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Mechanisms of Sustained Selective Attention in 3- to 5-year-old Children: Evidence from a New Object Tracking Task

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Abstract

Sustained selective attention is a crucial component of many higher-order cognitive processes; yet there is little research into the mechanisms of this ability early in development. One of the challenges in investigating mechanisms of sustained selective attention in young children is lack of appropriate experimental paradigms. This paper reports findings from a novel paradigm designed to investigate mechanisms of sustained selective attention in young children - the Object Tracking task. Results of two experiments with 3- to 5-year-old children provided support to the notion that development of the endogenous component of selective sustained attention lags behind the development of the exogenous component of this process. Importantly, the Object Tracking paradigm allowed investigating both of these components within the same task, thereby making it possible to attribute changes in performance to different mechanisms of attentional control rather than to differences in the level of motivation and engagement in different tasks.

Keywords: Selective attention; Sustained attention; Focused Attention; Cognitive Development.

Introduction

The ability to selectively sustain attention is crucially important because it is an essential component of most higher-order cognitive processes, such as categorization, language comprehension, reasoning, and problem solving. For example, it takes preverbal infants as little as 500 ms to locate a target object among eight distracters (Adler & Orprecio, 2006), whereas it takes them approximately twenty times longer to categorize a single object (Quinn & Eimas, 1996). Similar latency differences between simple visual search tasks and higher-order categorization tasks are also present in older children and adults (Fisher, in press; Gerhardstein & Rovee-Collier, 2002; Trick & Enns, 1998). However, development of the mechanisms of sustained selective attention, also referred to as focused attention, has been sparsely investigated. The goal of the research presented below was to investigate mechanisms of sustained selective attention in 3- to 5-year-old children.

When several objects are present in a scene and one needs to focus attention on a single object, how is the competition resolved? One of the paradigms that has been widely used to explore this question in the domain of visual attention is the visual search paradigm pioneered by Treisman and Gelade (1980). The classic finding from this paradigm is that when adults are asked to search a visual array for a target object defined by a conjunction of features (e.g., color and shape), their reaction time increases with the increase in the number

of distracter objects in the display. However, when displays contain target objects defined by a single feature (e.g., color) visual search reaction times remain constant regardless of the number of distracters, as the target object seems to instantly “pop-out” from the display.

While there is no consensus on the mechanisms of visual search, many theories distinguish between two broad ways in which competition between multiple objects in a scene can be resolved. One way has been characterized as stimulus-driven, effortless, bottom-up, and passive, whereas the other way has been characterized as participant-driven, effortful, top-down, and active (Lavie, 2005; Lavie & Tsai, 1994; Kastner & Undergleider, 2000; Norman & Shallice, 1986; Schneider and Shiffrin, 1977; Schneider & Chein, 2003).

Research on the development of selective attention indicates that even newborns are not indifferent to what they attend to, and prefer to attend to some stimuli over others (Colombo, 2001; Fantz, 1963). However, this selectivity has been characterized as stimulus-driven or automatic (i.e., driven by exogenous factors), rather than participant-driven or voluntary (i.e., driven by endogenous factors). In particular, selective attention in newborns and young infants is driven to a large degree by the properties of the stimulus, such as its frequency and duration (for auditory stimuli) and intensity and brightness (for visual stimuli), rather than by infants’ intentions (Bornstein, 1990; Ruff & Rothbart, 1996).

By the time infants reach seven months of age, their allocation of attention is driven by a complex interaction of exogenous and endogenous factors (Oakes, Kannass, & Shaddy, 2002). For instance, exogenous factors, such as stimulus brightness and complexity still exert a strong pull on attention allocation; however, reorientation to salient distracters is less likely when infants are in a state of focused attention (i.e., concentrating on a particular toy or activity) than when infants are in a state of casual attention – suggesting that internal state of an infant (an endogenous factor) plays a role in how attention is allocated (Tellinghuisen, Oakes, & Tjebkes, 1999).

Considerable evidence suggests that when several objects compete for attention and one of these objects is defined by a unique feature, similar to adults, infants as young as 3 ½-months of age exhibit the “pop-out” effect (Adler & Orprecio, 2006; Gerhardstein & Rovee-Collier, 2002; Treisman & Gelade 1980). Search for objects defined by a conjunction of features has not been studied with preverbal infants, however findings with 12- to 36-month old toddlers

indicate that their response latency increases with increased number of distracters in the display – a pattern that is similar to that in adults (Gerhardstein & Rovee-Collier, 2002; Scerif, Cornish, Wilding, Driver, & Karmiloff-Smith, 2004; Treisman & Gelade 1980). Despite considerable quantitative differences in performance of children and adults persisting until at least until ten years of age (Trick & Enns, 1998), the qualitative pattern of results from the visual search tasks with young children is similar to that of adults.

However, higher-order cognitive processes (such as categorization, language comprehension, and reasoning among many others) impose greater demands on attention than simply selecting an object for processing. One of these demands is sustaining attention to the selected object for at least brief periods of time. Development of this ability has been often examined in natural settings (such as free play) in prior research as well as computerized vigilance-type tasks (Oakes, Kannass, & Shaddy, 2002; Ruff & Lawson, 1990; Sarid & Breznitz, 1997; Tellinghuisen, Oakes, & Tjebkes, 1999). These studies indicate dramatic improvements in this ability between 12 months and six years of age. For example, studies utilizing the context of free play suggest that duration of focused free play increases from approximately four minutes in 2- and 3-year-old children to over nine minutes in 5- and 6-year-olds (Ruff & Lawson, 1990; Sarid & Breznitz, 1997). Furthermore, these studies indicate that older children are markedly less distractible than younger children, and also more likely to return to an interrupted activity.

Another kind of paradigm that has been successfully used to investigate sustained selective attention in young children is a Continuous Performance Test – a vigilance-type task modeled after tests used with adults (Warm & Jerison, 1984). In this task participants are asked to attend to a stream of visual stimuli and to respond to a target stimulus while withholding response to non-target stimuli. For example, participants might be presented with a series of images depicting ducks and turtles, and instructed to press a button every time they see a duck and avoid pressing the button when they see turtles (Akshoomoff, 2002). The goal of this task is to investigate whether participants can remain alert for prolonged periods of time (e.g., 5- to 9-minute intervals) and accurately detect infrequently appearing target objects. A typical finding of such studies is that approximately 50% of 3 ½-year-old children fail to complete this task, indicating difficulty in sustaining their attention (Akshoomoff, 2002; Corkum, Byrne, & Ellsworth, 1995). Those 3-year-olds who can complete the task (thus demonstrating their ability to maintain attention for prolonged periods of time) exhibit high rates of both misses and false alarms, suggesting difficulty with the voluntary control of selectivity. Marked improvement on this task (in terms of proportion of children completing the task, response time, and accuracy) is observed between four and five years of age.

Studies of sustained selective attention in the context of free play and vigilance-type tasks provide valuable insights

regarding the milestones in the development of this important ability. However, these studies are limited in their ability to assess the mechanisms of sustained selective attention in young children and changes in these mechanisms in the course of development. One of the challenges in investigating this question stems from the lack of appropriate experimental paradigms. For example, it has been argued that differences in the level of performance on existing tasks of focused attention between younger and older children may arise as a result of differential levels of motivation and engagement in the task rather than developmental changes in mechanisms of attentional control (Ruff & Rothbart, 1996). Furthermore, there is currently no task that makes it possible to assess contribution of exogenous and endogenous factors to selective sustained attention within the same task, thus making it difficult to uniquely attribute changes in performance to different attentional mechanisms rather than to task-specific factors. The goal of the present research was to develop a task suitable for investigation of the mechanisms of sustained selective attention in young children, and to use this task to investigate the contribution of exogenous and endogenous factors to sustained selective attention in 3- to 5-year-old children.

The Object Tracking Task

The Object Tracking task is reminiscent of the Multiple Object Tracking (MOT) task used with adults to study properties of visual attention (Pylyshyn & Storm, 1988; Yantis, 1992). In the MOT task participants are asked to visually track several identical target objects moving along random trajectories among a larger set of identical objects, also moving along random trajectories. In this paradigm target objects are distinct only at the beginning of each trial (all target objects pulsate for a brief period of time at the onset of each trial), however adult participants (often to their own surprise) are capable of tracking four targets in the field of eight distracters with accuracy approaching 90% (Pylyshyn & Storm, 1988). While this paradigm has been successfully used to investigate properties of object-based attention in adults for over twenty years, our pilot testing suggested that the task is prohibitively complex for young children. Furthermore, the MOT paradigm does not allow assessment of automatic and voluntary components of sustained selective attention within the same task. The new Object Tracking task was created specifically to investigate mechanisms of sustained selective attention with young children.

In the Object Tracking task participants are presented with a three by three grid, with each of the nine grid locations identified by a popular cartoon character, and a target object moving on the grid along a random trajectory. Participants are asked to visually track the target and identify the grid location last visited by the target before it disappears. The moving target in this task can be accompanied by zero to eight distracters, also moving along a random trajectory. Target and distracter objects are randomly selected on each trial from a pool of nine different

geometric shapes. At the beginning of each trial participants are presented with still objects, and the object designated as the target is clearly marked at the beginning of each trial by being encircled in red (see Figure 1 for a schematic depiction of the task).

There are no restrictions on the motion paths of distracter objects, but there are two restrictions on the motion paths of the target objects. First, the target object has to disappear in the middle of one of the nine cells to reduce possible confusion if the target disappears on the border of two or more cells. Second, the target object must visit all nine screen locations at least once before disappearing. In all the experiments presented below, the speed of motion for all target and distracter objects was set at 800 pixels per frame at 30 frames per second (this speed was chosen during pilot testing with a separate group of 3- to 5-year-old children). Average trial duration was approximately 11 sec (a more detailed description of trial duration is provided in the Methods section).

When presented with the task, participants are explained that (1) objects will start moving when the experimenter pushes a button, (2) the goal of the task is to watch the object encircled in red, (3) the red circle will disappear as soon as objects start moving, and (4) once all objects disappear from the screen participants will need to point to the grid location last visited by the target object. Notice, that participants are not asked to perform visual search since the target is clearly marked at the beginning of each trial.

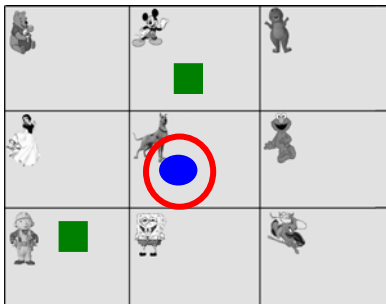


Figure 1. Schematic depiction of the Object Tracking task.

It has been demonstrated that salient objects engage attention automatically, whereas less salient objects may require voluntary processing (Koch & Ullman, 1985; Smith, et. al., 1996; Trick & Enns, 1998; Underwood, et. al., 2006). Therefore, distracter manipulations in the Object Tracking task can allow assessment of the contribution of exogenous and endogenous factors to selective sustained attention in the visual domain. In particular, it is expected that target objects will be more salient when distracters are identical to each other and different from the target (All Same Distracters condition) than when distracter objects are different from the target and from each other (All Different Distracters condition) (Treisman & Gelade, 1980). Thus, tracking accuracy in the All Different Distracters condition will reflect the contribution of predominantly endogenous

factors, whereas tracking accuracy in the All Same Distracters condition will reflect the contribution of both exogenous and endogenous factors. The difference in performance between these conditions will be reflective of the unique contribution of exogenous attention. Experiment 1 investigated mechanisms of sustained selective attention in 3- to 5-year-old children using the Object Tracking task in which target objects were accompanied by two distracters, and Experiment 2 investigated performance with six distracters.

Experiment 1

Method

Participants

Participants were 15 3-year-old children ($M = 3.66$ years, $SD = .28$ years; 5 females and 10 males), 17 4-year-old children ($M = 4.49$ years, $SD = .25$ years; 5 females and 12 males), and 18 5-year-old children ($M = 5.23$ years, $SD = .23$ years; 7 females and 11 males).

Design and Procedure

There were two within-subject conditions in Experiment 1: All Same Distracters and All Different Distracters condition. The order of these two conditions was counterbalanced across participants; both conditions were completed on two separate testing sessions that were spaced one to two weeks apart.

As described in the introduction, the Object Tracking task is designed such that the target objects have to appear at least once in each of the nine on-screen locations and disappear in the middle of one of these locations. Due to these restrictions, trial duration is not fixed but varies slightly from trial to trial. In Experiment 1, minimum trial duration was set to 10 s and mean trial duration was 11.00 s ($SD = 0.95$ s) in the All Same condition and 10.98 s ($SD = 1.03$ s) in the All Different condition.

To control for the possibility that any observed differences in tracking accuracy may stem from children being more likely to remember what object they were supposed to track in the All Same Distracters condition than in the All Different Distracters condition, at the end of each trial participants were asked to identify which object served as target on the trial they had just completed. Children were presented with a card depicting all nine shapes that could serve as target objects in this task, and asked to point to the shape they had been tracking.

All participants were tested by hypothesis-blind experimenters in quiet rooms in their day care centers. Participants completed 11 trials of the Object Tracking task in each condition. The first trial was completed with assistance from the experimenter who traced the moving target with their index finger. Participants were then explained that they needed to complete the rest of the task by themselves, tracking the target objects only with their

eyes. Data from the first experimenter-assisted trial were discarded from the analyses.

Results

Memory Accuracy

Accuracy with which children recognized the target object (among 9 possible objects) at the conclusion of each trial is presented in Table 1. Memory scores were submitted to a mixed ANOVA with age as a between-subject factor and condition (All Same vs. All Different) as a within-subject factor. This analysis indicated a main effect of age, $F(2, 47) = 5.77, p < .01, \eta^2 = .20$. Post-hoc Tukey HSD tests indicated that overall memory accuracy was lower in 3-year-old children ($M = .67$) than in both older age groups ($p < .05$), and statistically equivalent in 4- and 5-year-old children ($M = .83$ and $M = .86$, respectively). Most importantly however, there was no effect of condition and no age-by-condition interaction, both F s < 1 , ns. Therefore, results of the memory check indicate that if any significant differences in object tracking accuracy are observed between the All Same and the All Different Distracters conditions, these differences are unlikely to stem from differential demands on working memory.

Table 1: Memory accuracy in Experiments 1-2 (standard deviations in parentheses).

	All Same Distracters	All Different Distracters	t-test p -values
Experiment 1 (2 Distracters)			
3-y.o.	.69 (.22)	.65 (.22)	$p > .53$
4-y.o.	.83 (.17)	.83 (.17)	$p > .83$
5-y.o.	.86 (.13)	.86 (.22)	$p > .95$
Experiment 2 (6 Distracters)			
3-y.o.	.47 (.31)	.44 (.39)	$p > .75$
4-y.o.	.75 (.29)	.73 (.29)	$p > .83$
5-y.o.	.79 (.19)	.85 (.2)	$p > .44$

Object Tracking Accuracy

Tracking accuracy scores were averaged across 10 trials for each participant and submitted to a mixed ANOVA with experimental condition (All Same and All Different Distracters) as a within-subject factor and age (3-, 4-, and 5-years of age) as a between-subject factor. Results of this analysis revealed a main effect of experimental condition, $F(1, 47) = 11.46, p < .002, \eta^2 = .19$ and age $F(2, 47) = 8.04, p < .002, \eta^2 = .25$. These main effects were qualified by an age by condition interaction, $F(2, 47) = 3.43, p < .05, \eta^2 = .13$.

Planned comparisons indicated that participants in all conditions in all age groups identified the final location of the target object at above chance level (chance = 11% given nine response options), all one-sample t s $> 5.85, ps < .0001$. Five-year-old children were equally accurate in both conditions (83% and 84% of correct in the All Same and All Different condition, respectively) paired-sample $t(17) < 1,$

ns. However, younger children exhibited higher tracking accuracy in the All Same than in the All Different condition (see Figure 2): 4-year-olds averaged 76% and 65% of correct responses, respectively, paired-sample $t(16) = 2.26, p < .05, \text{Cohen's } d = .57$; and 3-year-olds averaged 67% and 48% of correct responses, respectively, paired-sample $t(14) = 2.63, p < .05, \text{Cohen's } d = .77$.

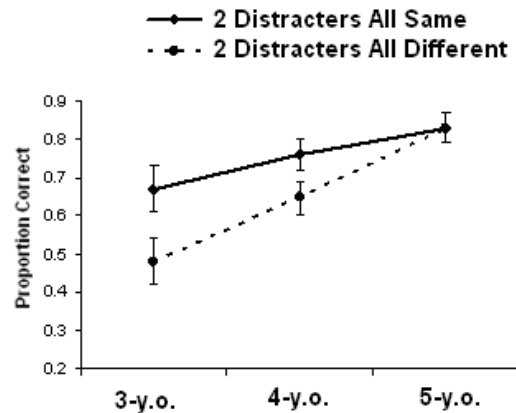


Figure 2. Tracking accuracy scores in Experiment 1.

Overall, results of Experiment 1 suggest that the ability to accurately track an object amidst heterogeneous distracters shows more protracted development than the ability to accurately track an object amidst homogenous distracters. Notice however, that 5 year-old children in Experiment 1 exhibited no effect of condition on tracking accuracy. At the same time, it has been shown that voluntary control of attention continues to mature well beyond the preschool years (Casey, Tottenham, & Fossella, 202; Trick & Enns, 1998). It is possible therefore, that condition differences in tracking accuracy will emerge in 5-year-old children if the task difficulty is increased (e.g., by increasing the number of distracters in the task). This possibility was investigated in Experiment 2.

Experiment 2

Method

Participants

Participants were 15 3-year-old children ($M = 3.33$ years, $SD = .27$ years; 6 females and 9 males), 16 4-year-old children ($M = 4.41$ years, $SD = .32$ years; 8 females and 8 males), and 20 5-year-old children ($M = 5.33$ years, $SD = .37$ years; 11 females and 9 males).

Design and Procedure

Design and procedure of Experiment 2 were identical to that of Experiment 1 with one important exception: the number of distracter objects was increased to six (compared to two distracters in Experiment 1). Mean trial duration was 11.00s

($SD = .94s$) in the All Same condition and $10.92s$ ($SD = .86s$) in the All Different condition.

Results

Memory Accuracy

Memory accuracy data are presented in Table 1. Memory scores were submitted to a mixed ANOVA with age as a between-subject factor and condition (All Same vs. All Different) as a within-subject factor. The analysis indicated a main effect of age, $F(2, 48) = 11.08, p < .0001, \eta^2 = .33$. Post-hoc Tukey HSD tests indicated that overall memory accuracy in 3-year-old children ($M = .45$) was lower than in older children ($p < .05$), and statistically equivalent in 4- and 5-year-old children ($M = .74$ and $M = .82$, respectively). Similar to Experiment 1, there was no effect of condition and no age-by-condition interaction, both $F_s < 1, ns$.

Object Tracking Accuracy

Tracking accuracy scores were submitted to a mixed ANOVA with experimental condition (All Same and All Different) as a within-subject factor and age (3-, 4-, and 5-years of age) as a between-subject factor. Results of this analysis revealed a main effect of experimental condition $F(1, 48) = 23.40, p < .0001, \eta^2 = .32$, and a main effect of age $F(2, 48) = 8.93, p < .005, \eta^2 = .27$. Unlike Experiment 1, the age by condition interaction did not reach significance, $F(2, 48) < 1, ns$.

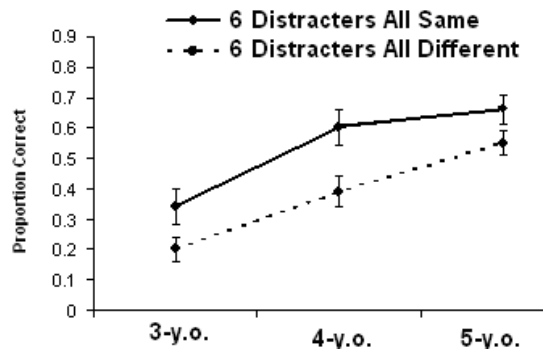


Figure 2. Tracking accuracy in Experiment 2.

Similar to Experiment 1, participants in all conditions in all three age groups identified the final location of the target object at above chance level (chance = 11%), all one-sample $t_s > 2.44, p_s < .03$. However, unlike Experiment 1, 5-year-old children exhibited the effect of condition with higher accuracy in the All Same condition (66%) than in the All Different condition (55%), paired-sample $t(19) = 2.52, p < .05$, Cohen's $d = .35$. Similarly, 4-year old children exhibited higher accuracy in the All Same condition compared to the All Different condition (60% and 39%, respectively), paired-sample $t(15) = 3.71, p < .005$, Cohen's $d = .97$, as did 3-year-old children (34% and 20%, respectively), paired-sample $t(14) = 2.07, p = .05$, Cohen's $d = .69$.

Across the two experiments, it appears that overall level of performance in all three age groups was lower in Experiment 2, when six distracters were present, than in Experiment 1, when two distracters were present. Indeed, when the data from both experiments were submitted to a mixed ANOVA with age and number of distracters (two vs. six) as between-subject factors and type of distracters (All Same vs. All Different) as a within-subject factor, the analysis revealed a main effect of the number of distracters, $F(1, 95) = 34.09, p < .0001$. This main effect was qualified by the distracter number by distracter type interaction, $F(1, 95) = 33.88, p < .0001$, suggesting that decrease in accuracy with the increase in the number of distracters was greater in the All Different condition than in the All Same condition (mean decrease in accuracy across all age group was 27% and 22%, respectively).

General Discussion

This paper presents findings from a novel task in which children were asked to track a moving target object accompanied by distracters that varied in type (all same versus all different) and number (two versus six). The results pointed to several novel findings. First, tracking accuracy improved with age. Second, tracking accuracy was higher in the All Same Distracters condition than in the All Different Distracters condition for all age groups when target objects were accompanied by six distracters; a similar difference between conditions was observed in 3- and 4-year-old children when targets were accompanied by two distracters. Third, unlike the visual search tasks, increase in the number of homogenous distracters resulted in lower accuracy for all three age groups tested in this study. Finally, there was no effect distracter type on children's ability to remember which object they were supposed to track; therefore, effects reported in this paper can not be attributed to differences in memory demands in different conditions.

The central finding reported in this paper is that preschool-age children are more successful at tracking targets moving among homogeneous than among heterogeneous distracters. This pattern of performance may arise for two different reasons. Consistent with the notion that the speed of engaging attention (or attention-getting) and speed of releasing attention (or attention-holding) are separate factors (Cohen, 1972), one possibility is that homogeneous distracters provide less competition for attentional resources and therefore children are less likely to glance away from the target moving amidst identical distracters. In other words, low competition for attentional resources may enhance attention-holding properties of the target. Alternatively, it is possible that children are equally likely to glance away from the target regardless of the type of distracters; however children are more successful in locating the target after glancing away in the homogeneous than in the heterogeneous distracter condition. In other words, low competition for attentional resources may

enhance attention-getting properties of the target. These possibilities remain to be addressed in future research.

Overall, findings presented above support the notion that development of endogenous attention (probed by the All Different Distracters condition) lags behind the development of exogenous attention (probed by the All Same Distracters condition). Importantly, the Object Tracking task makes it possible to assess both mechanisms within the same paradigm and quantify this lag in terms of the differences in tracking accuracy. Therefore, this new paradigm allows attributing changes in performance to different mechanisms of attentional control rather than to differences in the level of motivation and engagement in different tasks.

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