childhood. We then present a synthesis argument that complex interactions across learning goals, the contexts of learning environments and tasks, and developing attention control mechanisms will determine whether attending to competing information helps or hinders learning.

*Keywords: attention control, executive attention, attention flexibility, context, learning*

Visually attending to competing or distracting information is often viewed as a processing failure. While there are scenarios where distraction hinders learning, the complexity generated by competing information may also offer rich input for learning. Here we argue that whether competing information hinders or helps learning likely depends on multiple factors, including the learning context and the developmental state of attention control and learning and memory systems. Although we will primarily focus on formal learning environments in which learning goals are more clearly defined (e.g., controlled laboratory tasks, classrooms), we will also consider how attending to competing information may influence learning in informal contexts without a defined learning goal. We focus this review as much as possible on literature specific to early and middle childhood (i.e., 3-10 years of age) to align the discussion with broader issues in education and learning spaces.

Attention control is often equated with executive attention, the ability to select goal-relevant information while suppressing irrelevant competing information (Burgoyne & Engle, 2020). Yet daily adaptive behavior requires focusing on high-level task goals while also remaining sensitive to novel or changing contexts (Chevalier, 2015; Dajani & Uddin 2015). For example, one might have the goal of making a jelly sandwich and must execute a series of subtasks in sequential order to successfully complete this goal (Desrochers et al., 2016). Within each sub-task, one must be sensitive to detailed contextual visual information. If someone has moved the jar of jelly from its habitual cupboard location, one must engage attention control to arbitrate among possible locations the jar could be found while also inhibiting attention to irrelevant objects and locations, all while maintaining the high-level goal of making the sandwich. Thus, attention control comprises both executive attention as well as the ability to flexibly allocate attention in service of a broader goal (Braem & Egner, 2018; Diamond, 2013). We will first describe the development of these attention control mechanisms and review research demonstrating that attending to irrelevant or extraneous competing information can hinder children's learning in childhood. Next, we will describe evidence indicating that contextual information can provide meaningful input for learning and attending to this relevant competing input can facilitate and broaden the scope of learning. Finally, we will synthesize these literatures by reviewing data that suggest that multiple factors may define whether attending to competing information is a useful part of the learning process. Rather than assuming that all competing information will hinder learning, we argue that the learning goals and context, paired with developing attention control and memory processes, influence children's learning in the presence of competing information.



***Developing Attention Control***

We live in complex, dynamic environments that contain multiple sources of competing sensory inputs. To avoid information overload, we rely on attention to select a subset of these inputs and enhance processing of the selected information (Luck & Vecera, 2002; Oakes & Amso, 2018). Learning environments typically contain a wide range of multisensory information and past research has shown that the presence of redundant audiovisual cues may promote children's learning to a greater extent than visual or auditory cues alone (Broadbent et al., 2018, 2019). However, while researchers have begun to examine the development of multisensory attention control mechanisms (Matusz et al., 2015, 2018, 2019; Turoman et al., 2021), most research linking developing attention control to learning outcomes has focused on children's attention to competing visual inputs. We will therefore primarily focus on visual attention mechanisms that allow for selection of relevant information and suppression of competing information in the visual environment. This concurrent selection and suppression results in sharpened visual processing of objects and locations and provides input for subsequent perception, action, and learning and memory systems (Amso & Scerif, 2015; Carrasco, 2011, 2014; Markant et al., 2015; Zhang et al., 2011).

Posner and Petersen's (Petersen & Posner 2012; Posner & Petersen, 1990) seminal model defined three separate but interrelated attention processes, including alerting, orienting, and executive attention. Alerting maintains a state of arousal and readiness to respond to external information. Orienting involves shifting attention to select information in the environment, which can occur either with a concurrent eye movement (overtly) or independent of an eye movement (covertly). Finally, executive attention processes resolve conflict between competing sources of input in order to efficiently select goal-relevant information (Fan et al., 2003; Posner & Rothbart, 2009). Executive attention is one component of a broader set of executive functions (e.g., Diamond, 2013), with executive attention mechanisms specifically supporting top-down guidance of attention and inhibition of task-irrelevant information (e.g., Rothbart et al., 2007; Tiego et al., 2020).



Researchers have relied on a broad range of tasks to examine these attention processes. The development of attention orienting has been studied extensively using visual search tasks, in which a single target item appears among a varying number of competing distractors (Treisman & Gelade, 1980). When the target and distractors share multiple features there is increased competition across stimuli in the search array. In this case, increasing the number of distractors slows search times, reflecting the increased effort associated with selecting the target from among multiple competing distractors (e.g., Treisman & Gelade, 1980). Studies using visual search tasks have demonstrated that target selection becomes increasingly accurate and efficient between one and ten years of age (Donnelly et al., 2007; Gerhardstein & Rovee-Collier, 2002; Scerif et al., 2004; Trick & Enns, 1998).

Researchers have examined the development of executive attention using tasks that require inhibiting competing or conflicting information for effective task performance. Early foundations of executive attention can be measured using tasks that require control over eye movements. For example, in the antisaccade task individuals respond by looking away from a visual cue, requiring them to inhibit an initial tendency to automatically fixate the cue. Four-month-old infants can inhibit orienting to a visual cue (Johnson, 1995), and by 12- to-18 months of age toddlers can additionally orient to the opposite, noncued location (Scerif et al., 2005). Researchers have used a range of additional tasks that require inhibiting dominant responses to respond to arbitrary rules or conflicting information (e.g., Simon Says, Tower, Day-Night Stroop) to demonstrate rapid improvement in executive attention skills between 3 and 5 years of age (see Garon et al. 2008 for review). These developing executive attention skills have also been observed in studies using the Flanker task (Eriksen & Eriksen 1974) and Attention Network Task (Fan et al., 2002), in which participants indicate the directionality of a central arrow while ignoring surrounding arrows. During some trials the competing arrows point in the same direction as the target, but during other trials they point in the opposite direction, requiring increased executive attention to resolve the competition with the target. Children show improved performance on this task from 4 to 6 years of age (e.g., Rueda et al., 2004; 2005) but also continue to show increasingly efficient executive attention skills into middle childhood, especially between 5 and 8 years of age (see Best et al., 2009 for review). Studies using the antisaccade and Flanker task have also shown that the ability to engage executive attention continues to develop into early adolescence (Hwang et al., 2010; Luna, et al., 2004; Waszak et al., 2010). For example, in a study examining the development of attention orienting and executive attention skills from 6 to 89 years of age, children's orienting skills reached adult levels by age 10 but 15-year-old adolescents continued to show poorer executive attention performance (Waszak et al., 2010). Thus, while children show significant improvements in executive attention in early childhood these skills continue to develop gradually through childhood and early adolescence. These age-related changes in executive attention are a core component of developing attention control as they allow for increased focus on task-relevant information and reduced interference from competing, task-irrelevant information.

Attention control also requires an ability to flexibly shift attention to new information when task demands change. This flexibility reflects the integration of multiple processes as individuals must detect changes in task contexts, disengage from currently selected targets, and shift attention to information that is relevant to new task goals (Dajani & Uddin, 2015). Researchers have studied the development of attention flexibility using tasks in which stimulus features that were initially irrelevant become relevant for successful task performance (see Hanania & Smith 2010 for review). For example, in the Dimensional Change Card Sort (DCCS) task, participants sort cards based on a single feature (e.g., shape), while ignoring a second feature (e.g., color). The rule is then switched and participants are instructed to sort cards based on the previously ignored feature. Three-year-old children typically have difficulty sorting based on a previously ignored feature, but by 5 years of age children successfully sort based on the new rule (e.g., Brooks et al., 2003; Frye et al., 1995; Kirkham et al., 2003; Perner & Lang, 2002; Towse et al., 2000; Zelazo et al., 1996). Compared to adults, young children spend more time looking at the irrelevant feature (Chevalier et al. 2010) and children show enhanced performance when the task design facilitates focusing on only the relevant information (Bohlmann & Fenson, 2005; Brace et al., 2006; Diamond et al., 2005; Kirkham et al., 2003; Kloo & Perner, 2005; Towse et al., 2000). These results suggest that successful performance on this task reflects improvements in the ability to flexibly shift attention across relevant stimulus features. Although children typically show successful performance on the DCCS by age 5, studies using more complex tasks have shown that attention flexibility continues to develop after this age (e.g., Amso et al., 2014, 2019; Dick, 2014). For example, during the modified Flexible Item Selection Task (e.g., Blair & Razza 2007; Jacques & Zelazo 2001), participants select two objects from a larger array based on a single matching feature (e.g., color). On subsequent trials participants are asked to select new object pairs that match based on a different feature (e.g., shape). Children showed improvements in their ability to flexibly shift across features during this more complex task from 6 to 8 years of age, and performance reached adult levels by 10 years of age (Dick, 2014). This improving flexibility over childhood may reflect qualitative changes in children's use of strategies (Chevalier, 2015) as well as increased working memory capacity and reduced interference from irrelevant information (Cragg & Chevalier, 2012).

The DCCS requires shifting attention across multiple features within a single stimulus. Children also develop increasing control over their ability to flexibly allocate attention across multiple stimuli or locations. Previous work using a range of tasks (e.g., flanker, visual crowding, multiple object tracking) has shown that younger children allocate attention broadly but can focus attention more narrowly with age (Bondarko & Semenov, 2005; Enns & Girgus, 1985; Jeon et al., 2010; Pasto & Burack, 1997; Wolf & Pfeiffer, 2014). For example, Pasto & Burack (1997) examined 4-, 5-, 7-, and 9-year-old children and adults' ability to rapidly respond to targets while ignoring distractors that appeared at varying distances (< 1 vs. 5.7 degrees) from the target. Compared to when distractors were absent, 4-year-old children responded more slowly when any distractors were present, regardless of their distance from the target. However, their filtering of more distant distractors improved when a visual cue limited attention to the space around the target.

Older children were slower only when distractors were located close to the target and adults showed similar responses regardless of whether distractors were present or absent (Pasto & Burack, 1997). These results suggest that young children distribute attention broadly and have difficulty independently scaling attention to narrowly focus on a target location. Enns and Girgus (1985) also examined 8- and 10-year-old children and adults' ability to rapidly classify stimuli by either selectively focusing on a single feature or attending to multiple features. All participants responded more slowly when selectively attending to stimuli that were located close together or when attending to multiple features that were spaced far apart. However, the youngest children showed the largest response time costs in both of these cases, suggesting that they had increased difficulty scaling their attention as task demands changed (Enns & Girgus, 1985). Overall, these results demonstrate that children distribute attention more broadly in early childhood and develop increasing control over the ability to flexibly scale attention based on changing task demands.

In sum, the development of attention control includes improvements in executive attention skills that support children's ability to resolve conflict across competing inputs and efficiently select goal-relevant information. Children show significant improvements in these executive attention skills between 3 and 5 years of age, but these skills continue to become more refined through middle childhood and into early adolescence. However, developing attention control is also characterized by increased flexibility in attention allocation. Children become better able to shift attention across multiple relevant inputs or to newly relevant information during early and middle childhood, with the most robust improvements occurring by 10 years of age. Although children also show dramatic improvements in their ability to narrowly focus on task-relevant targets in early childhood, the ability to flexibly scale attention either broadly across multiple stimuli or more narrowly based on task demands continues to develop into middle childhood. The development of attention control thus involves achieving a balance between efficiently selecting targets and flexibly allocating attention based on task demands.

***Attending to Task-Irrelevant Competing Information Hinders Learning***

Researchers studying attention and learning typically emphasize the importance of attention orienting and executive attention for learning. Many studies have demonstrated that improvements in children's ability to efficiently select task-relevant stimuli and ignore task-irrelevant distractors promotes enhanced learning and memory for the attended information (Blanco & Sloutsky, 2019; Deng & Sloutsky, 2016; Hagen & Hale, 1973; Markant & Amso, 2013, 2014, 2016; Plebanek & Sloutsky, 2017). For example, in an early incidental learning paradigm, Hagen and colleagues (Hagen & Hale, 1973) showed 7-13- year-old children cards containing a target image (e.g., animal) and a second competing non-target image (e.g., household object). Participants were instructed to remember the location of the target image and researchers later assessed their memory for the target location and their incidental learning of the pairing between the target and nontarget images. All children showed better memory for target locations without competing images present and the oldest children showed poorer incidental learning of target-nontarget pairs, suggesting increasing selective focus on targets with age (Hagen & Hale, 1973).

The presence of competing visual or auditory information can also hinder children's learning in academic or classroom contexts. Individual differences in developing selective attention skills predicted classroom learning efficacy among kindergarten students (Erickson et al., 2015) and relates to academic performance more broadly across development (Stevens & Bavelier, 2012). Fisher et al. (2014) compared kindergarten students' learning of science lessons that were taught in classrooms without visual displays versus classrooms that were richly decorated with multiple sources of potential visual distraction (e.g., science posters, maps, artwork). During the lessons, researchers observed the children's attention to the instructor, visual displays, and other aspects of the environment. Children who experienced the richly decorated classroom showed reduced engagement with the science lessons, spent more time looking at the visual displays, and demonstrated poorer learning of the lesson content (Fisher et al., 2014). Eight- to twelve-year-old children also showed poorer spatial attention and memory performance when they were tested in a richly decorated vs. a sparsely decorated space (Rodrigues & Pandeirada, 2018). These effects also extend beyond classroom environments to specific learning materials. Kaminski & Sloutsky (2013) presented kindergarten, first- and second-grade students with bar graphs that contained perceptual features that were irrelevant to the mathematical concept conveyed by the graph. The presence of this irrelevant information interfered with children's ability to accurately read the graphs, especially at younger ages (Kaminski & Sloutsky, 2013). Eng et al. (2020) similarly examined effects of extraneous story book illustrations on first- and second-grade students' attention and reading comprehension. Children viewed a book in which a portion contained standard illustrations while the remainder was presented with extraneous illustrations removed. Children were less likely to look away from the text and showed improved story comprehension when the extraneous illustrations were removed.

Some of these studies have further found that these effects are exacerbated for children who are prone to attend to competing visual or auditory information due to immature or atypical attention skills. Massonnie et al. (2019) used idea generation tasks to assess the effects of moderate-level classroom noise on 5-8 and 8-11-year-old children's creativity. The researchers also assessed children's performance on a Stroop executive attention task that required inhibiting conflicting information to correctly identify task-relevant targets, with more mature executive attention characterized by faster target responses despite the presence of conflicting information. Older children's creative responses were not affected by the presence of classroom noise. In contrast, the impact of classroom noise on the younger children's creativity was influenced by individual differences in their attention skills. Specifically, those with more mature executive attention showed similar levels of creativity regardless of classroom noise. However, those who showed poorer executive attention performance were less creative in the presence of classroom noise, suggesting that they may be more susceptible to distraction during classroom activities (Massonnie et al., 2019). Similar effects have been observed using video stimuli designed to simulate classroom environments. Five- to thirteen-year-old typically developing children and children with autism spectrum disorders (ASD) viewed instructional videos that appeared either without peripheral visual information or with multiple images appearing in the background (Hanley et al., 2017). All children spent more time looking at the background images when they were present but this effect was enhanced among children with ASD, with more severe autistic symptoms and poorer sustained attention skills predicting increased looking to the competing peripheral information. Overall, these studies suggest that extraneous visual or auditory information in classroom settings can negatively impact learning, particularly for children with poorer attention skills who may have more difficulty inhibiting attention to this competing information.

### *The Value of Considering Learning Contexts*

Researchers often ensure that laboratory-based experiments examining attention and learning include clearly defined tasks with distinct goal-relevant targets and competing information (i.e., distractors) that is irrelevant for successful task completion. In these "context-independent" tasks, efficient performance requires a selective focus on the target and suppression of the competing distractors (Ackerman, 1990). Attending to competing information in this context would be expected to hinder learning of the target. For example, a series of studies using a spatial cueing task demonstrated that engaging visual selective attention to select a target while inhibiting attention to a competing spatial location supported enhanced memory for the attended target. During the spatial cueing task participants focused on a central location while a salient cue appeared in the periphery. After a brief delay a target object appeared in either the same cued location or in the opposite, noncued location. A short cue-target delay (< 250 ms) facilitates orienting responses to targets appearing in the cued location, whereas longer delays elicit an inhibition of return (IOR) response in which orienting to the cued location is suppressed and participants are biased to select targets appearing in the noncued location (Posner, 1980; Posner 1985). In a subsequent memory task, infants, children and adults consistently showed enhanced recognition memory when they engaged this IOR response to select the target while inhibiting orienting to the previously cued location (Markant & Amso, 2013, 2014; Markant et al., 2015). Thus, in this context-independent task, the ability to efficiently suppress competing information during target selection was related to enhanced learning about the selected information.

However, one can envision a learning context where competing information is not arbitrary but instead provides meaningful input for learning. For example, the spatial context in which a child typically plays with a toy (e.g., their playroom) may provide cues that facilitate their attention to and learning about the toy. A rich adult literature has extensively considered how these scene semantics influence both attention and learning. A classic example used in Loftus & Mackworth (1978) is a line drawing of a farmyard with objects strewn about including a tractor on one trial and an octopus in the same location on another trial. Observers attended more to the octopus, even when in the same location, as it was incongruent with the scene context. This top-down mechanism involves goal-directed attention control (Hayhoe et al., 2003; Jovancevic et al., 2006) paired with prior learning of scene content (Neider & Zelinsky, 2006; Henderson et al., 2009; Tatler et al., 2010). Wu, Wick, and Pomplun (2014) argue that scene semantic content or contextual information is processed in a memory-based manner and indeed this memory guides visual attention (memory-guided attention). In our view, the content of competing information must be considered in any discussion of attention control for learning, since children often bring prior knowledge to real-world scenes and learning environments.

Indeed, research using learning and memory paradigms has confirmed that the presence of competing contextual information that is task relevant can facilitate learning. For example, when a target is learned in relation to a repeated background context, the competing nontarget information may be encoded broadly as target relevant. When presented later in isolation in a subsequent memory task, the target may not be recognized as familiar because it is no longer presented paired with the previous context. Consistent with this idea, infants', children's, and adults' memory performance can be disrupted by changes to contextual information (e.g., background colors, scene information) that was reliably present during target encoding (e.g., Edgin et al., 2014; Hayes et al., 2007; Hayne et al., 2000; Jones et al., 2011). Edgin et al. (2014) found non-linear changes in the extent to which changing contextual information disrupted memory encoding from 3 to 16-years of age. Participants encoded target objects that were learned in the context of naturalistic scenes (e.g., a table within a dining room). During a subsequent recognition memory test, the target objects appeared either within the same scene context or on a white background. Although children younger than 4.5 years and older than 13 years of age both had more difficulty recognizing target objects when the context was changed, the authors attributed younger and older children's use of contextual information during encoding to different underlying mechanisms. Specifically, they argued that the youngest children encoded the targets and their context into a single unified representation, whereas the oldest children's increased reliance on contextual information reflected an increased ability to remember scene details and link them to the target. This pattern of results suggests that developing memory skills allow children to increasingly recognize target-context associations and flexibly use relevant contextual information during learning (Edgin et al., 2014).

These findings suggest that more work needs to be done to understand the mechanisms that contribute to poorer memory for targets in the presence of competing contextual information, as well as those that boost learning when relevant contextual information is available. Indeed, unlike experiments in which "task-relevant" targets and "task-irrelevant" distractors are clearly defined, the competing information that is present in young children's daily learning tasks often cannot be easily classified as goal-irrelevant noise. It is in these "context-interactive" situations that attending to competing information that is meaningful to ongoing tasks can facilitate task performance (Ackerman, 1990). While most work has emphasized the importance of executive attention for effective learning, additional research has demonstrated that young children's broader distribution of attention may facilitate learning from both target and competing non-target information. In their incidental learning paradigm described earlier, Hagen and Hale (1973) found that younger children showed enhanced incidental learning of the target/non-target image pairs, suggesting that their broader distribution of attention promoted learning of both target and competing information. In more recent work, Deng and Sloutsky (2015, 2016) found age-related changes in children's processing of non-target information during category learning tasks. In these studies, 4- and 6-7-year-old children and adults viewed items from two categories of novel alien creatures consisting of seven features (i.e., head, body, hands, feet, antennae, tail, body mark). One of these features (the "deterministic feature") could be used to reliably distinguish between the two categories. The remaining features (the "probabilistic features") frequently predicted category membership but also sometimes appeared on items from the opposite category. As a result, participants could categorize items based on a single deterministic feature or multiple probabilistic features. Older children and adults relied on the deterministic feature for categorization and showed better memory for this target feature, unless attention was intentionally directed to the probabilistic features. In contrast, 4-year-old children showed similar memory for deterministic and probabilistic features, regardless of their categorization strategy, suggesting that they attended to and learned from a broader range of information (e.g., Deng & Sloutsky, 2016). Compared to adults, 4-5-year-old children also showed enhanced memory for irrelevant features during a visual search task and were more likely to notice changes that occurred on irrelevant, uncued objects (Plebanek & Sloutsky, 2017). These findings suggest that young children's broader distribution of attention promotes learning from both task-relevant targets and competing, non-target information.

This broader distribution of attention can be especially beneficial when the competing information is meaningful to an ongoing learning task. In a study similar to those described above, 4-year-old children and adults completed a learning task in which two categories of novel alien creatures could be defined based on a single deterministic feature or multiple probabilistic features (Blanco & Sloutsky, 2019). Each exemplar also contained a feature that was initially irrelevant for categorization, but then became the defining feature midway through the task. Adults showed a larger performance cost after this shift, suggesting that they focused narrowly on the initial deterministic feature while ignoring the irrelevant feature and had difficulty learning about this feature when it became relevant. Young children's broader attention may have allowed them to more quickly shift to learning about the previously irrelevant feature when it became meaningful for the ongoing task (Blanco & Sloutsky, 2019). Additional work has shown similar beneficial effects of broadly distributing attention on the ability to learn from relevant competing information in both infancy (Best et al., 2013) and in older adulthood (Amer et al., 2016; Weeks & Hasher, 2014). Taken together, these findings suggest that younger children are more likely to attend to competing information, rather than focusing narrowly on task-relevant targets, and that this broader attention to competing information may be especially beneficial for learning when the content is relevant to an ongoing task.

These studies demonstrate that attending to competing contextual information can benefit learning when the information is relevant to task goals. One challenge is how to define learning environments that are context-interactive, in which competing information is meaningful for learning, versus those in which competing information will interfere with task goals and detract from learning. One possibility is that in novel contexts, learning or information-gathering is always part of the broad goal. In such cases, attending to competing information offers an opportunity to build scene semantic content or object category information. Moreover, learning tasks and goals may be clearly defined within formal learning environments (e.g., classrooms) but more difficult to explicitly identify within informal learning contexts (e.g., free play). Thus, the distinction between meaningful context versus unhelpful distraction can depend on the learning environment. Defining the task-relevance of competing information may also depend on the extent to which the learning environment contains redundant features that can support learning. For example, Kloos and Sloutsky (2008) found that categories with only one defining feature were learned most effectively when participants' attention was explicitly directed to this feature, whereas unsupervised learning without any explicit instruction was more effective when multiple features predicted category membership. These results indicate that the structure of the learning task (i.e., feature redundancy) influenced whether attending to competing information was beneficial for learning.

As described above, the benefits of ignoring task-irrelevant competing information for learning have been observed in a range of learning tasks and environments, including controlled laboratory tasks, formal classrooms, computer-based lessons and specific learning materials. To date, researchers have relied on a narrower range of tasks to demonstrate that attending to task-relevant competing information can facilitate children's learning, although work with older adults has identified this benefit across multiple paradigms (e.g., Amer et al., 2016; Weeks & Hasher, 2014). Future research can investigate whether there are differential impacts of task-relevant and -irrelevant sources of competing information across varying learning environments and tasks. In particular, research can further examine how attending to relevant competing information affects children's learning in both formal learning environments with clearly defined learning goals as well as informal learning environments in which learning goals are less well defined. In the sections below we review available evidence suggesting that developing attention control skills will support more effective learning from relevant competing information in both contexts.



### ***The Value of Developing Attention Control: Defined Learning Goals***

Although the research described above has shown that young children may more readily learn from a wider range of both target and competing non-targets (Blanco & Sloutsky, 2019; Deng & Sloutsky, 2015, 2016; Hagen & Hale, 1973; Plebanek & Sloutsky, 2017), additional data suggest that taking advantage of relevant contextual information during target learning requires developing attention control. In a series of studies, Ackerman and colleagues (Ackerman 1986, 1987a, 1987b;

Ackerman et al., 1989) demonstrated that processing conceptual links between target and non-targets can facilitate learning. In these studies, children and adults completed an oddity task in which they viewed three words and were asked to identify and remember a target word that was conceptually distinct from the remaining words. During easy trials the target word (e.g., nurse) was clearly unique from the non-targets (e.g., rain, snow), whereas during hard trials it was more closely related to the non-targets (e.g., doctor, dentist). At all ages, participants showed enhanced recall for target words encoded during the hard trials. These results suggest that attending to and contrasting the targets and non-targets during the hard trials facilitated encoding, whereas focusing on the conceptually distinct targets during the easy trials was less beneficial for learning (Ackerman 1990; Ackerman et al. 1989). However, the youngest children were less likely to engage in this more difficult contrastive processing during trials in which they could rely on the researcher to identify the unique target word (Ackerman et al., 1989). These results demonstrate that the presence of relevant competing information can benefit children's learning, but young children will not always automatically take advantage of this information.

More recent work similarly demonstrated that the mere presence of relevant competing information does not necessarily benefit children's learning. Remington et al. (2019) examined whether lesson-relevant and -irrelevant classroom decorations differentially affected learning among 7- to 14-year-old typically developing children and those diagnosed with ASD. Children viewed instructional videos in which a teacher appeared in a sparse display without any peripheral images or in a highly decorated display containing background images that were either relevant or irrelevant to ongoing story book lessons. Following the lessons children were tested on their knowledge of the primary lesson topics as well as the background visual information. Children in the ASD group remembered more details about the irrelevant background images, but overall children showed similarly effective learning of the primary story lessons in the context of both relevant and irrelevant background images (Remington et al., 2019). Like Ackerman et al. (1989), this research suggests that children do not always automatically process relevant contextual information when it is available. Instead, developing attention control skills that affect children's selection of relevant vs. irrelevant competing information may affect learning to a greater extent than the mere presence of this information. As described above, prior studies have found that the extent of children's looking to irrelevant competing information was an important predictor of learning outcomes (Erickson et al., 2015; Fisher et al., 2014; Hanley et al., 2017). Consistent with this, additional work found that 4-8-year-old children's learning from relevant non-targets during a visual search task was predicted by both their attention skills and their looking to the relevant information during search (King & Markant, 2020). Children completed an initial encoding task and a secondary visual search task that included a subset of objects from encoding as non-targets. These objects were labeled "relevant non-targets" since they were related to the initial learning task but were not central to the visual search task. Individual differences in developing attention skills were assessed based on children's response times to detect the target object during the search task. Finally, participants completed a recognition memory task that included all of the objects presented during encoding. Children showed overall better memory for objects that appeared as relevant non-targets, with the extent of this benefit predicted by children's developing attention skills and patterns of looking to the relevant non-targets during search. Children with more efficient attention skills showed a larger learning benefit only if they also engaged in increased scanning of the relevant non-targets following target detection (King & Markant, 2020). These results suggest that children's learning from relevant competing information is an active process that requires developing attention skills to support effective search strategies.

Overall, several studies have indicated that young children with poorer selective attention skills may learn more from competing non-target stimuli due to their broader attention allocation (Blanco & Sloutsky, 2019; Deng & Sloutsky, 2015, 2016; Hagen & Hale, 1973; Plebanek & Sloutsky, 2017). However, additional work also suggests that children's ability to learn from task-relevant competing information may depend on developing selective attention control (King & Markant, 2020). Blanco and Sloutsky (2019) argued that young children's more distributed attention may allow them to learn from a wider array of information whereas older children and adults may be able to more flexibly control their attention to shift between selective or distributed attention or shift attention across multiple sources of input. Thus, developing control over attention may allow for more effective learning from contextual information as increasing flexibility supports attention to multiple sources of relevant input (Hanania & Smith, 2010) while increasingly efficient selection supports enhanced processing of attended information (Markant & Amso, 2013, 2014).

***The Value of Developing Attention Control: Undefined Learning Goals***

Developing attention control may also be important for children's learning in informal learning contexts characterized by multiple sources of sensory input but no clearly identified learning goal. Effective learning within these contexts requires learning the structure of the environment while remaining sensitive to relevant information that occurs across multiple inputs. Because complex, dynamic environments contain vast amounts of potentially relevant information, individuals must adopt a search strategy that balances information gathering ("exploration") with effective use of the acquired information ("exploitation"; Gopnik 2020; Nussenbaum & Hartley, 2019). Strategies weighted more towards exploration are aimed at gathering a wider range of information, rather than maximizing the value of available information. Alternatively, individuals can more narrowly align their search based on the value of available information and strategically adjust their search as these values change (Gopnik 2020; Nussenbaum & Hartley, 2019).

Researchers studying reinforcement learning, value-based decision making, and causal learning have found that young children are more likely to engage in broad exploratory strategies rather than responding based on utility or reward outcomes (Gopnik et al., 2015, 2017; Lucas et al., 2014; Nussenbaum & Hartley, 2019; Schulz et al., 2019). Younger children show this increased exploration despite being able to correctly identify the most valuable reward option (Plate et al., 2018). Instead, this broader exploration may reflect young children's less fixed knowledge about their environments, prompting them to more readily shift search behaviors. For example, among 5-, 6-, and 7-year-old children, only the youngest children generated novel problem-solving uses for a tool, regardless of whether they were initially informed of the conventional use of the tool (German & Defeyter, 2000).

Researchers have argued that visual attention, like exploration, functions as a search mechanism aimed at reducing uncertainty about the environment (e.g., Gottlieb 2012, 2018). From this perspective, young children's broader distribution of attention may parallel their increased exploration and reflect increased uncertainty about their environment. Blanco & Sloutsky (2020) examined the relationship between attention and exploration during 4-year-old and adults' performance on a value-based decision-making task in which a perceptually salient cue indicated either the highest or lowest value choice. Introducing this salient attention cue interfered with children's systematic exploration of response options but had little effect on adults' exploitation of high-value choices. These results suggest that adults selectively attend to value whereas children attend to a broader range of information in support of systematic exploration (Blanco & Sloutsky, 2020).

Young children's broad distribution of attention may be especially adaptive in undefined learning contexts and/or in novel contexts when pre-existing knowledge about the structure of the environment is limited. Attending to a wider range of information ensures that children remain sensitive to novel information that may become relevant for learning (Blanco & Sloutsky, 2019; Rich & Gureckis, 2018). However, the tradeoff of this broad attention distribution is that the quality of information processing of attended information is reduced (Blanco & Sloutsky, 2019). Thus, as the structure of the environment or task context is learned, attention control may become increasingly adaptive to allow for suppression of competing information that is understood to be irrelevant while also flexibly shifting attention across relevant inputs. This shift from broad distribution of attention to increasing strategic control over attention may parallel observed developmental shifts from broad exploration to increasingly strategic exploration. For example, compared to children, adults more rapidly adjusted their search strategies to consistently select the highest-valued options, despite showing similar levels of initial exploration (Plate et al., 2018). These results suggest that adults are better able to strategically control the extent of their exploration as they learn the structure of the task. As children acquire knowledge, developing attention control may similarly allow them to strategically attend to and learn from multiple sources of relevant input while ignoring irrelevant competing information.

### ***Summary***

Competing information can provide rich input for learning – and should not always be ignored. But whether the presence of this competing information will help or hinder learning will depend on multiple factors, including the learning goals of the developing child, the learning context that determines the relevance of competing information to ongoing tasks, and children's ability to engage attention control to select relevant information and encode relations across multiple sources of relevant inputs. Future research should be aimed at understanding how these complex interactions across learning contexts and developing attention and memory systems shape children's learning in dynamic environments.

## References

Ackerman, B. P. (1986). The relation between attention to the incidental context and memory for words in children and adults. *Journal of Experimental Child Psychology, 42*(1), 149-183.

Ackerman, B. P. (1987a). Attention and memory in children and adults in context-interactive and context-independent situations. *Journal of Experimental Child Psychology, 44*(2), 192-221.

Ackerman, B. P. (1987b). Selective attention and distraction in context-interactive situations in children and adults. *Journal of Experimental Child Psychology, 44*(1), 126-146.

Ackerman, B. P. (1990). Attention and memory in context-independent and context-interactive situations. In *Advances in Psychology* (Vol. 69, pp. 289-304): North-Holland.

Ackerman, B. P., Spiker, K., & Bailey, K. (1989). The relation between resource limitations and optional conceptual processing by children and adults. *Child Development*, *60*(5), 1200–1211.

Amer, T., Campbell, K. L., & Hasher, L. (2016). Cognitive control as a double-edged sword. *Trends in Cognitive Sciences*, *20*(12), 905–915. https://doi.org/10.1016/j.tics.2016.10.002

Amso, D., Haas, S., McShane, L., & Badre, D. (2014). Working memory updating and the development of rule-guided behavior. *Cognition*, *133*, 201–210. https://doi.org/10.1016/j.cognition.2014.06.012

Amso, D., Salhi, C., & Badre, D. (2019). The relationship between cognitive enrichment and cognitive control: A systematic investigation of environmental influences on development through socioeconomic status. *Developmental Psychobiology*, *61*(2), 159–178. https://doi.org/10.1002/dev.21794

Amso, D., & Scerif, G. (2015). The attentive brain: insights from developmental cognitive neuroscience. *Nature Reviews Neuroscience, 16*(10), 606-619.

Best, J.R., Miller, P.H., & Jones, L.L. (2009). Executive functions after age 5: Changes and correlates. *Developmental Review, 29*(3), 180-200.

Best, C. A., Yim, H., & Sloutsky, V. M. (2013). The cost of selective attention in category learning: Developmental differences between adults and infants. *Journal of Experimental Child Psychology, 116*(2), 105-119.

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*(2), 647–663. https://doi.org/10.1111/j.1467-8624.2007.01019.x

Blanco, N. J., & Sloutsky, V. M. (2019). Adaptive flexibility in category learning? Young children exhibit smaller costs of selective attention than adults. *Developmental Psychology. 55(10), 2060-2076.*

Blanco, N. J., & Sloutsky, V. M. (2020). Attentional mechanisms drive systematic exploration in young children. *Cognition, 202*, 104327.

Bohlmann, N. L., & Fenson, L. (2005). The effects of feedback on perseverative errors in preschool aged children. *Journal of Cognition and Development, 6*(1), 119-131.

Bondarko, V. M., & Semenov, L. A. (2005). Visual acuity and the crowding effect in 8-to 17-year-old schoolchildren. *Human Physiology, 31*(5), 532-538.

Brace, J. J., Morton, J. B., & Munakata, Y. (2006). When actions speak louder than words: Improving children's flexibility in a card-sorting task. *Psychological Science, 17*(8), 665-669.

Braem, S., & Egner, T. (2018). Getting a grip on cognitive flexibility. *Current Directions in Psychological Science*, *27*(6), 470–476. https://doi.org/10.1177/0963721418787475

Broadbent, H. J., Osborne, T., Mareschal, D., & Kirkham, N. Z. (2019). Withstanding the test of time : Multisensory cues improve the delayed retention of incidental learning. *Developmental Science*, *22*, e12726. https://doi.org/10.1111/desc.12726

Broadbent, H. J., White, H., Mareschal, D., & Kirkham, N. Z. (2018). Incidental learning in a multisensory environment across childhood. *Developmental Science*, *21*(2018), e12554. https://doi.org/10.1111/desc.12554

Brooks, P. J., Hanauer, J. B., Padowska, B., & Rosman, H. (2003). The role of selective attention in preschoolers' rule use in a novel dimensional card sort. *Cognitive Development, 18*(2), 195-215.

Burgoyne, A. P., & Engle, R. W. (2020). Attention control: A cornerstone of higher-order cognition. *Current Directions in Psychological Science*, *29*(6), 624–630. https://doi.org/10.1177/0963721420969371

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research, 51*(13), 1484-1525.

Carrasco, M. (2014). Spatial covert attention: Perceptual modulation. In A. C. Nobre & S. Kastner (Eds.), *Oxford Library of Psychology. The Oxford Handbook of Attention* (pp. 183-230). Oxford: Oxford University Press.

Chevalier, N. (2015). The Development of executive function: Toward more optimal coordination of control with age. *Child Development Perspectives*, *9*(4), 239–244. https://doi.org/10.1111/cdep.12138

Chevalier, N., Blaye, A., Dufau, S., & Lucenet, J. (2010). What visual information do children and adults consider while switching between tasks? Eye-tracking investigation of cognitive flexibility development. *Developmental Psychology*, *46*(4), 955–972. https://doi.org/10.1037/a0019674

Cragg, L., & Chevalier, N. (2012). The processes underlying flexibility in childhood. *Quarterly Journal of Experimental Psychology*, *65*(2), 209–232. https://doi.org/10.1080/17470210903204618

Dajani, D. R., & Uddin, L. Q. (2015). Demystifying cognitive flexibility: Implications for clinical and developmental neuroscience. *Trends in Neurosciences*, *38*(9), 571–578. https://doi.org/10.1016/j.tins.2015.07.003

Deng, S., & Sloutsky, V. M. (2015). The development of categorization: Effects of classification and inference training on category representation. *Developmental Psychology, 51*(3), 392-405.

Deng, S., & Sloutsky, V. M. (2016). *Plasticity of categorization: Developmental differences in category learning and transfer between children and adults.* Paper presented at the Cognitive Science Society, Philadelphia, PA.

Desrochers, T. M., Burk, D. C., Badre, D., & Sheinberg, D. L. (2016). The monitoring and control of task sequences in human and non-human primates. *Frontiers in Systems Neuroscience*, *9*, 1–18. https://doi.org/10.3389/fnsys.2015.00185

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., Carlson, S. M., & Beck, D. M. (2005). Preschool children's performance in task switching on the dimensional change card sort task: Separating the dimensions aids the ability to switch. *Developmental Neuropsychology, 28*(2), 689-729.

Dick, A. S. (2014). The development of cognitive flexibility beyond the preschool period: An investigation using a modified Flexible Item Selection Task. *Journal of Experimental Child Psychology*, *125*(1), 13–34. https://doi.org/10.1016/j.jecp.2014.01.021

Donnelly, N., Cave, K., Greenway, R., Hadwin, J. A., Stevenson, J., & Sonuga-Barke, E. (2007). Visual search in children and adults: Top-down and bottom-up mechanisms. *Quarterly Journal of Experimental Psychology, 60*(1), 120-136.

Edgin, J. O., Spano, G., Kawa, K., & Nadel, L. (2014). Remembering things without context: development matters. *Child Development, 85*(4), 1491-1502.

Eng, C.M., Godwin, K.E., & Fisher, A.V. (2020). Keep it simple: streamlining book illustrations improves attention and comprehension in beginning readers. *npj Science of Learning, 5,*(14)

Enns, J. T., & Girgus, J. S. (1985). Perceptual grouping and spatial distortion: A developmental study. *Developmental Psychology, 21*(2), 241-246.

Erickson, L. C., Thiessen, E. D., Godwin, K. E., Dickerson, J. P., & Fisher, A. V. (2015). Endogenously and exogenously driven selective sustained attention: Contributions to learning in kindergarten children. *Journal of Experimental Child Psychology, 128*, 126-134.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*(1), 143-149.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340-347.

Fan, J., Raz, A., & Posner, M. I. (2003). Attentional mechanisms. In R. Daroff & M. Aminoff (Eds.), *Encyclopedia of the Neurological Sciences*: Elsevier Science.

Fisher, A. V., Godwin, K. E., & Seltman, H. (2014). Visual environment, attention allocation, and learning in young children: When too much of a good thing may be bad. *Psychological Science, 25*(7), 1362-1370.

Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development, 10*(4), 483-527.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gerhardstein, P., & Rovee-Collier, C. (2002). The development of visual search in infants and very young children. *Journal of Experimental Child Psychology, 81*(2), 194-215.

German, T. P., & Defeyter, M. A. (2000). Immunity to functional fixedness in young children. *Psychonomic Bulletin and Review, 7*, 707-712.

Gopnik, A. (2020). Childhood as a solution to explore–exploit tensions. *Philosophical Transactions of the Royal Society B, 375*(1803), 20190502.

Gopnik, A., Griffiths, T. L., & Lucas, C. G. (2015). When younger learners can be better (or at least more open-minded) than older ones. *Current Directions in Psychological Science, 24*(2), 87-92.

Gopnik, A., O'Grady, S., Lucas, C. G., Griffiths, T. L., Wente, A., Bridgers, S., . . . Dahl, R. E. (2017). Changes in cognitive flexibility and hypothesis search across human life history from childhood to adolescence to adulthood. *Proceedings of the National Academy of Sciences, 114*(30), 7892-7899.

Gottlieb, J. (2012). Attention, learning, and the value of information. *Neuron, 76*(2), 281-295.

Gottlieb, J. (2018). Understanding active sampling strategies: Empirical approaches and implications for attention and decision research. *Cortex, 102*, 150-160.

Hagen, J. W., & Hale, G. A. (1973, February). *The development of attention in children*. Paper presented at the Minnesota Symposia on Child Psychology, Minneapolis, MN.

Hanania, R., & Smith, L. B. (2010). Selective attention and attention switching: Towards a unified developmental approach. *Developmental Science, 13*(4), 622-635.

Hanley, M., Khairat, M., Taylor, K., Wilson, R., Cole-Fletcher, R., & Riby, D. M. (2017). Classroom displays—Attraction or distraction? Evidence of impact on attention and learning from children with and without autism. *Developmental Psychology, 53*(7), 1265-1275.

Hayes, S. M., Nadel, L., & Ryan, L. (2007). The effect of scene context on episodic object recognition: Parahippocampal cortex mediates memory encoding and retrieval success. *Hippocampus*, *17*, 873–889. https://doi.org/10.1002/hipo.20319

Hayhoe, M. M., Shrivastava, A., Mruczek, R., & Pelz, J. B. (2003). Visual memory and motor planning in a natural task. *Journal of Vision*, *3*(1), 49–63. https://doi.org/10.1167/3.1.6

Hayne, H., Boniface, J., & Barr, R. (2000). The development of declarative memory in human infants: Age-related changes in deferred imitation. *Behavioral Neuroscience, 114*(1), 77-83.

Hedges, J. H., Adolph, K. E., Amso, D., Bavelier, D., Fiez, J. A., Krubitzer, L., . . . Ghajar, J. (2013). Play, attention, and learning: how do play and timing shape the development of attention and influence classroom learning? *Annals of the New York Academy of Sciences, 1292*(1), 1-20.

Henderson, J. M., Chanceaux, M., & Smith, T. J. (2009). The influence of clutter on real-world scene search: Evidence from search efficiency and eye movements. Journal of Vision, 9(1), 1–8. https://doi.org/10.1167/9.1.32

Hwang, K., Velanova, K., & Luna, B. (2010). Strengthening of top-down frontal cognitive control networks underlying the development of inhibitory control: a functional magnetic resonance imaging effective connectivity study. *Journal of Neuroscience, 30*(46), 15535-15545.

Jacques, S., & Zelazo, P. D. (2001). The Flexible Item Selection Task (FIST): A measure of executive function in preschoolers. *Developmental Neuropsychology*, *20*(3), 573–591. https://doi.org/10.1207/S15326942DN2003_2

Jeon, S. T., Hamid, J., Maurer, D., & Lewis, T. L. (2010). Developmental changes during childhood in single-letter acuity and its crowding by surrounding contours. *Journal of Experimental Child Psychology, 107*(4), 423-437.

Johnson, S. P. (1995). *Young infants perception of surface in-depth-transparency, texture, and illusory contours.* Paper presented at the Investigative Ophthalmology & Visual Science, Philadelphia, PA.

Jones, E. J. H., Pascalis, O., Eacott, J. E., & Herbert, J. S. (2011). Visual recognition memory across contexts. *Developmental Science, 14*(1), 136-147.

Jovancevic, J., Sullivan, B., & Hayhoe, M. (2006). Control of attention and gaze in complex environments. *Journal of Vision*, *6*(12), 1431–1450. https://doi.org/10.1167/6.12.9

Kaminski, J. A., & Sloutsky, V. M. (2013). Extraneous perceptual information interferes with children's acquisition of mathematical knowledge. *Journal of Educational Psychology, 105*(2), 351-363.

King, J., & Markant, J. (2020). Individual differences in selective attention and scanning dynamics influence children’s learning from relevant non-targets in a visual search task. *Journal of Experimental Child Psychology, 193*, 104797.

Kirkham, N. Z., Cruess, L., & Diamond, A. (2003). Helping children apply their knowledge to their behavior on a dimension-switching task. *Developmental Science, 6*(5), 449-467.

Kloo, D., & Perner, J. (2005). Disentangling dimensions in the dimensional change card-sorting task. *Developmental Science, 8*(1), 44-56.

Kloos, H., & Sloutsky, V. M. (2008). What’s behind different kinds of kinds: Effects of statistical density on learning and representation of categories. *Journal of Experimental Psychology: General*, *137*(1), 52–72. https://doi.org/10.1037/0096-3445.137.1.52

Konrad, K., Neufang, S., Thiel, C. M., Specht, K., Hanisch, C., Fan, J., . . . Fink, G. R. (2005). Development of attentional networks: an fMRI study with children and adults. *Neuroimage, 28*(2), 429-439.

Loftus, G. R., & Mackworth, N. H. (1978). Cognitive determinants of fixation location during picture viewing. In *Journal of Experimental Psychology: Human Perception and Performance* (Vol. 4, Issue 4, pp. 565–572). https://doi.org/10.1037//0096-1523.4.4.565

Lucas, C. G., Bridgers, S., Griffiths, T. L., & Gopnik, A. (2014). When children are better (or at least more open-minded) learners than adults: Developmental differences in learning the forms of causal relationships. *Cognition, 131*(2), 284-299.

Luck, S. J., & Vecera, S. P. (2002). Attention. In H. Pashler & S. Yantis (Eds.), *Stevens' Handbook of Experimental Psychology: Sensation and Perception* (Vol. 1, pp. 235-286). Hoboken: John Wiley & Sons, Inc.

Luna, B., Garver, K. E., Urban, T. A., Lazar, N. A., & Sweeney, J. A. (2004). Maturation of cognitive processes from late childhood to adulthood. *Child Development, 75*(5), 1357-1372.

Markant, J., & Amso, D. (2013). Selective memories: infants' encoding is enhanced in selection via suppression. *Developmental Science, 16*(6), 926-940.

Markant, J., & Amso, D. (2014). Leveling the playing field: Attention mitigates the effects of intelligence on memory. *Cognition, 131*(2), 195-204.

Markant, J., & Amso, D. (2016). The development of selective attention orienting is an agent of change in learning and memory efficacy. *Infancy, 21*(2), 154-176.

Markant, J., Oakes, L. M., & Amso, D. (2016). Visual selective attention biases contribute to the other-race effect among 9-month-old infants. *Developmental Psychobiology, 58*(3), 355-365.

Markant, J., Worden, M. S., & Amso, D. (2015). Not all attention orienting is created equal: Recognition memory is enhanced when attention orienting involves distractor suppression. *Neurobiology of Learning and Memory, 120*, 28-40.

Massonnié, J., Rogers, C. J., Mareschal, D., & Kirkham, N. Z. (2019). Is classroom noise always bad for children? The contribution of age and selective attention to creative performance in noise. *Frontiers in Psychology, 10*, 381.

Matusz, P. J., Broadbent, H., Ferrari, J., Forrest, B., Merkley, R., & Scerif, G. (2015). Multi-modal distraction: Insights from children's limited attention. *Cognition*, *136*, 156–165. https://doi.org/10.1016/j.cognition.2014.11.031

Matusz, P. J., Merkley, R., Faure, M., & Scerif, G. (2019). Expert attention: Attentional allocation depends on the differential development of multisensory number representations. *Cognition*, *186*(June 2018), 171–177. https://doi.org/10.1016/j.cognition.2019.01.013

Matusz, P. J., Turoman, N., Tivadar, R., Retsa, C., & Murray, M. M. (2018). Brain and cognitive mechanisms of top-down attentional control in a multisensory world: Benefits of electrical neuroimaging. *Journal of Cognitive Neuroscience*, *31*(3), 412–430. https://doi.org/10.1162/jocn_a_01360

Neider, M. B., & Zelinsky, G. J. (2006). Scene context guides eye movements during visual search. *Vision Research*, *46*(5), 614–621. https://doi.org/10.1016/j.visres.2005.08.025

Nussenbaum, K., & Hartley, C. A. (2019). Reinforcement learning across development: What insights can we draw from a decade of research? *Developmental Cognitive Neuroscience, 40*, 100733.

Oakes, L. M., & Amso, D. (2018). Development of visual attention. In S. Ghetti (Ed.), *Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience* (Vol. 4, pp. 1-33). Hoboken: John Wiley & Sons, Inc.

Pasto, L., & Burack, J. A. (1997). A developmental study of visual attention: Issues of filtering efficiency and focus. *Cognitive Development, 12*(4), 523-535.

Perner, J., & Lang, B. (2002). What causes 3-year-olds' difficulty on the dimensional change card sorting task? *Infant and Child Development: An International Journal of Research and Practice, 11*(2), 93-105.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*(1), 73-89.

Plate, R. C., Fulvio, J. M., Shutts, K., Green, C. S., & Pollack, S. D. (2018). Probability learning: Changes in behavior across time and development. *Child Development, 89*(1), 205-218.

Plebanek, D. J., & Sloutsky, V. M. (2017). Costs of selective attention: When children notice what adults miss. *Psychological Science, 28*(6), 723-732.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25. https://doi.org/10.1080/00335558008248231

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*(1), 25-42.

Posner, M. I., Rafal, R. D., & Choate, L. S. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology*, *2*, 211–228. https://doi.org/10.1080/02643298508252866

Posner, M. I., & Rothbart, M. K. (2009). Toward a physical basis of attention and self-regulation. *Physics of Life Reviews, 6*(2), 103-120.

Remington, A., Hanley, M., O'Brien, S., Riby, D. M., & Swettenham, J. (2019). Implications of capacity in the classroom: Simplifying tasks for autistic children may not be the answer.

*Research in Developmental Disabilities*, *85*, 197–204. https://doi.org/10.1016/j.ridd.2018.12.006

Rich, A. S., & Gureckis, T. M. (2018). The limits of learning: Exploration, generalization, and the development of learning traps. *Journal of Experimental Psychology: General, 147*(11), 1553-1570.

Rodrigues, P. F. S., & Pandeirada, J. N. S. (2018). When visual stimulation of the surrounding environment affects children's cognitive performance. *Journal of Experimental Child Psychology, 176*, 140-149.

Rothbart, M. K., Sheese, B. E., & Posner, M. I. (2007). Executive attention and effortful control: Linking temperament, brain networks, and genes. *Child Development Perspectives, 1*(1), 2-7.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia, 42*(8), 1029-1040.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences*, *102*(41), 14931–14936. https://doi.org/10.1073.pnas.0506897102

Scerif, G., Cornish, K., Wilding, J., Driver, J., & Karmiloff-Smith, A. (2004). Visual search in typically developing toddlers and toddlers with Fragile X or Williams syndrome. *Developmental Science, 7*(1), 116-130.

Scerif, G., Karmiloff-Smith, A., Campos, R., Elsabbagh, M., Driver, J., & Cornish, K. (2005). To look or not to look? Typical and atypical development of oculomotor control. *Journal of Cognitive Neuroscience, 17*(4), 591-604.

Schulz, E., Wu, C. M., Ruggeri, A., & Meder, B. (2019). Searching for rewards like a child means less generalization and more directed exploration. *Psychological Science, 11*, 1561-1572.

Stevens, C., & Bavelier, D. (2012). The role of selective attention on academic foundations: A cognitive neuroscience perspective. *Developmental Cognitive Neuroscience, 2*, S30-S48.

Tatler, B. W., Wade, N. J., Kwan, H., Findlay, J. M., & Velichkovsky, B. M. (2010). Yarbus, eye movements, and vision. I-Perception, 1(1), 7–27. https://doi.org/10.1068/i0382

Tiego, J., Bellgrove, M. A., Whittle, S., Pentalis, C., & Testa, R. (2020). Common mechanisms of executive attention underlie executive function and effortful control in children. *Developmental Science, 23*(3), e12918.

Towse, J. N., Redbond, J., Houston-Price, C. M., & Cook, S. (2000). Understanding the dimensional change card sort: Perspectives from task success and failure. *Cognitive Development, 15*(3), 347-365.

Trick, L. M., & Enns, J. T. (1998). Lifespan changes in attention: The visual search task. *Cognitive Development, 13*(3), 369-386.

Triesman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*(1), 97-136.

Turoman, N., Tivadar, R. I., Retsa, C., Maillard, A. M., Scerif, G., & Matusz, P. J. (2021). The development of attentional control mechanisms in multisensory environments. *Developmental Cognitive Neuroscience*, *48*(November 2020).

https://doi.org/10.1016/j.dcn.2021.100930

Waszak, F., Li, S. C., & Hommel, B. (2010). The development of attentional networks: Cross-sectional findings from a life span sample. *Developmental Psychology, 46*(2), 337-349.

Weeks, J. C., & Hasher, L. (2014). The disruptive–and beneficial–effects of distraction on older adults' cognitive performance. *Frontiers in Psychology, 5*, 133.

Wolf, K., & Pfeiffer, T. (2014). The development of attentional resolution. *Cognitive Development, 29*, 62-80.

Wu, C. C., Wick, F. A., & Pomplun, M. (2014). Guidance of visual attention by semantic information in real-world scenes. *Frontiers in Psychology*, *5*(FEB), 1–13. https://doi.org/10.3389/fpsyg.2014.00054

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11*(1), 37-63.

Zhang, Y., Meyers, E. M., Bichot, N. P., Serre, T., Poggio, T. A., & Desimone, R. (2011). Object decoding with attention in inferior temporal cortex. *Proceedings of the National Academy of Sciences, 108*(21), 8850-8855.

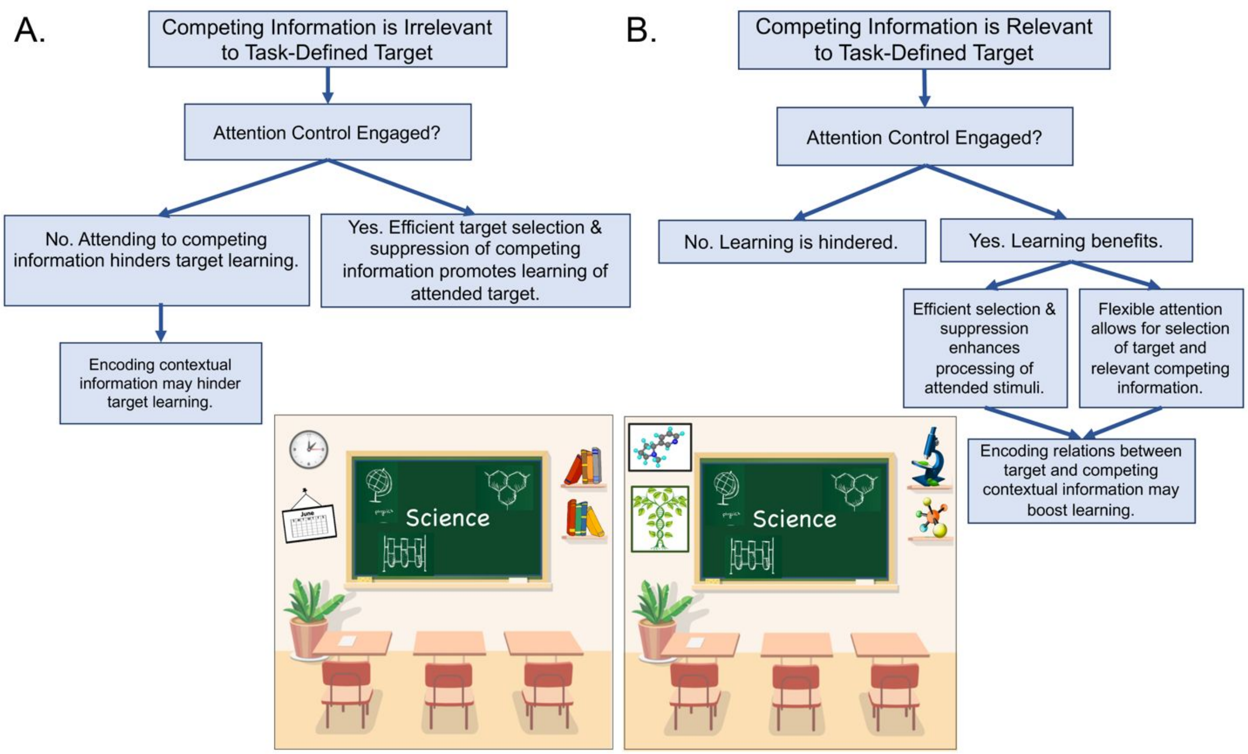



Figure 1. An illustration of the effects of learning context, attention control, and relational encoding on children's learning. (A) In the context of a clearly defined learning task occurring in the context of irrelevant competing information, engaging attention control promotes learning by supporting efficient target selection and suppression of competing distractors. In this case, attending to goal-irrelevant competing information and encoding relations between the target and competing distractors would be detrimental for learning. For example, attending to unrelated or extraneous contextual information during a science lesson can be detrimental to learning. (B) In contrast, when competing information is relevant to an ongoing learning task attending to this information can benefit learning. In this case attention control remains valuable as efficient selection and suppression enhances processing of attended stimuli while flexible attention shifting allows for selection of both the target and relevant contextual information. Encoding relations across the target and competing information may boost learning and provide guidance for subsequent attention orienting. For example, if competing contextual information is related to an ongoing science lesson, attending to this information and encoding the relations between the contextual information and lesson material may benefit learning.