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The Effect of Disrupted Attention on Encoding in Young Children

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Abstract

There is a growing body of research experimentally demonstrating a relationship between selective sustained attention and young children's learning outcomes. Collectively, this work has documented that as selective sustained attention decreases children's learning also declines. However, a precise understanding of how disrupted attention negatively impacts learning is lacking. The present experiment expands upon the existing work and explores three potential mechanisms by which inattention may impede learning: 1) inattention may disrupt encoding of the individual features of the stimulus, 2) inattention may impede children from binding the features together, or 3) inattention may disrupt both feature encoding and binding.

Keywords: Learning; Attention; Encoding; Off-Task Behavior

Introduction

Attention is a factor widely believed to be important to learning. As stated by Oakes and colleagues (2002), "if attention were constantly reoriented to every new event, it would be difficult ... to learn about any single object or event" (p.1644). The association between attention and learning has been examined in the laboratory (e.g., Fisher, Godwin & Seltman, 2014; Godwin & Fisher, 2014; Yu & Smith, 2012; Cowan, Fristoe, Elliot, Brunner, & Saults, 2006; Choudhury & Gorman, 2000; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; DeMarie-Dreblow & Miller, 1988; Healey & Miyake, 2009) and in relation to academic outcomes (e.g., Commodari, 2012; Duncan et al. 2007; Howse, Lange, Farran, & Boyles, 2003; NICHD, 2003). However, the mechanisms underlying this effect have not been fully explicated.

The present study aims to examine the relationship between selective sustained attention and young children's learning outcomes by experimentally inducing lower or higher levels of selective sustained attention. Selective sustained attention was manipulated by introducing or removing visual distractions (e.g., educational displays irrelevant to the learning task) and observing the consequences on children's ability to encode the individual features of the stimuli (i.e., auditory and visual features) as well as their ability to bind this information together.

Selective sustained attention

Selective sustained attention is defined as: "a state of engagement that involves narrowed selectivity and increased commitment of energy and resources on the targeted activity" (Setliff & Courage, 2011, p. 613). The present work focuses on the relationship between selective sustained attention and encoding in children as the task of flexibly modulating attention may be particularly challenging for young children due to the protracted maturation rate of selective sustained attention. In infancy precursors to this ability are evident. For example, newborns are able to orient to a specific stimulus, although initially the orienting response is based on exogenous factors such as saliency and novelty of the stimulus (Barry, 2009; Ruff & Rothbart, 1996; see Fisher & Kloos, in press for review). With age, endogenous control of attention emerges (Setliff & Courage, 2011; Oakes, Kannass, & Shaddy, 2002) resulting in a gradual decrease in distractibility (Oakes et al., 2002; Ruff & Capozzoli, 2003). The duration of selective sustained attention also increases with significant improvements evident in middle childhood – particularly after age 7 (for review see Fisher & Kloos, in press; White 1970; Bartgis, Thomas, Lefler, & Hartung, 2008).

In addition to developmental constraints on children's attentional capacity there are environmental demands that may make it difficult for young children to maintain a state of selective sustained attention in learning contexts. For example, traditional learning environments may inadvertently compete for children's attention as the classroom visual environment itself can serve as a source of distraction (see Fisher, Godwin, & Seltman, 2014). Thus, in the present study educational displays were utilized as an ecologically valid source of distraction.

Encoding and binding

Inattention, or off-task behavior, is problematic as selective sustained attention is hypothesized to be important for general cognitive processes (see Choudhury & Gorman, 2000). In the present work we focus on two cognitive processes, feature encoding and binding - where binding refers to the process in which individual features that have been encoded are combined to form coherent integrated representations (e.g., Treisman, 1998; Ueno, Mate, Allen, Hitch, & Baddeley, 2011). Successfully encoding and binding features together are important cognitive processes that support learning. For example, in order to learn to associate a novel label to a novel visual stimulus, individuals must encode the features of the stimulus (e.g., the label and the image) and bind these two features together.

In a recent experiment, Godwin and Fisher (2014) gave kindergarten children a computerized paired-associates learning task in which levels of selective sustained attention were experimentally manipulated by introducing or removing visual distractions. Godwin and Fisher found that low levels of selective sustained attention impeded children's recall accuracy. However, from this single study the mechanisms by which inattention disrupts learning cannot be explicated, as there are multiple reasons that retrieval may have failed (e.g., encoding issues, interference). The present experiment expands upon this work by examining what information or characteristics of the stimuli have been encoded in the presence of environmental distractions and whether learning decrements are a result of disrupted attention preventing binding or result from partial encoding of the individual features of a stimulus (i.e., the auditory and visual features). Specifically, we explore three potential mechanisms by which inattention may impede learning: 1) inattention may disrupt encoding of the individual features, 2) inattention may impede children from binding the features together, or 3) inattention may disrupt both feature encoding and binding.

In the present experiment we are interested in examining the role of selective sustained attention on young children's feature encoding and binding during an explicit learning task in which individuals learn to pair a novel label with a novel image. Children's accuracy for the individual features (i.e., the image and the label) as well feature binding will be assessed. Thus, the goal of present experiment is two fold: (1) examine whether disrupting selective sustained attention hinders children's learning outcomes, (2) examine the mechanisms by which disrupting selective sustained attention may impede children's learning.

Method

Participants

The sample consisted of 23 kindergarten children (*Mage* = 5.60 years, *SD* = 0.26 years, 9 females, 14 males). All participants attended a laboratory school at a private university in Pennsylvania. Children were tested individually in a quiet room adjacent to their classroom by the first author of this paper.

Design

The present study utilized a within-subject design. The visual environment was the within-subject factor (presence or absence of environmental distractions). There were two experimental conditions: (1) High Visual Distraction (HVD) condition and (2) Low Visual Distraction (LVD) condition. In the HVD condition the environmental distractions consisted of educational displays common in elementary school classrooms (i.e., solar system replica, model tornado, bulletin board, basket of supplies, etc.). In the LVD condition the environmental distractions were removed or obscured behind a curtain; See Figure 1.

Presentation order of the conditions (HVD first or LVD first) was counterbalanced across participants and the presentation of the conditions was interleaved across testing sessions (i.e., HVD-LVD-HVD-LVD or LVD-HVD-LVD-HVD). The version of the Paired-Associates Learning Task (*Fish*, *Plants and Flowers*, *Fruit*, and *Exotic Mammals*) was also counterbalanced across conditions.

(A) **(B)**

Figure 1. Photographs of the visual environment in each experimental condition: panel A shows the laboratory in the High Visual Distraction Condition and panel B shows the laboratory in the Low Visual Distraction condition.

The dependent variable was children's accuracy on the learning task in the HVD and LVD conditions (i.e., proportion of correct responses). The amount of time children spent off-task was calculated as a measure of children's selective sustained attention. A within-subject design was utilized to ensure any learning differences obtained were a result of the experimental manipulation rather than variability across groups of children.

Procedure

Children participated in 4 testing sessions. Each testing session lasted approximately 15 minutes. In each session, children completed a Paired-Associates Learning task in either the HVD or LVD conditions according to their condition assignments. Thus, all children completed a total of 4 Paired-Associates Learning tasks, 2 tasks in each condition. These sessions were videotaped for coding purposes in order to calculate the proportion of time children spent off-task.

Learning Task. The Paired-Associates Learning (PAL) task is a computer-based learning task. The PAL task consists of three phases: pre-test, learning phase, and post-test. In the pre-test, children were asked to identify the object labeled by the experimenter from 3 pictorial response options. The pre-test included 18 trials, which consisted of 9 novel test items and 9 familiar items which served as fillers. Two presentation orders were created. In Order 1 the test items were randomized with the constraint that the pre-test began and ended with a familiar item. For Order 2 the presentation order utilized in Order 1 was simply reversed. The pre-test was administered in order to ensure that the PAL content was novel to the children.

In the learning phase, children were presented with the 9 novel natural kinds encountered during the pre-test and taught the corresponding label for each object. Each item was presented three times during the learning phase for a total of 27 trials. Two presentation orders were created. For Order 1 items were blocked and randomized within each block (i.e., 3 blocks each containing the 9 novel items). For Order 2 the presentation order utilized in Order 1 was simply reversed.

The learning phase was designed to approximate 'seat-work,' an independent learning activity common in elementary school classrooms. During seat-work the teacher typically circulates throughout the classroom assisting individual students as needed. As a result, the amount of direct supervision that a particular child receives during seat-work is typically minimal as the teacher's attention is being distributed across the entire classroom. Consequently, in the present study the experimenter stood in the hallway while the child completed the learning phase of the PAL task independently.

The post-test consisted of 3 basic question types: visual questions, auditory questions, and binding questions (recognition and recall questions); See Figure 2. The post-test phase included 36 test items, 9 items per question type. Two presentation orders were created. For Order 1 question type was blocked (Block 1: visual, Block 2: auditory, Block 3: recognition, and Block 4: recall) and the items were randomized within each block. For Order 2 the blocking sequence was held constant; however, the presentation order of the items within each block was reversed. Question type was blocked as the binding questions provided children with information they could utilize to answer the feature encoding questions (i.e., visual and auditory questions). Consequently, the feature encoding questions were always presented before the binding questions. Four versions of the PAL task were created in which children learned about different types of natural kinds: *Fish, Plants and Flowers, Fruit,* and *Exotic Mammals.* A brief overview of each question type (visual, auditory, and binding questions) is provided below.

For visual questions, children were asked to point to the picture they saw during the game from among 3 response options (1 target and 2 novel lures); See Figure 2. For auditory questions children were asked to identify the name of the item they heard during the *learning phase*, see Figure 2. The response options included the target and two lures that were matched as closely as possible to the target for syllable length.

Children also completed two types of binding questions: recognition and recall items; See Figure 2. Recognition items required children to identify a particular item they learned about during the game from 3 pictorial response options (e.g., *"Point to the Platy"*). The response options included the target object and 2 lures (a novel lure and a familiar lure – another item children learned about during the task). For recall items, children were shown a picture of an object they saw during the game and asked to recall the name of the item.

Children completed the PAL tasks under two conditions: (1) under the presence of environmental distractions (HVD) and (2) without environmental distractions present (LVD). Presentation order (HVD first or LVD first) was counterbalanced across participants. PAL version (*Fish, Plants and Flowers, Fruit,* and *Exotic Mammals*) was also counterbalanced across conditions. Duration of children's off-task behavior as well as PAL accuracy was compared across conditions (HVD vs. LVD).

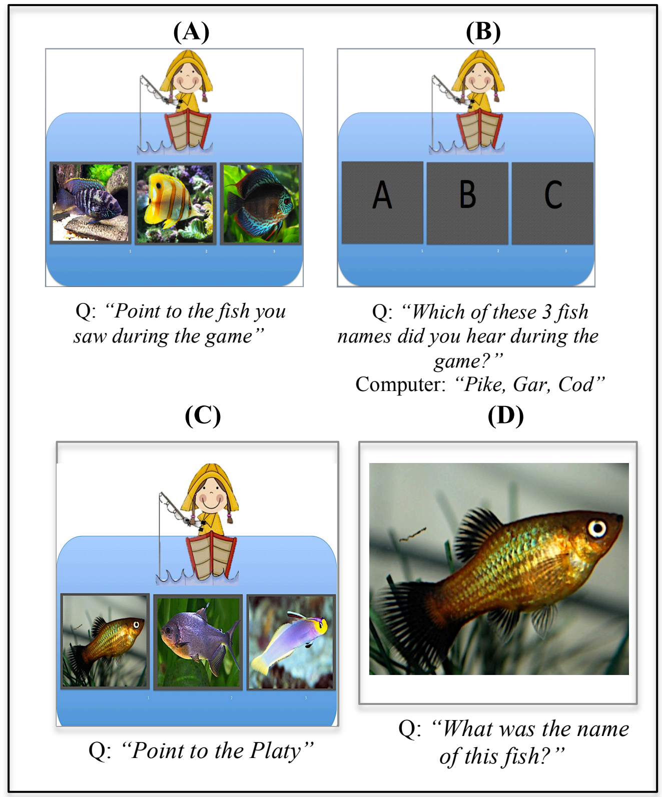

Figure 2. Sample assessment items from the *Fish* paired-associates learning task. Panel A provides an example visual test item, Panel B an example auditory test item, Panel C an example recognition test item, and Panel D an example recall test item.

Coding. PAL sessions were videotaped for coding purposes. Children's behavior was coded at the second-by-second level in order to calculate the proportion of time children spent off-task. Coders were taught to classify the child's behavior as on- or off-task. On-task behavior was operationalized as engagement with the learning materials (i.e., the computer). Engagement was determined by the direction of children's gaze which is a common measure of visual attention (see Henderson & Ferreira, 2004; Just & Carpenter, 1976).

For each instance of off-task behavior, the coders marked the timing of its onset and cessation. Utilizing time off-task as a measure of selective sustained attention allows for a more precise examination of the extent to which children are attending to the learning task. All coders were trained by the first author of this paper. Training consisted of extensive practice coding videotapes. A subset of the data (25%) is currently being re-coded to ensure good inter-rater reliability. All coders are hypothesis-blind. The duration of children's off-task behavior as well as PAL accuracy were compared across conditions (HVD vs. LVD).

Results

Off-Task Behavior

The total proportion of time spent off-task was measured, and group means were compared in each condition. The overall proportion of time spent off-task was significantly greater in the HVD condition (*M* = 35%, *SD* = 22%) compared to the LVD condition (*M* =13%, *SD* = 10%), paired-sample $t(22) = 5.59$, $p < 0.0001$, Cohen's $d = 1.29$. This finding suggests the experimental manipulation of the visual environment was effective in inducing lower or higher levels of selective sustained attention during the learning task.

Learning Outcomes

Pre-test. Pair-wise comparisons were conducted to examine children's performance on the pre-test in the HVD and LVD conditions. The analysis revealed no significant difference across conditions at pre-test ($M_{HVD} = 0.30$, $SD = 0.12$; $M_{LVD} = 0.31$, $SD = 0.10$), suggesting that the counterbalancing procedure was effective; $t(22) = 0.22$, $p = 0.83$. Additionally, the test stimuli were novel to the children as performance on the pre-test was not significantly different from chance (0.33); single sample $ts \leq 1.32$, both $ps \geq 0.20$.

Post-Test. It is important to note that the difficulty level of the binding questions is higher than the difficulty level of the feature encoding questions, as children are able to answer the feature encoding questions based on familiarity alone (i.e., recognizing the familiar test item from among two novel lures). In contrast, for binding questions children must recognize the correct target from among one familiar lure and one novel lure in the case of recognition questions and for recall questions children must generate the object label when supplied with the image. Due to differences in the difficulty level of the post-test questions (e.g., feature encoding vs. binding questions) it is not very informative to compare effects of inattention across question types. However, by looking at the effect of condition within each question type, it is possible to determine whether inattention disrupts feature encoding and/or binding.

A composite score, *Feature Encoding*, was created by averaging together the mean performance on auditory and visual questions for each child in order to evaluate how accurately children encoded the features of the stimuli. Composite scores were calculated separately for each visual distraction condition. Children obtained relatively high feature encoding accuracy scores suggesting that in both conditions children were able to encode the individual features of the stimuli ($M_{LVD} = 0.85$, $SD = 0.10$; $M_{HVD} = 0.79$, $SD = 0.16$). Pair-wise comparisons were then conducted to examine children's feature encoding performance in the HVD and LVD conditions. Performance did vary as a function of condition with children exhibiting significantly higher feature encoding scores in the LVD condition compared to the HVD condition; $t(22) = 2.45$, $p = 0.023$, Cohen's $d = 0.45$. Thus, supporting the hypothesis that disrupting attention during encoding negatively impacts children's ability to encode the individual features of the stimuli.

Pair-wise comparisons were also conducted to examine children's performance on the visual and auditory questions independently; see Figure 3. A similar pattern of results was obtained for both visual and auditory questions. For the visual questions children obtained higher scores in the LVD condition ($M_{LVD} = 0.94$, $SD = 0.08$) compared to the HVD condition ($M_{HVD} = 0.88$, $SD = 0.16$); however this difference was only marginally significant; $t(22) = 1.70$, $p = 0.10$, Cohen's $d = 0.47$. Additionally, children's performance was significantly above chance (0.33) in both conditions (single sample $ts \geq 15.99$ $ps < 0.0001$). Nevertheless this pattern of results provides some preliminary evidence that disrupting attention with visual distractions during a learning task can result in decrements in encoding of the visual components of the stimuli.

Next, pair-wise comparisons were conducted to examine children's performance on the auditory questions in the HVD and LVD conditions. Children obtained higher scores in the LVD condition ($M_{LVD} = 0.75$, $SD = 0.16$) compared to the HVD condition ($M_{HVD} = 0.70$, $SD = 0.22$); this difference was also marginally significant; $t(22) = 1.95$, $p = 0.06$; Cohen's $d = 0.26$. Additionally, children's performance was significantly above chance (0.33) in both conditions (single sample $ts \geq 8.18$, $ps < 0.0001$). Taken together these findings suggest that disrupting attention during a learning task reduces encoding of the visual and auditory characteristics of the stimuli.

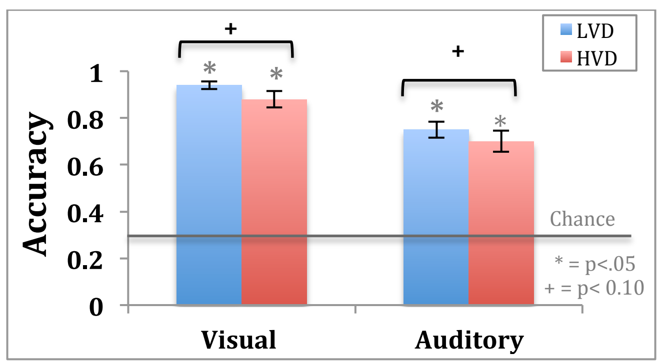

Figure 3. Mean encoding accuracy for visual and auditory features of the PAL stimuli. Error bars represent the standard errors of the means. Line indicates chance performance (0.33).

A composite score, *Binding*, was created by averaging together the mean performance on recognition and recall questions for each child in order to evaluate how accurately children were able to pair the label and image together. Binding performance ($M_{LVD} = 0.41$, $SD = 0.16$; $M_{HVD} = 0.39$, $SD = 0.17$) was significantly lower than children's ability to encode the stimuli features ($M_{LVD} = 0.85$, $SD = 0.10$; $M_{HVD} = 0.79$, $SD = 0.16$); paired sample $ts \geq 11.68$, $ps < 0.0001$. This result is not surprising as noted previously the binding questions are more difficult than the feature encoding questions, as children are able to answer the feature encoding questions based on familiarity alone where as binding questions require recollection. Condition differences in binding accuracy as a function of the LVD or HVD condition were not significant in the present experiment; Paired sample $t(22) = 0.77$, $p = 0.45$ *ns*. We return to this issue in the discussion section. Pair-wise comparisons were also conducted to examine condition differences on the PAL post-test for both recognition and recall subscales separately. For both recognition and recall scores there was no significant effect of condition; paired sample $ts \leq 1.08$, $ps \geq 0.29$.

Predicting Children's Learning Outcomes

A significant difference in children's feature encoding performance was found as a function of the manipulation to the visual environment. Consequently, the following set of analyses were conducted in order to examine whether children's pattern of selective sustained attention is in fact predictive of their feature encoding accuracy.

Total time off-task (pooled across both the LVD and HVD conditions was found to be significantly correlated with children's Total Feature Encoding Scores (pooled across both the LVD and HVD conditions); see Figure 4. Thus, the more time children spent off-task the lower their learning scores; $r = -0.552$, $p = 0.006$. This effect was consistent in its direction across both conditions; however, the association was only significant in the HVD condition ($r = -0.63$, $p = 0.001$) and was not significant in the LVD condition ($r = -0.34$, $p = 0.12$). The observed pattern of results may be due to the truncated range in off-task behavior observed in the LVD condition (Range: 0%-36%) compared to the HVD condition (Range: 2%-81%). The limited variability in the proportion of time spent off-task in the LVD condition makes it more difficult to detect an association with children's learning outcomes.

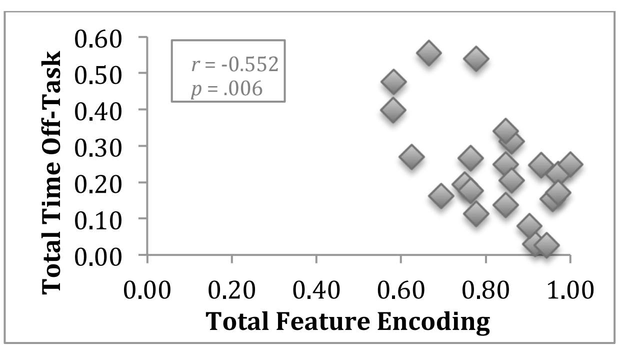

Figure 4. Scatterplot of the total amount of time children spent off-task (mean proportion of time off-task pooled across the HVD and LVD conditions) and children's total feature encoding score (mean accuracy for identifying the visual and auditory features of the PAL stimuli pooled across the HVD and LVD conditions).

When entered in a linear regression Total Time Off-task was a significant predictor of children's Feature Encoding scores ($F(1,21) = 9.23$, $p = 0.006$) and accounted for 27% (adjusted R^2) of the variability in children's performance. These findings indicate that selective sustained attention is in fact predictive of children's feature encoding accuracy and corroborates the results obtained in prior work (Fisher, Godwin, & Seltman, 2014; Godwin & Fisher, 2014) suggesting the importance of selective sustained attention, among other individual difference factors, on children's learning outcomes.

Discussion

The results from the present study suggest that the experimental manipulation of the visual environment was effective in inducing lower or higher levels of selective sustained attention during the learning task. Additionally, these findings serve to replicate our previous work (Fisher, Godwin & Seltman, 2014; Godwin & Fisher, 2014) indicating that the visual environment can in principle impact children's attention allocation as evidenced by the increase in children's off-task behavior in the HVD condition compared to the LVD condition.

Children's patterns of attention allocation were also found to impact children's learning outcomes. Specifically, Children's PAL Feature Encoding scores were significantly higher in the LVD condition compared to the HVD condition providing supporting evidence that disrupting attention during encoding negatively impacts children's ability to encode the individual features of the stimuli. Furthermore, Total Time Off-task was found to be a significant predictor of children's Feature Encoding scores and accounted for 27% of the variability in children's performance.

Prior work (Godwin & Fisher, 2014) utilizing a computerized paired-associates learning task found that disrupting attention hampers recall accuracy. The present experiment expanded upon this work by examining whether learning decrements result from partial encoding of the individual features of a stimulus (i.e., the auditory and visual features) and/or disrupted binding. The results support the partial encoding hypothesis and indicate that disrupting attention negatively impacts feature encoding as evidenced by children's lower feature encoding scores in the HVD condition compared to the LVD condition. However, it is currently an open question as to whether inattention also negatively affects binding accuracy due to the inconsistency of this effect across studies. Thus, additional research is needed to determine whether binding is unaffected by disrupted attention or alternatively if disrupted attention impedes binding. One possible alternative explanation for why binding accuracy was not affected in the present experiment pertains to specific design features employed in the experiment. For example, binding questions were administered as the last block of the post-test due to reasons discussed in the Method section. It is possible that the representations that children are creating are quite fragile. Consequently the added delay of administering two blocks of questions (auditory and visual questions) at post-test prior to the binding questions might have masked any condition differences that may have emerged. Additional research is needed to determine whether binding is truly unaffected by inattention or if the aforementioned delay hypothesis is able to account for this result. Future research can begin to explore this possibility by manipulating the length of the delay between the learning phase and post-test.

Understanding the nuanced relationship between attention and learning is an important area of research with potential practical implications for education. This line of work will ultimately help create a more comprehensive understanding of the relationship between attention and learning and its underlying mechanisms.

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