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The role of search speed in the contextual cueing of children's attention

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A R T I C L E I N F O

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A B S T R A C T

The contextual cueing effect is a robust phenomenon in which repeated exposure to the same arrangement of random elements guides attention to relevant information by constraining search. The effect is measured using an object search task in which a target (e.g., the letter T) is located within repeated or nonrepeated visual contexts (e.g., configurations of the letter L). Decreasing response times for the repeated configurations indicates that contextual information has facilitated search. Although the effect is robust among adult participants, recent attempts to document the effect in children have yielded mixed results. We examined the effect of search speed on contextual cueing with school-aged children, comparing three types of stimuli that promote different search times in order to observe how speed modulates this effect. Reliable effects of search time were found, suggesting that visual search speed uniquely constrains the role of attention toward contextually cued information.

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1. Introduction

Knowing where to look for relevant information in a cluttered visual environment is crucial to making rapid responses and learning from that information. Adults are equipped with abilities enabling

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them to exploit a variety of different cues that can rapidly guide attention in the moment (Chun & Wolfe, 2001; Luck & Vogel, 1997). One well-established phenomenon is known as contextual cueing (Chun & Jiang, 1998, 1999; Jiang & Wagner, 2004): repeated exposure to the same arrangement of randomly assigned elements serves as a predictor of a target location, implicitly cueing observers to the target's position more rapidly.

Contextual cueing has been proposed as a general learning effect potentially relevant to a number of developmental phenomena (Smith, Colunga, & Yoshida, 2010). However, previous studies investigating the effect with school-aged children report conflicting findings (Couperus, Hunt, Nelson, & Thomas, 2011; Dixon, Zelazo, & De Rosa, 2010; Vaidya, Huger, Howard, & Howard, 2007), possibly because these studies included a variety of modifications designed to make the task child friendly (Couperus et al., 2011; Dixon et al., 2010; Jiménez-Fernández, Vaquero, Jiménez, & Defior, 2011). The present study focuses specifically on search speed (how long it takes children to find a target) and its potential role in the contextual cueing effect. The contextual cueing effect in adults depends on learning the configural relations among distractors and targets to aid search. Overly rapid or non-thorough search in more child-friendly tasks may limit learning of these relations, attenuating contextual cueing effects. Here, we describe first the contextual cueing findings from research with adults and then the mixed results with children, with emphasis on the different task contexts. We then introduce our hypothesis regarding the relevance of search speed in the emergence of contextually cued attention.

In the standard contextual cueing paradigm developed by Chun and Jiang (1998), computer-based search displays are presented to adult participants with various configurations of stimuli, such as those shown in Fig. 1b. Participants must find a specific target, for example, the letter T, among an array of distractors, such as multiple images of the letter L. The target and distractors are composed of the same intersecting features; thus, greater numbers of distractors on the screen result in slower search speeds (Treisman & Gelade, 1980). The key manipulation is whether the elements vary in position over time—more specifically, whether particular arrays of targets and distractors are repeated. Across trials, half of the target locations are paired with repeated distractor configurations and the other half are paired with randomly generated distractor configurations. Adults are faster at finding a target in a repeated configuration than in a new configuration of distractors, meaning that they must store the target's location with respect to the array of distractors. This phenomenon is well established in adults, and the cueing effect emerges after very few trials—as few as five repetitions of the display (Chun & Jiang, 1998)—and can persist for up to a week (Chun & Jiang, 2003).

Although there are different accounts of the underlying mechanism, there is general consensus that the cueing effect emerges because the visual context in which the target is placed—repetition of the configuration of distractors—serves as a guide for effective and rapid search (Chun, 2000; Chun & Jiang, 1998, 1999; Endo & Takeda, 2004; Lleras & von Mühlenen, 2004; Olson & Chun, 2002; Tseng & Li, 2004; but see Kunar, Flusberg, Horowitz, & Wolfe, 2007).

1.1. *Developmental findings*

The attentional process just described is thought to play a general role in visual learning in everyday cluttered scenes and in object recognition (Brockmole & Henderson, 2006; Hidalgo -Sotelo, Oliva, & Torralba, 2005) and may therefore be important to the development of object recognition and attentional learning more broadly. However, there have been very few developmental studies of contextual cueing and most efforts have concentrated on school-aged children (Barnes et al., 2008; Couperus et al., 2011; Vaidya et al., 2007; but see Dixon et al., 2010). The results have been mixed, with two studies demonstrating the effect (Barnes et al., 2008; Barnes, Howard, Howard, Kenealy, & Vaidya, 2010), four showing patterns consistent with contextual cueing, but with tasks that contained additional nonspatial cues (Brown, Aczel, Jiménez, Kaufman, & Grant, 2010; Couperus et al., 2011; Dixon et al., 2010; Jiménez-Fernández et al., 2011), and others not replicating or only partially replicating the phenomenon (Couperus et al., 2011; Vaidya et al., 2007).

Given these mixed findings, more evidence is needed with respect to contextual cueing in children. Understanding the developmental trajectory is important to constraining theories about both underlying mechanisms and how the effect may be relevant to the development of visual attentional processes and object recognition, which appears to extend well into adolescence (Nishimura, Scherf,

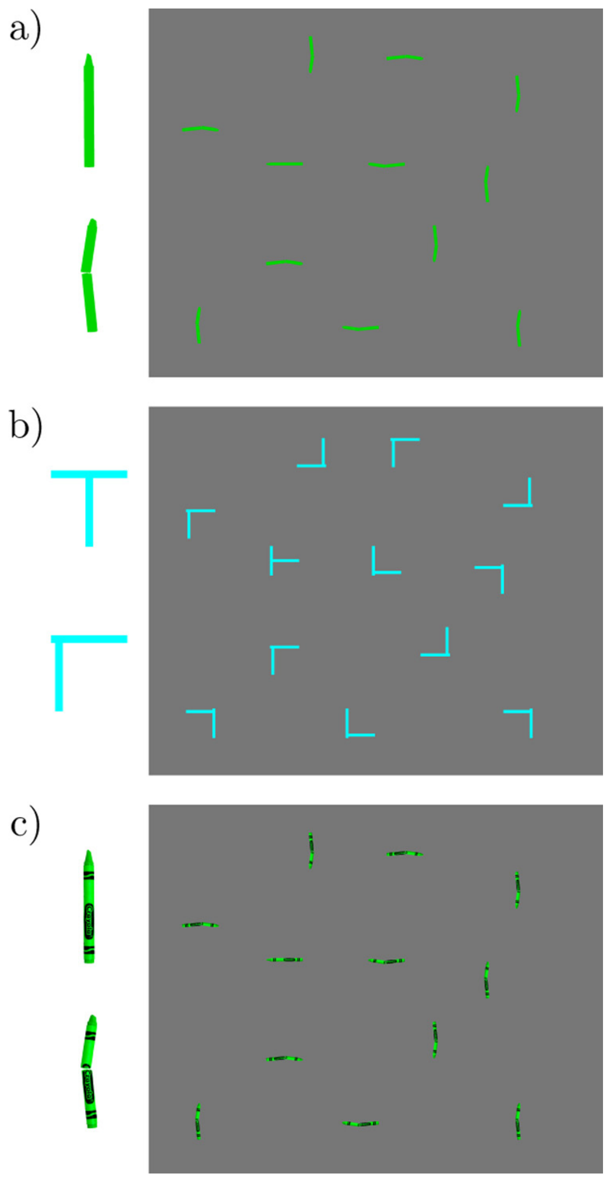

Fig. 1. Illustrations of the stimulus configurations used in (a) the sparse crayon condition, (b) the letter condition, and (c) the rich crayon condition. The rightmost image illustrates an entire configuration of stimuli as seen by participants, while the left images illustrate a distractor (top) and target (bottom) for each stimulus type.

& Behrmann, 2009). How and when children show adult-like contextual cueing is also critical because the mechanisms responsible are thought to play a role in fundamental processes such as word learning in preschool-aged children (Horst, Parsons, & Bryan, 2011; Smith et al., 2010; Vlach & Sandhofer, 2011) although the phenomenon has never actually been demonstrated in preschoolers.

1.2. Potentially limiting task factors

Mixed findings with school-aged children point to several task factors possibly relevant to the emergence of contextual cueing, including task length, stimulus type, age, and density of repetition. Two studies (Couperus et al., 2011; Vaidya et al., 2007) that did not find a reliable contextual cueing effect differed in both age group and task length. Vaidya et al. (2007) used a range of ages (6–13) and Couperus et al. (2011) used one (10-year-olds), but both studies employed the same letter stimuli (Ts and Ls) commonly used in adult studies (Chun & Jiang, 1998, 1999; Jiang & Wagner, 2004). Vaidya et al.'s task contained 720 trials, similar to a typical adult task, whereas Couperus et al. used half that number. Both studies reported no contextual cueing effect with typical statistical measures. However, Couperus et al., using the smaller number of trials, also documented that when they looked exclusively at trials where children attended to more than 75% of stimuli (color coded to manipulate the number of distractors), there was a reliable effect. Thus, contextual cueing may emerge in young children, but perhaps in limited circumstances. Important to the present study, trials in the Couperus et al. (2011) study that induced the effect also involved a slower search speed. Although this trend was seen in a single study with attentional guidance potentially provided by color, it suggests that *thorough* search contributes to learning the relation between the configuration of distractors and the target for specific arrays.

However, in two studies using similar letter stimuli and conducted with a similar age group (7–14-year-olds) as done by Vaidya et al. (2007), Barnes et al. (2008, 2010) documented a reliable effect with both typically developing children and atypically developing high-functioning children with autism spectrum disorder or attention deficit hyperactivity disorder. These results appear to conflict with those of Vaidya et al. The designs are similar enough, however, to compare incremental differences in their results, and therefore limit the extent of speculations about their contrasting findings. Both studies used the same control group (14 age-matched, typically developing children) and only male participants. These studies again hint at a potential role of search speed generated by small alterations in the distractor item. Vaidya et al. (2007) used a letter L with the junction offset by three pixels as a distractor item, whereas Barnes et al. (2008, 2010) used an L without an offset (i.e., a block-like letter). The offset makes a distractor L more similar to the target T and makes the task more difficult in adult studies (Chun & Phelps, 1999). Barnes et al. (2008, 2010) documented contextual cueing effects accompanied by faster search speeds, whereas Vaidya et al. (2007) documented no effect by using an offset that generated slower search speeds. This pattern seems to contradict the theory that slower search speeds lead to increased cueing effects. However, it may also suggest that search speed interacts with task difficulty, pointing toward an optimal speed for contextual cueing (not too fast, not too slow).

One limitation of the studies just reviewed is that they used the same stimuli, Ts and Ls, which might be differentially familiar to young children. Three recent studies have documented the importance of the particular items in the search set (Brown et al., 2010; Dixon et al., 2010; Jiménez-Fernández et al., 2011). None of these three studies used letter stimuli; additionally, other task specifics were modified to be child friendly. Dixon et al. (2010) reported a robust effect in younger children (5–9-year-olds) using age-appropriate stimuli (familiar and recognizable objects—in this study, pictures of fish). Fish are recognizable objects for which children may already have robust representations; in contrast, school-aged children's letter representations may not be as robust as those of adults (Burgund & Abernathy, 2008; Burgund, Schlaggar, & Peterson, 2006). The effect reported by Dixon et al. suggests a potential role of strength of stimulus representation on early contextual cueing effects. Brown et al. (2010) and Jiménez-Fernández et al. (2011) documented the effect with 8–14-year-olds and 8–9-year-olds, respectively, using numerical stimuli in a modified contextual cueing task developed by Jiménez and Vázquez (2008, 2011). Numerical stimuli may induce less stable representations than do fish pictures, but the study used *different* numbers (as opposed to different types of the same number) as the target and distractors (e.g., finding a 4 among 5 s). In this case the target and distractors were composed of different features, in contrast to the traditional Ts and Ls whose features vary only in their point of intersection. The perceptual distance between target and distractors might therefore be larger than in studies using Ts and Ls, producing less clear evidence of contextual cueing in children.

Evidence from studies using number and picture stimuli suggest that representation of the local elements needs to be strong enough for participants to efficiently find the target (Brown et al., 2010; Dixon et al., 2010; Jiménez-Fernández et al., 2011; Newell, Brown, & Findlay, 2004). Additionally, a comparison of results from Vaidya et al. (2007) and Barnes et al. (2008, 2010) suggests a potential benefit of fast search speed. In contrast, evidence from trials using potentially more attended stimuli (Ts and Ls) suggests that learning the cue to the target's location requires a search difficult enough that it must be undertaken slowly and thoroughly, such that learners can map the array pattern as a cue to target location (Couperus et al., 2011). The hypothesis that a thorough search is needed—one not too fast to encode the entire array—is consistent with findings from adults that contextual cueing emerges from more effortful search involving scan paths through the field of distractors to the target (Brady & Chun, 2007). In one study, adults' attentional guidance was improved by repeated contextual cues only when search times were increased; these increased search times were achieved by increasing the complexity of the display (Kunar, Flusberg, & Wolfe, 2008). This is the approach we take here. We test the hypothesis that "thorough" searching may help children learn contextual cues. If correct, this hypothesis may also provide insight into whether "pop-out–like" effects prevent contextual cueing from emerging in adults (Geyer, Zehetleitner, & Müller, 2010; Kunar et al., 2007).

Previous findings from the adult and developmental literatures indicate a potential relation between search speed and the magnitude of the learning effect. Slow searches may reflect a reduction in the use of global context that constrains attention to local elements, increasing the necessary memory capacity to accommodate further fixations during difficult searches. Conversely, fast searches may limit encoding of local stimulus locations as a result of fewer fixations. The idea might be analogous to the "Goldilocks" effect of needing "just enough speed" for early learning (Kidd, Piantadosi, & Aslin, 2012).

1.3. Goals of the present study

Our central goal was to address the relevancy of search speed by comparing children's performance with the traditional Ts and Ls to performance with two different versions of child-friendly "crayons." The three sets of arrays are shown in Fig. 1. Past research shows that a number of factors make search more difficult and potentially slower. Two of these factors are discrimination and familiarity (Duncan & Humphreys, 1989; Mruczek & Sheinberg, 2005; Wang, Cavanagh, & Green, 1994). Laboratory versions of Ts and Ls make the discrimination task more difficult given their overlapping features. These letters may also be unfamiliar to children. Further, number of features (such as line segments, of which individual items in the array are composed) increases search time in adults (Duncan & Humphreys, 1989; Treisman & Gelade, 1980). In the present study, *rich* and *sparse* crayons differ in just this factor, as the sparse crayons were made by subtracting line segments from the rich ones. Both versions were explicitly referred to as crayons during instruction and should also be familiar, creating more child-friendly arrays. In addition to manipulating the kind of stimuli, with the expectation of effects on search speed, we increased the density of repetition by including fewer repeated configurations (600 trials) that were, as a result, seen more frequently than those in the original task created by Chun and Jiang (1998). Theoretically, this should aid learning of repeated configurations by reducing the interval between repetitions while still generating sufficient repetitions (50 per repeated array); we should then be able to examine the emergence of the effect across repetitions. Otherwise, the structure of the task and arrays closely follows the original Chun and Jiang (1998) experiment. We chose 8–12-year olds because of the reliable effect observed among 10-year-olds by Couperus et al. (2011) and among 7–14-year-olds by Barnes et al. (2008, 2010).

2. Method

2.1. Participants

Sixty children (mean age 10.53 years, range 8–12 years) participated in the study. Twenty children (mean age 10.59) were randomly selected to participate in the *letter* condition, 20 children (mean age 10.24) participated in the *sparse crayon* condition, and 20 children (mean age 10.77) participated in the *rich crayon* condition. Children were primarily from middle-class families and were recruited from local schools and after-school program centers. Highest level of education was collected from both parents, and the combined score revealed no significant differences across conditions ($p = .95$). Median adjusted gross income based on zip code information also did not differ across conditions ($p = .87$). Children participated either in a quiet room at the school or program center, or in an on-campus lab, and received a small gift (e.g., a Frisbee) for participating.

2.2. Stimulus materials

The stimuli are shown in Fig. 1. Target objects in the letter condition were the standard versions of the letter T, and distractors were the letter L (Fig. 1b) used in previous studies of contextual cueing (Barnes et al., 2008, 2010; Brady & Chun, 2007; Chun & Jiang, 1998; Peterson & Kramer, 2001). Target

Table 1
Range and mean of RTs in each condition along with standard deviations.

Condition	RT range (ms)		Mean RT (ms)	
	Min RT	Max RT	Repeated	Nonrepeated
Sparse crayons	208	5207	1700 ± 812	1725 ± 833
Letters	162	7151	1909 ± 975	1991 ± 1022
Rich crayons	351	9399	2276 ± 1485	2302 ± 1492

objects in the rich and sparse crayon conditions were straight (unbroken) crayon-shaped objects, and distractors were broken crayon-shaped objects (Fig. 1a and c). Rich crayons were actual images of crayons containing multiple colors, features, and, compared with sparse crayons, more line segments, which are known to increase search times (Duncan & Humphreys, 1989; Treisman & Gelade, 1980). Sparse crayon stimuli depicted the contour shape of a crayon with none of the internal details of the rich crayons. All images were of equal width and subtended at an angle of approximately 2.4°. The color of each stimulus type (blue for letters and green for crayons) was applied to both target and distractors and was constant across trials and configurations.

2.3. Procedure

Participants performed the task in a quiet room on a 21-in. Macintosh computer at a resolution of 1680 × 1050 pixels. Stimuli were presented using MATLAB. Participants were instructed to find the target stimulus as quickly as possible on the screen. If the child's first few responses were incorrect, the experimenter provided additional verbal instructions. Participants responded by pressing a key that corresponded to the orientation of the target. Stimuli were spatial configurations of 12 elements in blue on a neutral gray background (the letter condition) or in green on a gray background (the crayon conditions). Each display contained one target and 11 distractors. The target was a T (or unbroken crayon in the crayon conditions) pointing to the left (0°) or right (180°) and the distractors were always Ls (or broken crayons in the crayon conditions) randomly rotated by 0, 90, 180, or 270°. Each configuration was generated by random assignment of the 12 elements, each to a cell within an invisible grid of eight columns and eight rows. The display remained until the participant responded. Feedback for incorrect responses was given in the form of a low-frequency auditory tone and the word "incorrect" displayed in the center of the screen. Participants were allowed to take short breaks at five-block intervals.

The task consisted of 50 blocks of trials, with 12 trials per block, for a total of 600 trials. These blocks were combined into epochs to precisely observe development of the effect. The same 12 target locations were seen in each block in random order. Six were always paired with configurations that did not vary across blocks, while the remaining six were paired with configurations randomly generated for each block, such that each block consisted of six repeated and six nonrepeated configurations. On repeated configurations, the location of the target was the same, but its left and right orientation varied; therefore, the spatial configuration of the distractors predicted the location of the target but not the response to it.

3. Results

Contextual cueing is defined as faster search times for repeated than for nonrepeated arrays as the number of trials increases. Faster search times on repeated than nonrepeated arrays imply that participants have learned the distractor configuration and target location of the array. We first present standard analyses for measuring contextual cueing and then a more detailed analysis of how search speed and scene complexity may relate to the emergence of the effect over time.

To determine if response times (RT) for repeated arrays decreased as predicted, only accurate trials were considered. Outliers were empirically determined by bootstrap resampling the RT data ($n = 5000$) for each condition separately and calculating the 99% interval for each bootstrap sample (Wilcox, 2003). Perseverative (unusually fast) responses ranged in the lower tails from 162 ms to 351 ms, while prolonged (unusually slow) responses ranged in the upper tails from 5207 ms to 9399 ms (Table 1). Exclusion of trials due to accuracy and RT accounted for 2.83%, 3.25%, and 2.65% of the data for the letter, sparse crayon, and rich

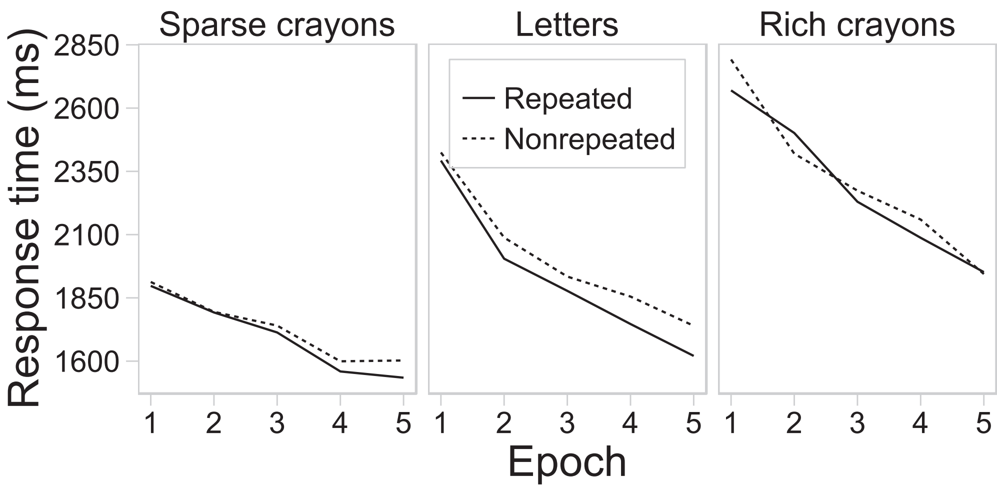

Fig. 2. Mean response time comparisons for repeated and nonrepeated configurations across epochs for each stimulus type.

crayon conditions, respectively. Mean RT for repeated and nonrepeated arrays was calculated for each of the 50 blocks of trials. Blocks of trials are typically aggregated further into epochs—usually 60–150 trials per epoch (Chun & Jiang, 2003; Peterson & Kramer, 2001). Combining blocks this way reduces variability and increases power. We collapsed blocks of trials into five epochs (10 blocks per epoch) and report results obtained from analysis of variance (ANOVA). We then analyze changes in search time for the repeated and nonrepeated arrays across the first and last epochs.

For the overall analysis, mean RTs were computed for each participant and were analyzed using a mixed repeated measures ANOVA, with repetition (repeated, nonrepeated) and epoch (1–5) as within-subject factors and condition (letter, rich crayon, sparse crayon) as a between-subject factor. Fig. 2 displays the decrease in response time across epochs for each condition. Participants' search times became faster across trials for both repeated and nonrepeated arrays, indicating an increase in target identification speed due to practice effects, $F(4, 228) = 102.49$, $p < .001$, $\eta_G^2 = .14$. More importantly, the main effect of repetition was significant, $F(1, 57) = 4.53$, $p < .05$, $\eta_G^2 = .002$, suggesting a general contextual cueing effect collapsed across all conditions. Differences in mean RT were found between conditions, with a large effect of stimulus type on response time, $F(2, 57) = 6.72$, $p < .01$, $\eta_G^2 = .17$. Overall, the sparse crayon condition yielded the fastest search times and the rich crayon condition yielded the slowest search times. Condition also interacted with epoch, $F(8, 228) = 5.22$, $p < .001$, $\eta_G^2 = .02$, suggesting that stimulus type led to different degrees of improvement in overall RT over the course of epochs. No other main effect or interaction reached significance. Follow up tests showed a main effect of epoch for all conditions, all $p < .001$; however, only the letter condition showed a difference in RT between repeated and nonrepeated configurations, $F(1, 19) = 5.8$, $p < .05$, $\eta_G^2 = .01$.

The significant interaction between condition and epoch suggests different patterns of RT (and thus search speed) over the course of epochs across conditions. We hypothesize that these different patterns may contribute to the degree of cueing in the latter portion of the task. If slower response times support learning the distractor configurations—and the cue to the target's location—for specific repeated contexts, we might expect earlier learning in the letter condition than in the sparse crayon condition and an increase in the magnitude of the effect during the last epoch. However, even further reduction in search speed and prolonged RT, such as is found in the rich crayon condition, might fail to elicit reliable cueing effects due to overall complexity of the visual array. The different conditions do conform to such trends in mean RT, and several pieces of evidence point to observable differences in responses by condition. Table 1 illustrates differences in RT ranges for each condition and mean RT for repeated and nonrepeated configurations.

To investigate further, we compared the size of the contextual cueing effect (the same measure taken from the last epoch) against an individual's search speed, collapsed across repeated and random configurations. This allows us to gauge a child's individual response speed and determine if it plays a role in the progression of the effect. Fig. 3 plots each child's cueing effect against the inverse of their mean RT. The larger, filled-in points indicate the mean cueing effect and search efficiency for a particular condition. To model the tendency of intermediate search speeds to lead to a contextual cueing advantage, we fit a quadratic curve (which takes on an inverted u-shaped form) to the data. We used the inverse transformation (1/RT) instead of raw RT scores in this analysis, given positively skewed response time distributions due to prolonged responses. This is common with RT data (Ratcliff, 1993), and was especially appropriate in this instance with children. The overall model was significant, $F(2, 57) = 6.83$, $p < .01$, adjusted $R^2 = .17$, with a downward decrease of the cueing effect (second degree polynomial) past the point of intermediate search speed (in the letter condition, $p < .01$).

An alternative theory is that the cueing effect linearly increases as a child increases search speed; if so, the sparse crayons should elicit a more pronounced difference between repeated and nonrepeated configurations by the last epoch. An ANOVA was conducted to compare the competing hypotheses for a quadratic or linear trend and to determine if the additional parameter estimate required to fit the former was a better model of the data. A significant reduction in residual error for the quadratic model was found, $F(1, 57) = 11.3$, $p < .01$, compared to the linear model. These results suggest that neither prolonged nor rapid searches give rise to a robust contextual cueing effect, and *intermediate* levels of search speed result in an improvement in search time for repeated contexts.

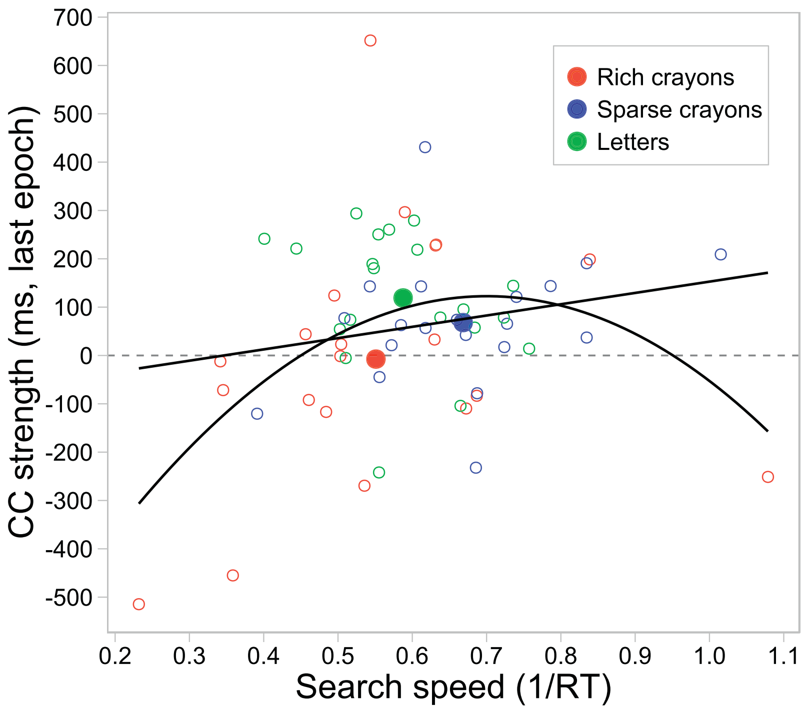

Fig. 3. Scatter plot showing comparisons between search efficiency (defined as the reciprocal of response time) and strength of the cueing effect (defined as the difference in average response times between repeated and nonrepeated configurations) in the last epoch. Larger, filled points are the averages per condition, while the dotted line is the point at which there is no cueing effect. Empty points represent data of individual participants. Solid lines are fitted linear and quadratic model predictions.

4. General discussion

This study demonstrates differential contextual cueing effects in school-aged children that vary as a function of search speed. Three stimulus types were used as a natural manipulation of search speed. Reliable effects were found using traditional letter-shaped stimuli (T's and L's), but not using crayon-shaped stimuli that generated slower and faster search speeds. A closer analysis suggests a possible effect of search speed on cueing strength. Specifically, search speed was compared to the strength of cueing effects for each participant. A quadratic model indicated that intermediate levels of search speed were associated with the largest contextual cueing effects regardless of stimulus type (Fig. 3). These results indicate a potential influence of search speed on the emergence of contextually cued attention, suggesting how these effects may function in development within this and potentially other cognitive domains.

4.1. Search demand and learning

Use of child-appropriate stimuli allowed for natural manipulation of search speed without sacrificing perceptual demands seen with the letter stimuli used in adult studies. This enabled us to explore the extent to which speed of visual processing plays a role in the development of the contextual cueing effect in school-aged children. Research has long acknowledged that slowed or distributed learning may benefit memory (Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; Dempster, 1996; Donovan & Radosevich, 1999; Glenberg, 1979). Much research on contextual cueing has focused on learning configurations of distractors and on the ability to use this method to efficiently guide attention to the target (Brady & Chun, 2007; but see Kunar et al., 2007, 2008). Using distracteors to find a target would seem to require *attending* to them during learning (Jiang & Chun, 2001; Jiang & Leung, 2005), and situations in which attention is too easily guided to the target location may take longer to facilitate a benefit of contextual repetition. Interestingly, Kunar et al. (2008) found that contextual cueing effects were accompanied by more efficient attentional guidance in adults only when participants were forced to spend more time encoding the display.

Our results also suggest, however, that an excess of time spent encoding the display may attenuate learning. Search that is too difficult may not facilitate learning of configural information. One study that failed to indicate a contextual cueing effect in children (Vaidya et al., 2007) used traditional letter stimuli that contained a small offset between the line junctions comprising the letter "L" of the distractor stimuli, making the task more difficult (Chun & Phelps, 1999). Researchers using the same methodology without this offset did demonstrate contextual cueing effects, both with typically and atypically developing children (Barnes et al., 2008, 2010). It seems reasonable, then, that time and effort spent attending to configural information may affect how children encode repeated information.

Time and effort spent learning configural cues may thus influence the strength of contextual cueing effects. One hypothesis is that *moderately* slow search contributes to a stronger emergence of the effect by allowing greater learning of relevant cues and unlearning of irrelevant cues, independent of stimulus type. In the present study, response time was naturally manipulated by using different types of stimulus items that yielded slower and faster RT patterns than typically seen when processing letter stimuli. Because we used different stimulus sets to create these differences in response time, we cannot be certain that the critical factor is response time rather than some aspect of the stimuli themselves. For example, perhaps it is the use of letters that supports sensitivity to repeated contexts at the search stage, given a child's history with letters observed in a locally surrounded context. Varying stimuli along a single linear dimension might help us gain a deeper understanding of the relationship between stimulus discriminability and contextual cueing effects. Resolving this issue is not straightforward, however, since the ideal approach would be to use the same stimuli to produce faster and slower response times. One approach might be to manipulate RT by perceptually training participants to discriminate between targets and distractors more or less easily. Alternatively, future researchers could use a variety of stimuli to document the generalizability of moderately slow search leading to more robust contextual cueing in children.

Such manipulations correspond to the three stages of a visual search framework specified by Solman, Cheyne, and Smilek (2011): (a) initial encoding, (b) search of the array, and (c) response selection and execution. Given the potential importance of contextual cueing for a variety of cognitive tasks, systematic study of the key processing stages and the role of complexity during each stage is also in order. If slower search leads to the use of contexts to find targets, prolonged durations at the second stage should benefit contextual cueing. At the same time, stimulus characteristics may lengthen the initial encoding stage, resulting in slower RTs but not necessarily facilitating contextual learning (Jiang, Sigstad, & Swallow, 2013). While our results do not resolve these questions, they implicate two factors, stimulus properties and search speed, that may influence contextual cueing and its development in young children.

4.2. *Local vs. global processing*

One possibility is that search speed affects the relation between global and local processing. This theory is particularly relevant to different accounts of contextual cueing, suggesting that perceivers encode the array as a configural *whole* before associating it with the target location (Brockmole, Castelhano, & Henderson, 2006; Hollingworth, 2009). It is also relevant to accounts that emphasize attentional pathways between individual distractors and the target location in the array (Brady & Chun, 2007). Contextual cueing may depend on the ability to process both global (holistic) and local (individual) elements of the scene. An overly simple discrimination between targets and distractors could lead to pop-out-like effects in which global processing of the array as a whole is not sufficient to guide attention to the target (Geyer et al., 2010). At the same time, overly difficult discrimination may lead to attentional fixation at the local level, such that global contextual information is not encoded. This hypothesis is supported during part-whole tasks (Navon, 1977), in which children's shifts of attention between local and global aspects of visual spatial patterns seem to depend on stimulus complexity, such that complex features constrain attention to process local features (Dukette & Stiles, 1996, 2001; Harrison & Stiles, 2009; Prather & Bacon, 1986).

Following this hypothesis, moderate search speeds in the letters condition in the present study may have enabled partial processing of both local and global information. Why, then, have letter stimuli not consistently supported children's contextually cued attention in other developmental studies?

This study differed from others that documented no effect with letter stimuli in terms of increased repetition density. It included fewer repeated arrays seen more times and with greater frequency than those in previous studies (Vaidya et al., 2007). This further suggests a potential role of repetition density in cueing effects (and a unique relation to stimulus speed), which we did not examine directly in this study. The hypothesis that contextual cueing effects vary with the discriminability of the stimuli, reflecting differences in depth of processing of local and global elements, is speculative. However, revealing the exact processes involved in shifts between local and global visual processing has substantial implication for the nature of early contextual cueing. For example, if processing the whole array as a configuration is critical to the effect, manipulations that assist global processing —such as correlated colors or gestalt structures in the array—should benefit its emergence (Brown et al., 2010; Chun & Jiang, 1998; Couperus et al., 2011; Dixon et al., 2010; Huang, 2006; Jiménez-Fernández et al., 2011).

4.3. *Implications for learning in general*

The presence of contextual cueing suggests that visual experience may influence stimulus discrimination. Speed of visual search is improved by practicing the same search task over several sessions (Logan, 1988; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) and made more efficient by searching for familiar (e.g., modern cars), rather than unfamiliar (e.g., antique cars), instances of the same category (Alvarez & Cavanagh, 2004; Bukach, Philips, & Gauthier, 2010). Experience with procedure search task stimuli may therefore improve performance. A key question, then, is whether general experience with objects leads to support of local discrimination that guides attention to relevant information, and, if so, how? If contextual cueing depends on (and thus also measures) developing expertise in object recognition, one should be able to show that practice with specific stimuli in non-search tasks generalizes to search tasks and to the emergence of contextual cueing effects for repeated arrays.

Investigating the relation between experience with objects and visual processing may help us understand what role contextual cueing plays in the development of other cognitive skills. A number of researchers have suggested that the process of learning to read may interact with visual skill and with the ability to efficiently scan and organize looking during reading (Chan & Vernon, 1988; Dehaene, 2009; Hoosain, 1991; McBride-Chang et al., 2011; Orton, 1925; Powers, Grisham, & Riles, 2008). In mathematics, the ability to focus on relevant information within a visual context may contribute to successful rule learning (Goldstone, Landy, & Son, 2008; Kellman et al., 2008; Kellman, Massey, & Son, 2010; Li & Huang, 2011; Silva & Kellman, 1999) and to the ability to attend to both denominator features and numerator features of fractions (Gelman, 1991). Thus, a question for future research is how contextual cueing might be related to—and might vary within—different domains.

Few studies have addressed the development of contextual cueing effects in children; therefore, strong conclusions are not warranted. However, our results indicate that search speed may play a role in contextually cued attention and may be relevant to both local and global information processing. To obtain a deeper understanding of the effect—which appears potentially relevant to broader cognitive development—it is necessary to further investigate what factors help children develop this sensitivity. In particular, we should investigate speed and how it may relate to task duration (i.e., spacing effects). We should also examine the contributions of stimulus familiarity, complexity, representative orientation, crowding, and distribution effects at different developmental points to better understand the potential role of early sensitivity to repetitive information in learning more generally.

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