Endogenously- but not Exogenously-driven Selective Sustained Attention is Related to Learning in a Classroom-like Setting in Kindergarten Children

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Abstract

Selective sustained attention (SSA) is vital for higher order cognition. Although endogenous and exogenous factors influence SSA, assessment of the degree to which these factors influence performance and learning is often challenging. We report findings from the Track-It task, a paradigm that aims to assess the contribution of endogenous and exogenous factors to SSA within the same task. Behavioral accuracy and eye-tracking data on the Track-It task were correlated with performance on a learning task. Behavioral accuracy and fixations to distractors did not predict learning when exogenous factors supported SSA. In contrast, fixations to distractors were negatively correlated with learning when endogenous factors supported SSA. Similarly, higher behavioral accuracy was correlated with greater learning when endogenous factors supported SSA. These findings suggest that although children showed equivalent levels of distractibility when exogenous and endogenous factors supported SSA, different conditions of the Track-It task likely engaged different attentional control mechanisms.

Keywords: selective attention; sustained attention; attention and learning; measurement; exogenous and endogenous factors

Introduction

Selective sustained attention (SSA) is the ability to process some parts of the environment at the exclusion of others over a period of time, an ability that has been argued to be fundamental to learning. In particular, selective sustained attention has been implicated in contexts ranging from infants learning their first words (e.g., Yu & Smith, 2012) to college students learning in formal educational settings (e.g., Wei, Wang, & Klausner, 2012). Despite agreement on the importance of SSA for human learning and performance, several key theoretical questions about the development of attention, and the relation between attentional processes and learning outcomes, remain unresolved.

One of the challenges in addressing questions about the relation between attention and learning is the paucity of appropriate experimental paradigms, particularly for preschool-age children. With regards to assessment of SSA, preschoolers are in a measurement gap: they are too old for the assessment tools used with infants and toddlers, but often too young to generate usable data on adult tasks adapted for use with children (e.g., Continuous Performance Task; for review see Fisher & Kloos, in press). Additionally, any paradigm assessing young children's SSA needs to be similarly motivating across a range of ages, such that age-related changes in young children's performance can be attributed to changes in psychological processes rather than to age-related differences in the level of motivation and engagement in the task. In order to address this measurement gap we developed a novel paradigm to study SSA in preschool-age children, the Track-It task (Fisher & Kloos, in press; Fisher, Thiessen, Godwin, Kloos, & Dickerson, 2013). In the Track-It task participants visually track a target moving along a random trajectory on a grid. The target can be accompanied by several distractors, also moving along random trajectories. The participants' task is to report the last grid location visited by the target before it disappears.

Prior research with the Track-It task has primarily focused on disentangling the *endogenous* and *exogenous* factors that support SSA. Exogenous factors relate to the characteristics

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of the stimuli (e.g., contrast, brightness, motion, etc.); they are often described in terms of the degree to which a stimulus is "salient." In newborns and very young infants, selection is typically described as stimulus-driven or automatic such that the locus of attention is determined largely by the physical properties of a stimulus (for reviews see Bornstein, 1990; Ruff & Rothbart, 2001). Over the course of development, endogenous factors come to play a larger role in SSA (Diamond, 2006; Colombo & Cheatham, 2006; Oakes, Kannass, & Shaddy, 2002; Ruff & Rothbart, 2001). Endogenous factors are cognitive processes, such as working memory which is necessary for goal representation, that allow the organism to voluntarily control the locus of its attention (Colombo & Cheatham, 2006; Kane & Engle, 2002).

In the Track-It task, the contributions of exogenous and endogenous factors are assessed through distractor manipulations. Specifically, in the Homogeneous distractors condition the distractors are identical to each other (e.g., red triangles) and different from the target (e.g., a blue square); in the Heterogeneous distractors condition the distractors are unique from each other (e.g., a red triangle and a green diamond) and from the target (e.g., a blue square). Tracking accuracy in the Heterogeneous distractors condition is hypothesized to reflect the contribution of predominantly endogenous factors: the task provides no contextual support to benefit performance (e.g., each object in the set is equally distinct and therefore targets are no more salient than distractors) and children have to exert effortful control to remain on-task. In contrast, in the Homogeneous distractors condition the target object is distinct and therefore more salient than the distractors. Thus, performance in the Homogeneous distractors condition is hypothesized to reflect the contributions of both endogenous factors (e.g., effortful control) and exogenous factors (e.g., higher saliency of target objects compared to distractors).

If different conditions of the Track-It task tap into separate and differentiable factors supporting attention, these conditions should be more or less predictive of learning outcomes as a function of how closely the learning task relates to (or depends upon) exogenous or endogenous processes. This prediction has not been thoroughly assessed in the developmental literature. Most claims about the relation between attention and learning outcomes have simply established that some form of attention is *necessary* for learning. For example, prior experiments have demonstrated that infants and young children learn better when they attend to the input, and that attention to particular aspects of the input facilitates learning of those aspects (e.g., Baker, Olson, & Behrmann, 2004; Toro, Sinnett, & Soto-Faraco, 2005). However, these prior experiments have not distinguished between exogenous and endogenous factors promoting attention, nor how these different factors might be differentially involved in different tasks.

We suggest that endogenous attention will be useful primarily in tasks that involve explicit learning, in settings where the child has some discretion over which aspect of the input to which he or she attends. By contrast, exogenous attention should be more useful in settings where learning is driven by the characteristics of the stimuli, such as implicit or statistical learning tasks. In this experiment, we test the first of these predictions. We placed children in a simulated classroom setting, presented them with a series of lessons on age-appropriate introductory science content, and subsequently tested children's learning of this material. In separate sessions, we assessed children's performance in the Homogeneous and Heterogeneous Distractor conditions of the Track-It task. We predict that children's performance in the Heterogeneous (but not Homogeneous) distractor condition will be correlated with their learning scores in the classroom-like setting. This is because the Heterogeneous Distractor condition taps into the kinds of endogenous factors (such as working memory and inhibition) that may be critical for success in formal education settings. By contrast, the abilities measured in the Homogeneous Distractor condition are predicted to be less relevant for success in the classroom.

Method

Participants

Participants were 24 typically developing kindergarten students (M_{age} = 5.37 years; 12 females, 12 males). None of the children who participated in the present study had been diagnosed with a learning disability. All participants were recruited from a laboratory school at a private university in Pittsburgh, PA.

Design, Stimuli, and Procedure

Children completed the Track-It task in the eye tracker. The Track-It task was administered twice during the 2012-2013 school year. Children also completed a classroom learning task which consisted of three lessons which occurred over a two-week period in the winter of 2012. Additional details regarding the administration of each task are provided below

Track-It Task. The Track-It task was presented on the Tobii T60 tracker. Fixations and behavioral accuracy data were collected. In the task (freely available for download at http://www.psy.cmu.edu/~trackit/), participants viewed a 3 x 3 grid and were asked to track a single target object moving around the screen among six distractors. After a variable length trial (M = 12.60 s, SD = 1.91 s), all of the objects disappeared from the screen and the participants were asked to select the grid location the target last visited prior to disappearing. Both targets and distractors were randomly selected from a pool of 72 unique objects (e.g., green diamond, orange triangle). Each grid location was marked in a pastel color to assist children in reporting the last location visited by the target.

In the Homogeneous Distractors Condition, all of the distractors were identical in shape and color. Consequently, the target was visually distinct from all distractors, and thus exogenous factors, in addition to endogenous factors, supported SSA. In the Heterogeneous Distractors Condition,

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each object was unique in shape and color. The saliency of the target and the distractors was equivalent, and thus only endogenous factors supported SSA. Objects subtended approximately 2.8° of the visual angle at a viewing distance of 50 cm. The speed of motion for objects was set to 500 pixels per frame at 30 frames per second, using a 17" monitor of 1024x768 resolution.

At the beginning of a trial, participants viewed a static image of the objects in a randomized starting position, with a red circle clearly marking the target. The experimenter waited until the participant was ready and initiated the trial, at which point the red circle disappeared and the objects began moving. The motion path of the distractors was not restricted, but the path of the target was restricted such that the trial would not end until the target had visited all nine possible locations. In order to minimize possible confusion when reporting the location last visited by the target object, the target would only disappear in the middle of the grid cell. The trial length was a minimum of 10s; however, the actual trial length varied slightly in order to adhere to the motion restrictions. A schematic depiction of the Track-It task is presented in Figure 1.
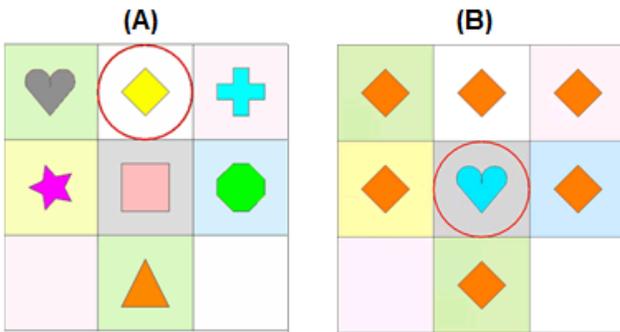

Figure 1. Schematic depiction of the Track-It task in the Heterogeneous Distractors condition (Panel A) and the Homogenous Distractors condition (Panel B).

After selecting the grid location in which the target disappeared, participants were given a memory check. Children were presented with a 2 x 2 grid of objects they had seen during the trial and asked to select the target object. The memory check served to differentiate between possible reasons why a participant might fail to select the appropriate target location. Specifically, if a participant failed to select the appropriate target location, and also failed to identify the target during the memory check, this might indicate that encoding of the target was insufficiently robust to last for the entire trial, rather than a failure of SSA. In contrast, if participants failed to select the appropriate target location, yet succeeded on the memory check, this would indicate that the failure was one of SSA rather than memory.

The experimental condition of the Track-It task (Homogeneous Distractors or Heterogeneous Distractors) was manipulated as a within-subjects variable. The experimental conditions were administered in two separate testing sessions. The condition order was counterbalanced across participants. The average delay between testing sessions was 5.02 weeks (SD = 2.99 weeks). Each session consisted of six test trials. The trials were broken into two sets, with each set containing three trials. This procedure allowed the experimenter to recalibrate the eye tracker in between sets.

Classroom Learning Task To prevent over-crowding in the laboratory classroom, the children were divided into two groups using stratified random assignment in order to equate groups on age and gender (Group 1: N = 12, M_{age} = 5.37 years, 6 females, 6 males; Group 2: N = 12, M_{age} = 5.39 years, 6 females, 6 males). However, one child was absent on all occasions when the classroom learning task was administered, and therefore provided no data on this task. As a result, the final sample used for subsequent analyses consisted of 23 children.

The classroom learning task took place in a research laboratory that was modified to look like a classroom. Instruction consisted of a short read-aloud, which is a common instructional activity in kindergarten classrooms. During the lessons, children sat on colorful carpet squares in a semi-circle facing the teacher. The seating arrangement was randomly assigned at the beginning of the study and remained constant for all of the testing sessions (akin to the stable seating arrangement participants experience in their own classroom). All lessons were conducted by a hypothesis-blind research assistant who had prior early childhood education experience.

Children participated in three lessons over a 2-week period. Lessons consisted of 5- to 7-minute read-alouds. Lesson topics included: Plate Tectonics, Volcanoes, and Bugs. The children had not received formal instruction on any of the lesson topics during the current academic year

Assessment workbooks were created to measure the children's learning outcomes. The assessments were administered at the end of each lesson. Each assessment included six questions in which children were asked to select the correct answer from four pictorial response options (one correct answer and three lures). All of the response options were novel (i.e., four pictures children did not see during the read-aloud) to ensure the children were not merely selecting an answer based on familiarity. Example lesson content and an assessment item are presented in Figure 2. Additionally, prior to the beginning of the study the children were pre-tested on their knowledge of the instructional content in order to ensure the lesson content was novel to the children. The format of the pre-test assessments was identical to the assessments described above

A delayed post-test was administered 13.63 weeks after the classroom learning task in order to assess retention of the lesson content. The delayed post-test was administered in a single testing session. The children were assessed individually in a quiet room adjacent to their classroom.
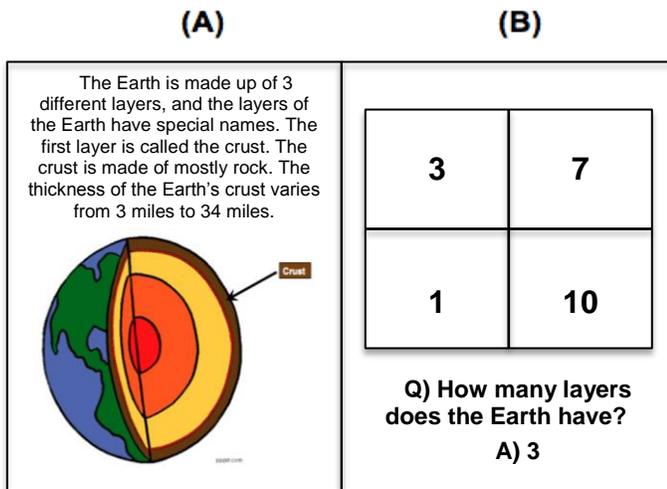
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Figure 2. Sample content from the Volcano lesson (Panel A) and a sample assessment question from the Volcano lesson (Panel B). All text was presented verbally.

Coding and Analyses of the Eye Tracking Data

Eye-tracking data were collected on a Tobii T60 Eye Tracker. The proportion of fixations to distractors, an index of children's distractibility, was defined as the number of fixations that were near a distractor but not near a target, divided by the total number of fixations. A fixation was defined as a look that fell within a certain radius of an object (70 pixels of any part of the 120 pixel-wide object), but did not enter the radius of an object from the opposing category during the duration of the look (e.g., a fixation to a distractor that never entered the radius of the target). Fixation data were not available for one child in both conditions because Tobii did not register any fixations. Fixation data could not be computed for one child in one condition due to experimenter error. As a result, statistical analyses utilizing fixation data were obtained from 23 of the 24 children in the homogeneous condition and 22 of the 24 children in the heterogeneous condition.

Results

Performance on the Track-It Task

Paired t tests were used to determine whether memory and tracking response accuracy differed as a function of experimental condition. Memory accuracy approached ceiling, and did not significantly differ between the Homogeneous Distractors and Heterogeneous Distractors Conditions ($M = 97.92$, $SD = 7.47$ and $M = 95.83$, $SD = 7.37$, respectively), $t(23) = 1.14$, ns. Tracking accuracy was also high, and did not differ significantly between the Homogeneous Distractors and Heterogeneous Distractors Conditions ($M = 79.17$, $SD = 26.58$ and $M = 85.42$, $SD = 15.78$, respectively), $t(23) = 1.23$, ns.

Analysis of the eye-tracking data revealed that children were not more likely to fixate on distractors in the Heterogeneous Distractors Condition ($M = 0.32$, $SD = 0.19$) than in the Homogeneous Distractors Condition ($M = 0.36$, $SD = 0.14$) paired-samples $t(21) = 1.025$, ns. However, the correlation between proportion of fixations in the Heterogeneous and Homogeneous Distractors Conditions was not significant, ($r = 0.35$, $p = 0.11$), which may suggest that the two conditions of the Track-It task differed in the degree to which they relied on endogenous processes. For example, it is possible that re-fixating to the target object after getting distracted in the Homogenous distractors condition was aided by the target's saliency and required fewer endogenous resources than re-fixating to the target in the Heterogeneous Distractors condition. In contrast, in the Heterogeneous Distractors condition performance was only supported by endogenous factors as the saliency of the target and distractors was equivalent,

Performance on the Classroom Learning Task

Children's pre-test accuracy was not different from chance (25%), suggesting that the lesson content was in fact novel to the children; $M_{Pre-test} = 0.23$ (0.09) $t(22) = 1.26$, $p = 0.22$. Children's accuracy immediately following the administration of the lessons was significantly above chance, ($M = .54$, $SD = .21$), one-sample $t(22) = 6.83$, $p < .0001$. Furthermore, the results suggest that the children successfully learned from the instruction as evidenced by their higher accuracy on the post-test compared to their performance on the pre-test, paired-samples $t(22) = 7.42$, $p < 0.0001$.

Children's accuracy on the delayed post-test ($M = .34$, $SD = .21$) was considerably lower than on the immediate post-test, paired-sample $t(22) = 6.15$, $p < .0001$. Nonetheless, children's accuracy on the delayed post-test was marginally above chance, one-sample $t(22) = 2.02$, $p = .056$, suggesting some degree of retention of the learned material even after a significant delay (13.63 weeks).

The Relationship between Endogenously- and Exogenously-driven SSA and Learning

To explore the hypothesis that learning in formal settings requires endogenously-driven SSA to a greater extent than exogenously-driven SSA, we examined the pattern of correlations among children's learning scores on the classroom task, Track-It response accuracy, and fixations to distractors in the Track-It task.

We consistently observed a pattern of correlations that supported the hypothesis stated above: children's classroom learning scores were significantly correlated with their performance in the Heterogeneous Distractors condition but not in the Homogenous Distractors condition of the Track-It task. It is notable that this pattern of correlations was observed for both immediate and delayed post-test scores with both response accuracy and eye tracking data on the Track-It task (see Table 1 and Figure 3).

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Specifically, the proportion of fixations to distractors in the Heterogeneous Distractors Condition was negatively correlated with children's learning scores on the immediate post-test ($r = -0.43$, p = .05) and with their delayed post-test learning scores ($r = -.663$, $p < .005$; see Figure 3). In other words, greater proportion of fixations to distractors in this condition corresponded to lowers scores in the classroom learning task. In contrast, the proportion of fixations to distractors in the Homogeneous Distractors Condition was not significantly related to the immediate post-test learning scores ($r = -0.18$, $p = 0.42$) or the delayed post-test scores ($r = -.328$, $p = .136$).

Table 1: The pattern of correlations in the present study.

	1.	2.	3.	4.	5.	6.	7.	8.
1. Immediate Post-Test	1	.692**	.350	.574**	-.093	.012	-.181	-.434*
2. Delayed Post-Test		1	.284	.412~	-.234	-.138	-.328	-.663**
3. Track-It Response Accuracy, Homogenous Cond.			1	.396	.562**	.339	-.239	-.075
4. Track-It Response Accuracy, Heterogeneous Cond.				1	.346	.285	-.253	-.326
5. Track-It Memory Accuracy, Homogenous Cond.					1	.274	-.097	.097
6. Track-It Memory Accuracy, Heterogeneous Cond.						1	.279	-.030
7. Fixations to Distr., Homogenous Cond.							1	.354
8. Fixations to Distr., Heterogeneous Cond.								1

** p ≤ .01 (2-tailed); * p ≤ .05 (2-tailed); ~ p ≤ .06 (2-tailed)

A similar pattern emerged when we analyzed tracking response accuracy on the Track-It task: the more accurate children were in identifying the last location visited by the target in the Heterogeneous Distractors Condition, the higher their immediate post-test learning scores were ($r = 0.574$, $p = .01$). The correlation between Track-It response accuracy and delayed post-test scores was marginally significant ($r = .412$, $p = .051$). These findings are presented in Figure 3. At the same time, there was no significant association between Track-It response accuracy in the Homogeneous Distractors Condition and immediate post-test learning scores ($r = 0.350$, $p = 0.101$) or delayed post-test learning scores ($r = .284$, $p > .18$).
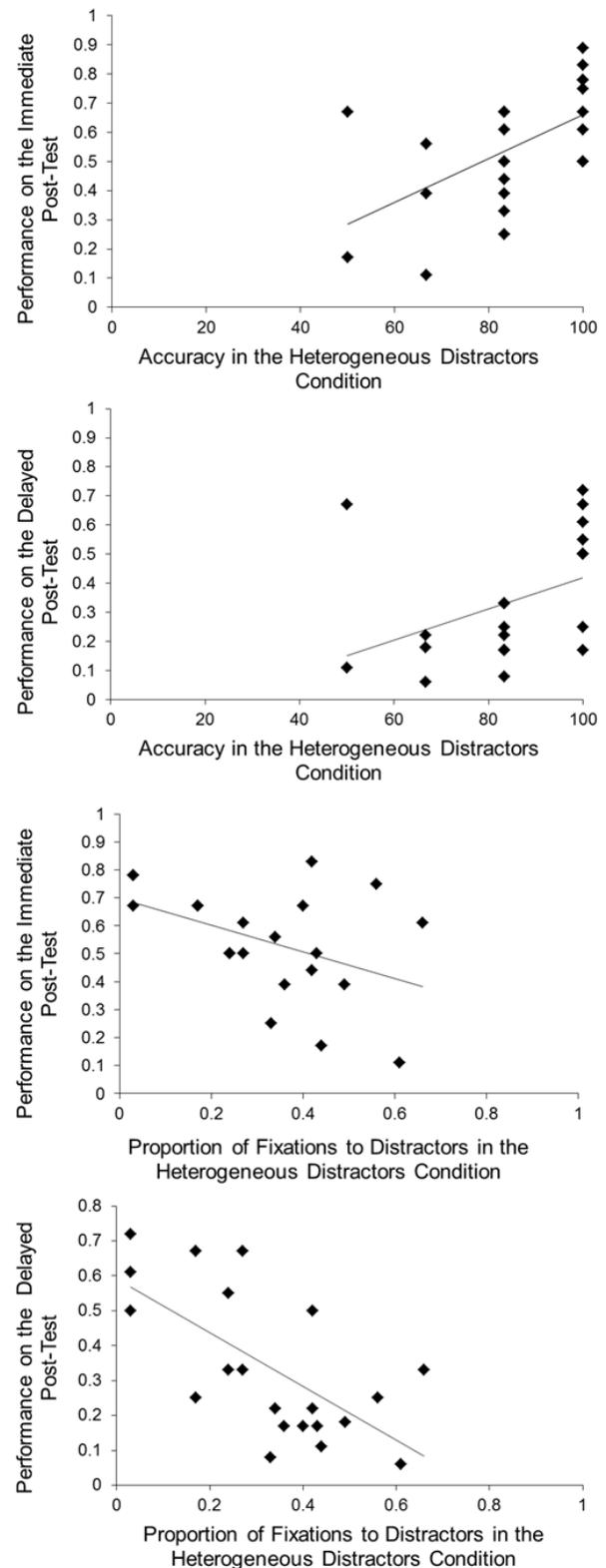

Figure 3. Scatterplots depicting significant correlations between both behavioral accuracy and the proportion of fixations to distractors and learning on the immediate and delayed post-tests.

Discussion

Kindergarten children were equally good at both tracking and encoding targets on the Track-It task regardless of whether the distractors were homogeneous (in which both endogenous and exogenous factors support SSA) or heterogeneous (only endogenous factors support SSA). Although previous findings indicate that children are superior at tracking targets among homogeneous distractors, these differences are more pronounced in 3- and 4-year-olds, with older children showing comparable performance when endogenous and exogenous factors support SSA (Fisher et al., 2013).

Although children showed equivalent accuracy and proportion of fixations to distractors in both conditions, performance in the two conditions may not have recruited the same attentional control mechanisms. Specifically, we hypothesize that the Homogeneous and Heterogeneous distractors conditions recruit exogenous and endogenous attentional control mechanisms respectively. This possibility is supported by (1) the patterns of correlations between performance in the two conditions and (2) the pattern of correlations between performance on the Track-It task and the immediate as well as the delayed post-test of the classroom learning task. Specifically, both behavioral tracking accuracy and fixations to the distractors in the Heterogeneous Distractors Condition were related to children's performance in the classroom learning task: children who were more accurate in identifying the last location visited by the target and whose attention was less easily captured by distractors tended to show superior learning scores. In contrast, in the Homogeneous Distractors Condition, accuracy and fixations to distractors were not significantly related to children's learning scores.

One likely possibility is that targets are more attention grabbing when the distractors are homogeneous than when they are heterogeneous. As a result, children who fixate on distractors during the task may have more difficulty re-orienting to the target when the distractors are heterogeneous than when they are homogeneous. Future research will be necessary to test this possibility.

The present findings dovetail with recent work suggesting that the Track-It task allows for the separation of endogenous and exogenous factors supporting SSA within a single task (Fisher et al., 2013). In addition, these results replicate the finding that distractibility as measured by accuracy on the Track-It task predicts learning in an ecologically valid task of classroom learning.

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