Journal of Experimental Child Psychology 121 (2014) 42–62

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

The impact of distracter–target similarity on contextual cueing effects of children and adults

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ARTICLE INFO

Article history:
Received 30 October 2012
Revised 17 October 2013
Available online 20 January 2014

Keywords:
Guided search
Distracter similarity
Contextual cueing
Development
Selective Attention
Implicit Learning

ABSTRACT

Contextual cueing reflects a memory-based attentional guidance process that develops through repeated exposure to displays in which a target location has been consistently paired with a specific context. In two experiments, we compared 20 younger children's (6–7 years old), 20 older children's (9–10 years old), and 20 young adults' (18–21 years old) abilities to acquire contextual cueing effects from displays in which half of the distracters predicted the location of the target and half did not. Across experiments, we varied the similarity between the predictive and nonpredictive distracters and the target. In Experiment 1, the predictive distracters were visually similar to the target and dissimilar from the nonpredictive distracters. In Experiment 2, the nonpredictive distracters were also similar to the target and predictive distracters. All three age groups exhibited contextual cueing in Experiment 1, although the effect was not as strong for the younger children relative to older children and adults. All participants exhibited weaker contextual cueing effects in Experiment 2, with the younger children not exhibiting significant contextual cueing at all. Apparently, when search processes could not be guided to the predictive distracters on the basis of salient stimulus features, younger children in particular experienced difficulty in implicitly identifying and using aspects of the context to facilitate with the acquisition of contextual cueing effects.

Introduction

The ability to learn spatial layouts is integral to a number of important everyday activities. For example, shopping is much easier when you shop the same supermarket regularly. It is also much easier to find your car after work if you can remember the general (or even exact) location of your

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http://dx.doi.org/10.1016/j.jecp.2013.10.009

car in the parking lot. During recent years, it has become increasingly clear that learning spatial layouts can be done in at least two fundamentally different ways. First, it is possible to learn spatial layouts by explicitly memorizing the locations of objects in the environment, as evidenced in tests of visuo–spatial working memory (Meneghetti, De Beni, Gyselinck, & Pazzaglia, 2011; Nori, Grandicelli, & Giusberti, 2009). Second, it is possible to learn spatial layouts in an incidental, virtually implicit manner, as evidenced by the phenomenon of contextual cueing (Chun & Jiang, 1998; Jiang & Chun, 2001). In our research, we focus on developmental variations in this second form of spatial learning. Although challenges to the claim that contextual cueing reflects a purely implicit process have been made (e.g., Smyth & Shanks, 2008), it is reasonable to suggest that many young adult participants who exhibit facilitation effects based on the spatial regularities found in complex visual stimuli do so without explicit awareness of the covariation between the target and other items in the displays.

Both natural and manmade environments incorporate spatial regularities associated with the relative location of objects. For example, the most common places to find berries in the woods can look very similar to each other, with berries in a location with an opening to sunlight and near the water. As a result, when searching for berries in the woods, you may be drawn to the "non-berry" features of the environment that signal that berries can be found nearby. In manmade cities, traffic signals along the streets are commonly found in the same relative locations (exceptions can lead to accidents). Learning about these regularities and what they predict make it possible for an organism to function efficiently in new environments as long as those regularities are maintained. More specifically, attention can be guided to objects that can provide benefit or information without calling on explicit and effortful learning processes to do so. The ability to use this information is important to the general cognitive processing efficiency of both children and adults. Hence, it is important to evaluate the relative abilities of children and adults to engage in implicit spatial learning. It is also important to be able to identify what factors, if any, may interfere with this type of learning for younger individuals relative to older individuals. Contextual cueing, as studied in laboratory settings, provides a means for evaluating age-related variations in the implicit associative learning of spatial information.

Contextual cueing refers to a form of attentional guidance where individuals are drawn to the location of a target object that has been consistently associated with the locations of the non-target objects in the visual environment (Chun & Jiang, 1998). Hence, it is the expression of the learning of associations between a specific target location and the spatial arrangement of the context in which the target is embedded. In Chun and Jiang's (1998) typical study of contextual cueing, participants were shown displays containing a target (e.g., the letter T rotated 90 degrees) and several distracters (e.g., the letter L rotated 90 degrees). They were required to locate and identify which direction the target T was pointing. What participants did not know was that some of the configurations of the distracters were consistently associated with a specific target location across trials and, thus, always predicted the location of the target (repeated display condition). In contrast, some configurations of the distracters were random from trial to trial (new display condition). Fig. 1 depicts a simplified example of the general paradigm. After several exposures to the repeated displays, participants responded faster to the repeated displays than to new displays. This difference in response time was assumed to be due to participants using the spatial layouts to implicitly predict the location of the target in each repeated display as a function of their repeated exposure to them. Tests of explicit memory for the layouts that were conducted after the experiments indicated that participants could not distinguish between the predictive and nonpredictive configurations, suggesting that contextual cueing in this and similar procedures does not rely on explicit memory.

Initial studies of contextual cueing in children seemingly demonstrated that the mechanisms responsible for contextual cueing were less well developed in children relative to young adults (e.g., Vaidya, Huger, Howard, & Howard, 2007). Using the stimuli and procedure developed by Chun and Jiang (1998), Vaidya and colleagues (2007) did not find contextual cueing in 10-year-old children. However, by adapting the basic procedure and stimuli specifically for children, more recent research has demonstrated that children, as well as adults, benefit from an ability to learn spatial layouts without the requirement to explicitly memorize all of the individual features of the environment. For example, Dixon, Zelazo, and Rosa (2010) found intact contextual cueing in school-aged children (5–9 years old). Children were asked to touch a red cartoon fish (the target) among a set of non-target red and blue cartoon fish. The authors observed contextual cueing under these conditions and sug-

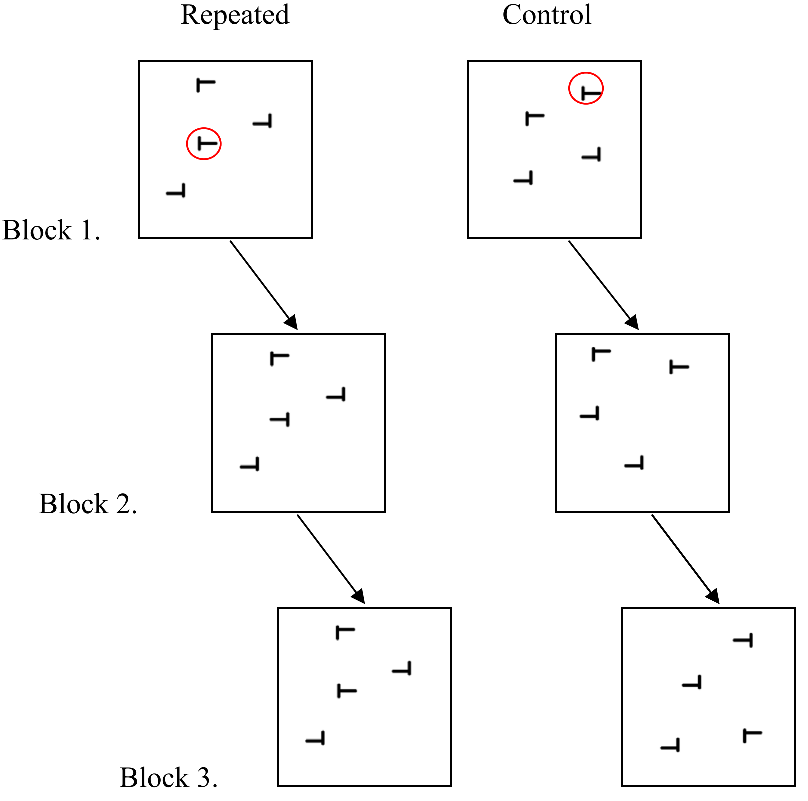

Fig. 1. Examples of displays used in the classic paradigm of contextual cueing effects. Note that in our examples, the locations of the target T have been highlighted by red circles in the Block 1 example. These were not present in the actual experiments. In addition, we reduced the number of distracters typically used in the classic paradigm to make the example displays easier to view. As shown in this figure, repeated displays repeated their configurations over blocks, whereas control displays were random from trial to trial.

gested that the observed effect was the result of implicit learning because the children could not recognize the predictive displays in a recognition test. Merrill, Conners, Roskos-Ewoldsen, Klinger, and Klinger (2013) found similar results after implementing a different modification of the contextual cueing task. They also reported that contextual cueing effects were relatively stable across ages, ranging from 6 to older than 65 years old.

Despite the fact that implicit spatial associative learning, as measured by contextual cueing effects, appears to be robust across a wide range of ages, the results of Vaidya and colleagues (2007) indicate that the factors that may either promote or interfere with implicit spatial learning may operate differently for children relative to young adults. In this research, we focused on one important variable that seems to affect the performance of children to a greater degree than it affects the performance of adults across a wide range of cognitive and learning tasks: the presence of irrelevant and uninformative information. In the explicit processing domain, this can be shown in a variety of processing conditions. For example, confronted with irrelevant competing information, younger children typically exhibit larger Stroop interference effects than do older children and adults (e.g., Bub, Masson, & LaLonde, 2006) and larger interference effects than do adults when flankers surrounding a target stimulus are incompatible (e.g., Ridderinkhof, van der Molen, Band, & Bashore, 1997; Tipper, Borque, Anderson, & Brehaut, 1989). Discrimination learning also appears to be disrupted more in younger children relative to older children when irrelevant information is present because younger children are more likely to exhibit a feature preference for an irrelevant stimulus dimension incorporated into the learning task (Schmittmann, van der Maas, & Raijmakers, 2012). More recently, Merrill and Conners (2013) reported that the presence of irrelevant and uninformative features had a greater impact on visual search for targets identified by a single feature for children relative to adults. These age differences are often attributed to increasing executive control in the operation of inhibitory processes with increasing age (e.g., Dempster, 1993; Harnishfeger, 1995; Rueda et al., 2004). Alternative but related explanations specifically highlight possible age-related improvements in the ability to maintain a consistent task-appropriate response set (Bub et al., 2006) and age-related improvements in the ability to use current goals to focus cognitive control (Lorsbach & Reimer, 2008, 2010; Marcovitch, Boseovski, & Knapp, 2007).

Implicit and explicit learning do not always follow the same rules (e.g., Jiménez, Vaquero, & Lupiáñez, 2006; Mathews et al., 1989; Reber, Walkenfield, & Hernstadt, 1991; Seger, 1994). Hence, we cannot assume that the presence of irrelevant information in implicit learning tasks will yield the same age-related differences typically found in explicit attention and learning procedures. In the studies reported here, we considered how the presence of irrelevant information affects the implicit spatial associative learning processes exhibited by children and young adults. More specifically, we asked whether age-related differences in the acquisition of contextual cueing effects emerge when some of the spatial context is irrelevant and does not predict the location of the target.

Jiang and Chun (2001) were the first to investigate the selective learning of associations between a subset of the spatial context and the target location in the study of contextual cueing. In a modification of the typical paradigm used to study contextual cueing effects, they presented 50% of the non-target items in the same color as the target (i.e., green) and 50% in a different color (i.e., red). Participants were explicitly told that the target was always in a specific color (green). Thus, those distracters that shared the color with the target were called the "attended subset" because it was expected that participants would attend to the stimuli that were in the color of the target for which they were searching. The distracters that were a different color from the target were called the "unattended subset." Results indicated that participants displayed significant and similar contextual cueing when both the attended and unattended distracters in the display predicted the target and when only the attended subset predicted the target. However, no contextual cueing was observed when only the unattended subset predicted the target. Therefore, Jiang and Chun concluded that selective attention modulates contextual cueing because participants needed to selectively attend to the subset that predicted the target to facilitate implicit spatial learning.

The basic results of Jiang and Chun (2001) have generated numerous studies of adult performance in contextual cueing procedures, yielding several refinements of their general conclusions. For example, later studies indicated that the spatial regularities associated with the unattended subset were learned when they became attended during a test phase by changing the target color (Jiang & Leung, 2005). In addition, contextual cueing is greater to the attended subset even when the target color varies across trials (Geyer, Shi, & Müller, 2010). Furthermore, Conci and von Mühlenen (2011) found that grouping distracters by color and size undermined contextual cueing compared with a condition in which the distracters were uniform. However, when participants restricted search to the relevant subset of distracters after learning the target was always in a particular size or color, contextual cueing effects were obtained. In summary, the observation that the acquisition of contextual cueing effects occurs when only a subset of the context predicts the location of the target has generated numerous studies that underscore the complexity of implicit spatial learning (e.g., Geyer et al., 2010; Jiang & Leung, 2005). In the experiments reported here, we provide some initial data on how different degrees of target–distracter similarity affect the expression of contextual cueing in children and young adults.

In two experiments, we evaluated age-related differences in the acquisition of contextual cueing effects during visual search by younger children, older children, and young adults when only 50% of the distracters predicted the location of the target. Hence, these experiments assessed the relative abilities of children and adults to identify and learn predictive information relative to nonpredictive information in the displays over repeated exposures to the search stimuli. Similar to Jiang and Chun (2001), Experiment 1 included two subsets of distracters that were easily distinguishable from each other. In addition, the subset of distracters that predicted the location of the target was more similar to the target than the subset that did not predict the target and served as a preattentive cue allowing participants to segment the search display (Wolfe, 1994, 2007). Goal-directed attentive processes involved in search can be called on to provide added activation to stimuli in the display based on their similarity to the target. Hence, participants should spend increased time looking at the similar predictive distracters than at the dissimilar nonpredictive distracters. Although adults are more efficient at engaging these goal-directed attentive processes during visual search than are children (Merrill & Conners, 2013; Merrill & Lookadoo, 2004), children as young as those used in the current study are more likely to search a subset of distracters that are similar to the target rather than dissimilar from the target. In Experiment 2, the ability to restrict search to the predictive stimuli was limited by making both the predictive and nonpredictive subsets similar to the target. Therefore, participants needed to distinguish between the predictive and nonpredictive distracters as they were learning the association between the predictive distracter locations and the target location.

Experiment 1

To our knowledge, there is only one study that has investigated whether or not children can learn relevant associations between target and context locations when only a portion of the context predicts the target location. Using a procedure closely patterned after Jiang and Chun (2001), Couperus, Hunt, Nelson, and Thomas (2011) reported that 10-year-old children exhibited contextual cueing effects only if the displays included a high ratio (75:25) of predictive distracters (those appearing in the same color as the target that consistently covaried with the location of the target) to nonpredictive non-targets (those appearing in a different color from the target that did not covary with the location of the target). Young adults, but not the 10-year-olds, were able to learn the repeated spatial layouts when only 50% of the distracters predicted the location of the target. Additional manipulations indicated that it was the ratio of predictive to nonpredictive distracters and not the overall number of distracters that determined whether the 10-year-old participants exhibited contextual cueing.

As noted earlier, procedures based on the standard adult contextual cueing paradigm (Chun & Jiang, 1998) have failed to elicit consistent contextual cueing effects in children (Vaidya et al., 2007). Therefore, it is reasonable to ask whether the age-related differences reported by Couperus and colleagues (2011) may underestimate the abilities of young children to identify and use associations between a subset of the distracter locations and the target location. The primary goal of Experiment 1 was to reevaluate children's abilities to exhibit contextual cueing effects when only 50% of the distracters accurately predicted the location of the target.

In addition to evaluating the performance of younger participants (6–7 years old), we made two changes in the basic method used by Couperus and colleagues (2011). First, Couperus and colleagues (2011) used a relatively high number of distracters in their displays (15 or 23). It may be that a high ratio of predictive distracters is necessary only when the overall number of distracters is also relatively large. Therefore, we reduced the overall number of distracters to 8, with 50% being predictive distracters and 50% being nonpredictive distracters. Second, Couperus and colleagues used stimuli patterned after Jiang and Chun's (2001) study of college students. These traditional stimuli (a rotated T embedded with rotated Ls that were offset to look more like the T) were constructed to make the search task sufficiently difficult for adult participants and to eliminate potential pop-out effects (e.g., Treisman & Gelade, 1980). Because Dixon and colleagues (2010) and Merrill and colleagues (2013) have shown that using easier to identify and more engaging cartoon stimuli increases the likelihood of observing contextual cueing effects in children, we used cartoon characters as stimuli in Experiment 1 to reevaluate contextual cueing effects derived from subsets of the display.

In Experiment 1, we tested three age groups: young children (6–7 years old), older children (9–10 years old), and adults (18+ years old). During an acquisition phase, participants searched for a designated target (one picture of Mickey Mouse) embedded in two subsets of distracters. The location of the distracters in one subset (a second picture of Mickey Mouse) predicted the location of the target, whereas the distracters in the second subset (a picture of "Jerry" Mouse) did not. That is, over repeated presentations, the predictive Mickey distracters remained in the same locations, whereas the nonpredictive Jerry distracters appeared in random locations in each presentation. Following the acquisition phase, participants searched for the target Mickey in these same repeated displays or in control displays where all of the distracters appeared in random locations. Contextual cueing effects would be evidenced by significantly faster response times to the repeated displays relative to the control displays. If adults use selective attention processes more effectively in the acquisition of contextual cueing effects than do children, then we should also observe a greater magnitude of contextual cueing effects or that contextual cueing develops at a faster rate in adults relative to children.

Method

Participants

In total, 21 college students were recruited from introductory psychology classes at the University of Alabama. One male participant had an error rate of more than 5%, and so his data were not included in the analyses. Child participants were recruited from local churches and home school programs. In total, 22 younger children (6–7 years old) and 20 older children (9–10 years old) were enrolled in the study. Two of the younger children were eliminated from the study because they were unable or unwilling to perform the task correctly. Hence, the final sample consisted of 20 participants in each of the three groups. The younger children (6 boys and 14 girls; 16 Caucasian, 1 Black, and 3 Asian) had a mean age of 6.86 years old ($SD = 0.64$). The older children (10 boys and 10 girls; 16 Caucasian, 1 Black, and 3 Asian) had a mean age of 9.77 years ($SD = 0.56$). The college students (4 men and 16 women; ethnicity information was unavailable, but they were predominantly Caucasian) were approximately 18 to 21 years old. All child participants were given two $5 gift cards to compensate for their time and cooperation. College students received course credit for participating. Because all participants actually participated in both experiments, half of the participants in each group completed Experiment 1 first and half completed Experiment 2 first. Preliminary analysis of presentation order indicated that performance did not differ as a function of using participants in both experiments. Hence, this variable was not considered in the main analyses reported below. Both experiments were completed in a single session that lasted 45 to 60 min, including breaks as needed.

Stimulus materials

Experimental materials were displays of cartoon characters presented on a computer monitor. In each display, there was a target Mickey Mouse, four pictures of a different version of Mickey Mouse that served as one subset of distracters, and four pictures of "Jerry" Mouse that served as a second subset of distracters (see Fig. 2). The individual characters could face either to the left or to the right. The target faced left in half of the displays and faced right in half of the displays. Initially, the specific locations of all the distracters were randomly determined using an invisible 4×4 matrix. Three different categories of displays were constructed: *repeated displays, new-location displays,* and *control displays.* Four different basic displays were constructed for use as repeated displays. The target location was in a different quadrant in each of these displays. In addition, for each repeated display, the locations of the Mickey Mouse distracters were invariant across presentations (predictive subset), but the locations of the Jerry distracters varied across presentations (nonpredictive subset). Hence, the predictive subset of distracters was much more similar to the target than was the nonpredictive subset. Therefore, the displays in this experiment were conceptually similar to the ones in Jiang and Chun's (2001) study in which the target and predictive distracters shared the same color, making them much more similar to the target than the target and nonpredictive distracters. In what we call the new-location displays, all distracter locations varied from trial to trial and the targets were in different locations from the targets in the repeated displays. Although it seemed an unlikely strategy, we included the new-location displays to prevent participants from developing the strategy of memorizing and checking only the four possible target locations associated with the repeated displays. In the control displays, the targets were in the same four locations as the repeated displays, but all of the distracter locations varied from trial to trial.

Design and procedure

The experiment was programmed using Superlab 4.5.2 software. All participants were tested individually. Prior to the start of the experiment, participants were shown one model display and given instructions to find the target Mickey Mouse. They were told to press "S" using the left hand if the tar-

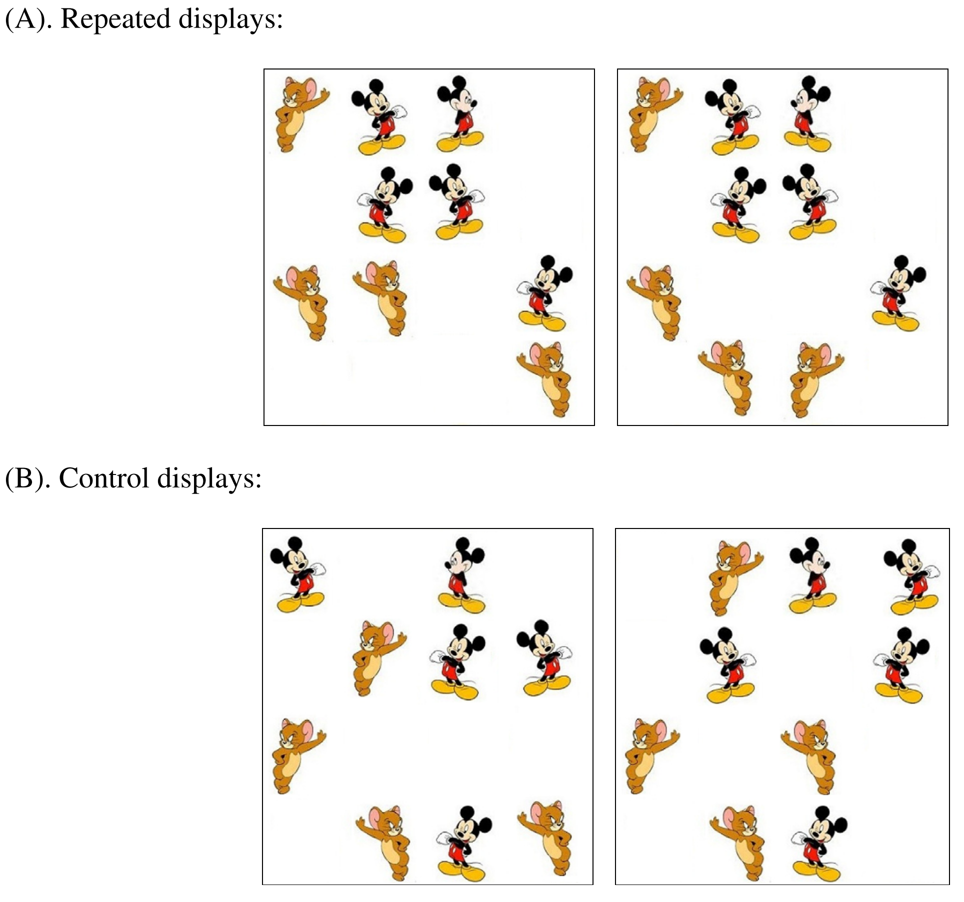

Fig. 2. Experimental stimuli of repeated and control displays in Experiment 1. The target is Mickey with both hands behind his back. (A) In the repeated displays, both the locations of the target and the Mickey distracters were repeated, whereas the locations of Jerry were random. (B) In the control displays, the locations of all the distracters varied, whereas the target location remained the same.

get Mickey faced left and to press "L" using the right hand if the target faced right. Participants had no trouble in complying with instructions. Speed and accuracy were emphasized. Each trial started with a fixation cross in the center of the display that remained visible for 1000 ms. The offset of the fixation cross was immediately followed by the stimulus display. The display remained visible until participants made a response. The next trial began automatically 1000 ms later. If participants made an error or did not respond within 10 s, a short beep was heard and an error was recorded. Participants completed 264 total trials in 10 blocks. Blocks 1 to 4 and Blocks 6 to 9 were considered to be learning phases. In each block of the learning phases, there were 20 trials that consisted of 16 trials of repeated displays and 4 trials of new-location displays. The four repeated configurations were presented four times per block. Blocks 5 and 10 were test blocks. For each test block, there were 52 randomly presented trials that consisted of 24 repeated displays (6 of each configuration), 24 control displays, and 4 new-location displays. For each type of display (repeated, control, and new location), there were equal numbers of left and right responses within each block. Response times to identify the direction the target was facing were automatically recorded to the nearest millisecond. At the end of each block of trials, there was a 10-s mandatory break (participants could take longer if they desired). There was a break of up to 5 min between experiments. During breaks, the experimenter engaged child participants in conversation and encouraged a continued high level of performance in the task. Breaks lasted until participants said they wanted to continue. All of the children indicated a readiness to continue prior to initiating the next block of trials.

Results

Errors were extremely rare, with no age group exhibiting error rates of more than 4%. Therefore, error rate was not subjected to further analysis. The primary dependent variable was response time to identifying which direction the target was facing. Mean response times (RTs) were calculated for the repeated displays (in all blocks) and the control displays (in Blocks 5 and 10) for each participant. RTs of trials in which an error was made were not included in the calculations. The new-location displays were uninformative with respect to learning and were relatively few in number (only 4 in each block). Hence, they were not included in the analyses.

General learning effects

First, we examined RTs of the repeated displays only over the 10 blocks as a general reflection of practice (see Fig. 3). A 3 (Age: younger children, older children, or adults) × 10 (Block) analysis of variance (ANOVA) with repeated measures on block was conducted. There was a main effect of age, $F(2, 57) = 48.05$, $p < .001$, $\eta_p^2 = .63$, with adults ($M = 1283$) responding significantly faster than older children ($M = 1858$), who were significantly faster than younger children ($M = 2541$). There was also a main effect of block, $F(9, 513) = 16.64$, $p < .001$, $\eta_p^2 = .23$, with participants responding faster with increased practice. No significant interactions were found.

Contextual cueing effects

We used two approaches to evaluate the contextual cueing effects. First, we compared group differences between mean RTs for the repeated and control displays. Second, we analyzed the proportion of facilitation (POF; explained later) observed for each participant.

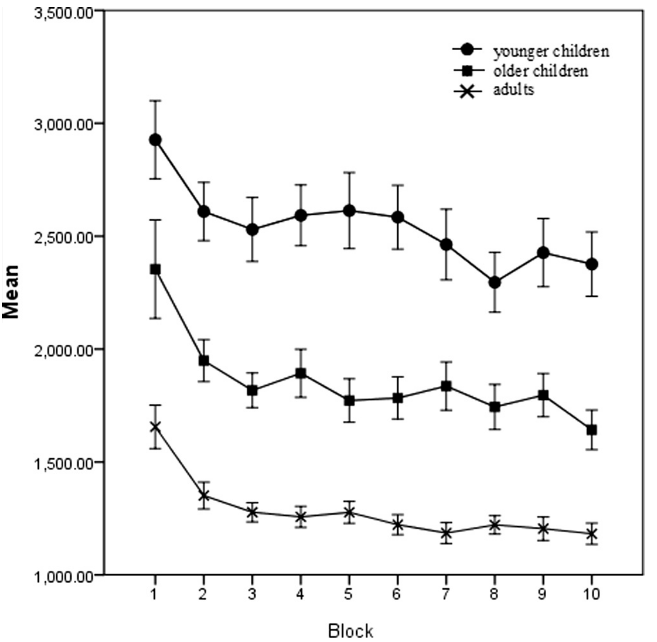

Fig. 3. General learning effects in Experiment 1. This figure reflects mean RTs of the repeated displays only across 10 blocks for the three age groups. Error bars: ± 1 *SE*.

Mean response time difference. Mean RTs for each condition were analyzed using a 3 (Age: younger children, older children, or adults) × 2 (Predictability: repeated or control) × 2 (Block: Block 5 or Block 10) ANOVA with repeated measures on the last two factors. The effect of age was significant, $F(2, 57) = 40.77$, $p < .001$, $\eta_p^2 = .59$, with adults ($M = 1274$) responding faster than older children ($M = 1765$), who were faster than younger children ($M = 2527$). The effect of predictability was also significant, $F(1, 57) = 17.30$, $p < .001$, $\eta_p^2 = .23$, with faster responses in the repeated condition ($M = 1810$) than in the control condition ($M = 1900$), indicating a significant contextual cueing effect. The effect of block, $F(1, 57) = 11.88$, $p < .001$, $\eta_p^2 = .17$, indicated that participants responded faster in Block 10 ($M = 1803$) than in Block 5 ($M = 1907$). The interaction between predictability and block was significant, $F(1, 57) = 6.16$, $p = .016$, $\eta_p^2 = .098$. Tests of simple effects suggested no difference in RT between the repeated and control displays ($M = 40$, *ns*) in Block 5. However, participants responded faster to repeated displays than to control displays in Block 10 ($M = 139$, $p < .001$). Overall, this indicates that contextual cueing effects were reliable in Block 10 but not in Block 5.

Table 1 presents the mean RTs and the mean differences between RTs for the repeated and control displays in each block. Because the focus of our research was on contextual cueing effects, we subsequently conducted a series of planned comparisons to assess whether each age group exhibited faster RTs to the repeated displays than to the control displays in the two test blocks. These tests were conducted using *t* tests. The purpose of these analyses was to caution against any conclusions regarding similar performance between groups if contextual cueing effects were not observed for any group. For younger children, a significant contextual cueing effect was observed only in Block 10 ($M = 133$), $t(19) = 1.86$, $p = .04$, Cohen's $d = 0.42$. For older children, significant contextual cueing effects were observed in Block 5 ($M = 83$), $t(19) = 2.29$, $p = .017$, Cohen's $d = 0.51$, and Block 10 ($M = 147$), $t(19) = 3.10$, $p = .003$, Cohen's $d = 0.70$. For adults, a marginally significant contextual cueing effect was observed in Block 5 ($M = 41$), $t(19) = 1.60$, $p = .063$, Cohen's $d = 0.37$, and a significant contextual cueing effect was observed in Block 10 ($M = 136$), $t(19) = 4.54$, $p < .001$, Cohen's $d = 1.04$. Hence, it does appear reasonable to conclude that the similarity in contextual cueing between groups suggested by the primary analyses reflects performance of the groups, at least for Block 10.

To summarize, the results first suggested that overall RTs decreased as the ages of participants increased. In addition, added practice decreased overall RTs between Blocks 5 and 10. Of major importance, we did observe significant contextual cueing effects for all groups. By Block 10, all three age groups exhibited significant contextual cueing effects. Although older children and adults did exhibit at least marginally significant contextual cueing by Block 5 and the younger children did not, this possible group difference was not significant in the main analyses and is not considered further.

Proportion of facilitation. To compare the magnitude of contextual cueing effects across different age groups, we calculated the POF as another index of contextual cueing effects based on the following formula (Jiang, Song, & Rigas, 2005):

$$\text{POF} = (\text{RT of control displays} - \text{RT of repeated displays})/\text{RT of control displays}. \qquad (1)$$

Table 1
Mean RTs and mean RT differences in Experiment 1.

Age group	Block 5			Block 10		
	Control	Repeated	Mean difference	Control	Repeated	Mean difference
Younger children	2609 (613)	2613 (752)	−4	2510 (667)	2376 (636)	133**
Older children	1856 (419)	1772 (430)	83**	1790 (421)	1642 (390)	147**
Adults	1318 (184)	1277 (215)	41*	1318 (242)	1182 (210)	136**

Note. Standard deviations are in parentheses. Mean RT difference = RT of control displays – RT of repeated displays.
* p marginally significant.
** $p < .05$.

The advantage of using this formula is that it takes into account overall RT differences associated with age. It is especially crucial in the current experiments because the three age groups had significantly different overall RTs. Because it is reasonable to think that contextual cueing reflects a general improvement in RT, we believe that this improvement is best evaluated in terms of relative time differences rather than absolute time differences across groups that differ in overall RT.

We conducted a 3 (Age) $\times$ 2 (Block) ANOVA on the POF scores. There was a significant main effect of block, $F(1, 57) = 6.76$, $p = .012$, $\eta_p^2 = .11$, with a larger POF in Block 10 ($M = .083$) than in Block 5 ($M = .032$). Neither the main effect of age nor the interaction was significant. Hence, the results from the POF analysis were consistent with those from the RT analysis. Both revealed that contextual cueing effects increased with additional exposure blocks. The POF analysis also indicated that the age groups did not differ significantly in the relative magnitude of contextual cueing effects they exhibited.

Discussion

In Experiment 1, we compared the performances of younger children, older children, and adults on a modified contextual cueing task using age-appropriate stimuli and a reduced number of distracters. In this task, a subset of the distracters that shared the most features with the target predicted the location of the target, whereas a second subset that was more different from the target did not. All three age groups demonstrated significant contextual cueing effects by the second test block. We also found that the proportion of facilitation attributed to contextual cueing did not differ significantly across the three groups. To our knowledge, this is the first study to observe that children as young as 6 years are able to employ selective attention during contextual cueing. In addition, both younger and older children exhibited significant contextual cueing effects when only 50% of the distracters predicted the target.

It is important to note that selective attending to the predictive distracters in our procedure, as well as that used by Jiang and Chun (2001), was likely a byproduct of the visual search process. It is generally thought that results such as these indicate that if the attended and ignored context can be separated on the basis of simple visual features such as color (Jiang & Chun, 2001) or shape (Chang & Cave, 2006), then the subset of distracters that are less similar to the target can be rejected preattentively and attention can be focused on those distracters that share a feature with the target. Preattentive selection processes are typically presumed to operate on a small set of basic visual features such as color, orientation, and size (see Treisman, 1988; Wolfe, 1994, 2007). We presume that the use of distinct cartoon characters provided a similar benefit for all of our participants in Experiment 1. All participants learned the associations between the predictive context and the target because they engaged in a guided visual search and restricted search to the distracters most similar to the target (e.g., Wolfe, 1994, 2007).

Our observation that a subset of predictive distracters can produce contextual cueing effects in a similar manner for adults and children is somewhat different from Couperus and colleagues (2011), who reported that 10-year-olds were able to selectively attend to the predictive subset only when the ratio of predictive and nonpredictive stimuli was relatively high (i.e., 75%). Several factors may account for this difference. First, we employed more age-appropriate stimuli. Couperus and colleagues used stimuli based on the classic paradigm that were composed of a target T and offset Ls as distracters. More age-appropriate materials, such as the cartoon characters in the current study and in Dixon and colleagues (2010), may be more engaging for children and, thus, permit a level of performance greater than that observed in previous studies. Second, we reduced the number of distracters from as many as 15 to 23 down to 8. Merrill and Lookadoo (2004) found that the ability of young children to restrict search based on target features in conjunctive search tasks was limited to smaller display sizes. Hence, it is reasonable to think that a larger overall display size may have interfered with the acquisition of contextual cueing effects by younger children in Couperus and colleagues (2011). Third, targets in Couperus and colleagues' study were defined by shape. Children may have found it to be more difficult to restrict search by color when the defining feature of the target was its shape. All of these possibilities suggest that although the basic mechanisms of contextual cueing may operate similarly across the age ranges tested in Experiment 1, there may be some important age-related variations in the expression of contextual cueing effects that need to be investigated.

Experiment 2

The results of Experiment 1 indicated that children as young as 6 years can demonstrate contextual cueing effects when only a portion of the contextual information (50% of the distracter locations) predicted the location of the target. However, the implication of this result is limited by the fact that the paradigm we used almost forced participants to restrict attention to the predictive stimuli (and thus is also very similar to Jiang & Chun, 2001). Because the predictive distracters shared many more salient features with the target than did the nonpredictive distracters, it is reasonable to assume that the participants were likely able to make use of a guided search process (Wolfe, 1994, 2007) to focus their search on the predictive distracters (Mickey Mouse) and limit attention to the nonpredictive distracters (Jerry Mouse) as a byproduct of participants' search for a Mickey Mouse target. We characterize this as a "feature-based" attentional mechanism that occurs as a consequence of performing the search task. As an alternative, we hypothesize that an "expectancy-based" attentional mechanism is necessary to produce contextual cueing when predictive and nonpredictive stimuli cannot be readily distinguished on the basis of their relative similarity to the target. More specifically, restricting attention to the predictive stimuli would be the result of learning the expectancy between the target location and the locations of the distracters in the predictive subset. The relation between this expectancy-based attentional mechanism and the expression of contextual cueing was the focus of Experiment 2.

In the second experiment, both the predictive and nonpredictive distracters, as well as the target, were depictions of Mickey Mouse. Hence, we expected the two subsets to be treated as functionally equivalent during initial exposures to the repeated displays. It is only with increased exposure to the predictive and nonpredictive distracters that participants would be able to gradually identify and weight the important features of the predictive distracters as relevant to the search process in a manner that would likely be analogous to perceptual learning (Goldstone, 1998). Because participants would need to learn the relevant dimensions of the predictive distracters as contextual cueing develops in Experiment 2, we expected that contextual cueing effects would accrue more slowly in Experiment 2 relative to Experiment 1. We also expected age differences in exhibiting contextual cueing effects to emerge in Experiment 2 that were not evident in Experiment 1. This expectation was based on two sources of evidence. First, evidence indicates that younger children initially perceive objects as identical if they are generally similar overall (Smith, 1989; Smith & Evans, 1989). This tendency would likely make it harder for the younger children to distinguish the predictive distracters from the nonpredictive distracters, thereby making perceptual learning of the relevant features of the predictive distracters more difficult (see Goldstone, 1998). Second, the ability to selectively attend to some stimuli and ignore others improves dramatically during childhood (Huang-Pollock, Maddox, & Karalunas, 2011; Plude, Enns, & Brodeur, 1994). To the extent that these results apply to implicit as well as explicit aspects of selective attention, younger children would be at a disadvantage in ignoring the nonpredictive distracters even if they implicitly recognize that the predictive subset might be more useful. Because the available evidence indicates that improvements in both processes occur over the age range of the participants who were tested in our experiments (Plude et al., 1994; Smith & Evans, 1989), we expected to observe age differences in the acquisition of contextual cueing effects in Experiment 2.

As in Experiment 1, three different age groups were tested in Experiment 2 (younger children, older children, and adults). Again, during an acquisition phase, participants viewed repeated displays that included predictive and nonpredictive distracters. This was followed by a test phase during which the repeated displays were intermixed with control displays. If adults are more likely than children to exhibit contextual cueing in Experiment 2, then adults would be expected to exhibit a significantly greater facilitation in response times due to contextual cueing than would children.

Method

Materials, design, and procedure

The displays for Experiment 2 were constructed in an identical manner to those for Experiment 1 except that the distracter Jerry Mouse was replaced by another picture of Mickey Mouse (see Fig. 4). Hence, the repeated stimuli in Experiment 2 had the same target and predictive distracters as

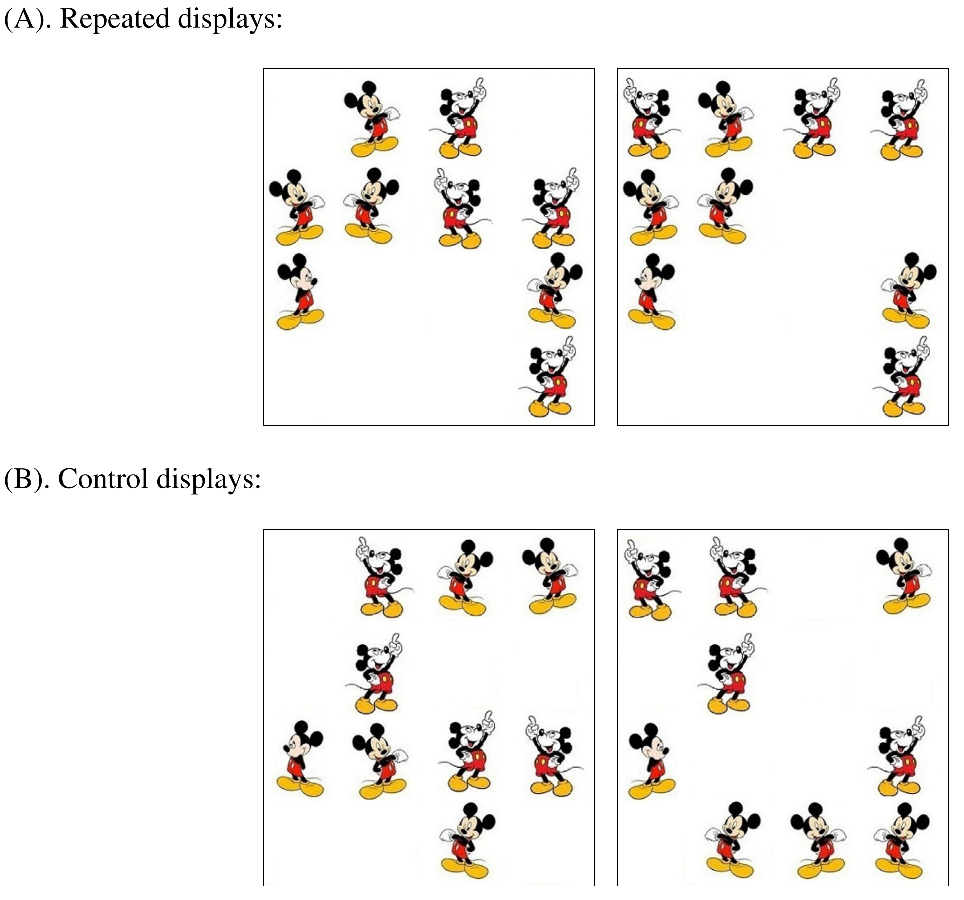

Fig. 4. Experimental stimuli of repeated and control displays in Experiment 2. The examples here are presented in the same manner as those in Fig. 1.

Experiment 1 (albeit in different locations). However, the nonpredictive distracters were highly similar to both the target and the predictive distracters in Experiment 2. The experimental design and procedures were identical to those in Experiment 1.

Results

Errors were again extremely rare (<4% for each group) and were not subjected to further analysis.

General learning effects

As in Experiment 1, we examined RTs of the repeated displays over the 10 blocks as a general reflection of practice (see Fig. 5). The ANOVA revealed a main effect of age, $F(2, 57) = 44.04$, $p < .001$, $\eta_p^2 = .61$, with adults ($M = 1473.89$) responding significantly faster than older children ($M = 1982.89$), who were significantly faster than younger children ($M = 2904.54$). There was also a main effect of block, $F(9, 513) = 17.58$, $p < .001$, $\eta_p^2 = .24$, indicating a significant practice effect. No interactions were significant.

Contextual cueing effects

As in Experiment 1, contextual cueing effects were evaluated using both mean RT and POF.

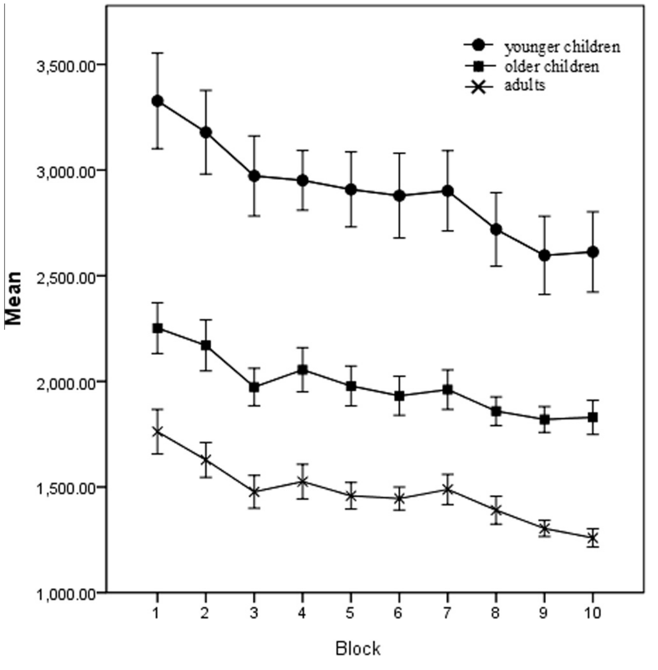

Fig. 5. General learning effects in Experiment 1. This figure reflects mean RTs of the repeated displays only across 10 blocks for the three age groups. Error bars: ± 1 *SE*.

Table 2
Mean RTs and mean RT differences in Experiment 2.

Age group	Block 5			Block 10		
	Control	Repeated	Mean difference	Control	Repeated	Mean difference
Younger children	2834 (695)	2907 (792)	−73	2598 (745)	2612 (848)	−14
Older children	2025 (356)	1977 (421)	48	1915 (292)	1829 (359)	86*
Adults	1513 (289)	1458 (282)	55*	1392 (229)	1259 (189)	133**

Note. Standard deviations are in parentheses. Mean RT difference = RT of control displays – RT of repeated displays.
* p marginally significant.
** $p < .05$.

Mean response time difference. Table 2 presents the mean RTs and the mean differences between RTs for the repeated and control displays in each block. RTs for each condition were analyzed using an Age × Predictability × Block ANOVA with repeated measures on the last two factors. The effect of age was significant, $F(2, 57) = 38.45$, $p < .001$, $\eta_p^2 = .57$, with adults ($M = 1405$) responding faster than older children ($M = 1937$), who responded faster than younger children ($M = 2738$). The main effect of predictability was marginally significant, $F(1, 57) = 2.82$, $p = .099$, $\eta_p^2 = .047$, with faster RTs in the repeated displays ($M = 2007$) than in the control displays ($M = 2046$). Hence, contextual cueing was somewhat less reliable in Experiment 2 relative to Experiment 1. There was a main effect of block, $F(1, 57) = 44.55$, $p < .001$, $\eta_p^2 = .44$, with faster responses in Block 10 ($M = 1934$) than in Block 5 ($M = 2119$). There was also a significant interaction between predictability and age, $F(2, 57) = 3.27$, $p = .045$, $\eta_p^2 = .103$. For younger children, RTs were actually faster for the control displays than for the repeated displays by 43 ms. Although not significant, this result is opposite of what would be expected for contextual cueing. For older children, RTs were faster for the repeated displays than for the control displays (M = 66 ms, p = .052, one-tailed), indicating a marginally significant contextual cueing effect. For adults, RTs were faster for the repeated displays than for the control displays (M = 94 ms, p = .011, one-tailed), revealing significant contextual cueing effects. No other interactions were significant.

Proportion of facilitation (POF). POF values were also calculated for Experiment 2. The analysis of POF indicated a main effect of age, $F(2, 57) = 5.07$, $p = .009$, $\eta_p^2 = .15$. Tests of simple effects indicated that the POFs for adults (M = .068) and older children (M = .041) did not differ from each other but were both significantly larger than those for younger children (M = −.009). This result provided additional support for the general conclusion that younger children were less effective than older children and adults at engaging expectancy-based attention processes in Experiment 2.

Discussion

In Experiment 2, we evaluated age differences in acquiring contextual cueing effects from a subset of distracters when the perceptual distinction between predictive and nonpredictive distracters was reduced. In contrast to Experiment 1 and Jiang and Chun (2001), the predictive and nonpredictive distracters were both similar to the target (and each other). Hence, it was not possible to focus on the predictive stimuli simply by looking for a feature of the target (as in, e.g., color in Jiang & Chun, 2001, or Mickey Mouse in Experiment 1). The results indicated that older children and adults exhibited significant or marginally significant contextual cueing effects by the second test block, whereas younger children did not. It appears that our younger children were at a disadvantage in identifying and learning which stimuli predicted the location of the target Mickey under these conditions.

Explaining the performance of the older children and adults in Experiment 2 is not a simple task. In Experiment 1, we assumed that attention was drawn to the predictive distracters because they shared a considerable overlap in features with the target. This feature-based attention process presumed to operate as a consequence of guided search (e.g., Wolfe, 1994, 2007) made it relatively easy to identify the relation between the locations of the predictive distracters and the location of the target and resulted in significant contextual cueing. In Experiment 2, participants needed to learn to distinguish between the two subsets of similar distracters and to learn that the relative locations of one subset also predicted the location of the target. Hence, participants needed to rely on an expectancy-based attention mechanism to restrict search to the predictive subset.[1] We suspect that the adult participants, and to a lesser degree the older child participants, became aware of the differences between the distracters through mechanisms typically associated with perceptual learning such as attention weighting and differentiation (see Goldstone, 1998). At the same time, they implicitly learned that the locations of one subset of distracters consistently covaried with the location of the target in any given display. The value of the predictive distracters would subjectively enhance the distinction between the predictive and nonpredictive distracters, and as a result the covariation between the distracter locations and the target location would be learned. We suspect that the reciprocity between feature-based and expectancy-based attention reflected in the conditions of Experiment 2 is highly consistent with naturally occurring manifestations of contextual cueing.

Next, we want to consider why younger children were unable to demonstrate contextual cueing in Experiment 2. It is possible that the ability of young children to focus on the predictive subset of Experiment 2 was impaired by the inability of children to effectively distinguish between the features of the predictive and nonpredictive distracters. This may reflect, for example, an age-related inefficiency in perceptual learning (Goldstone, 1998). As discussed previously, there is considerable evidence to indicate that young children initially perceive objects as identical if they are generally

[1] We view this distinction between feature-based and expectancy-based attention as similar to the distinction between stimulus-driven and goal-directed attention (see Egeth & Yantis, 1997; Theeuwes, Kramer, Hahn, & Irwin, 1998). Our preference for the terms feature-based and expectancy-based rests in the desire to emphasize the relatively implicit nature of attentional guidance associated with contextual cueing effects.

similar overall (Smith, 1989; Smith & Evans, 1989). Restricting attention to the predictive subset of distracters in support of contextual cueing would require that the participants first learn to distinguish relevant features from irrelevant features that identify the predictive distracters. The available evidence indicates that distinguishing between objects on the basis of individual dimensions may be very difficult for young children (Smith, 1989). Hence, it is reasonable to expect that the younger children may have been slower to identify the features that distinguished predictive distracters from nonpredictive distracters. As a result, it is likely that contextual cueing would develop much more slowly, if at all, for the younger children in Experiment 2. If this is the case, we might promote more rapid development of contextual cueing through prior training on discriminating relevant features.

There is an alternative to the perceptual learning account of the problem for the younger participants. It may be that they knew the distinguishing features of the predictive distracters but were unable to use the information. For example, 7- and 8-year-old children are especially susceptible to the interfering effects of stimulus similarity when selecting among stimuli relative to older children and adults (Lobaugh, Cole, & Rovet, 1998; see also Scialfa & Joffe, 1997). The addition of a second distracter subset of Mickey rather than a unique subset of Jerry makes the overall similarity between stimuli in the display much greater in Experiment 2 than in Experiment 1. Because younger children exhibit relatively greater deficits in inhibiting the irrelevant information (Baranov-Krylov, Kuznetsova, & Ratnikova, 2009; Hommel, Li, & Li, 2004; Johnson & Proctor, 2004), they would likely find it much more difficult to guide search to the predictive distracters than would older children and young adults. In this case, the inefficiency exhibited by the younger children would be associated with selection rather than identification of the relevant stimulus features. Hence, initial training to distinguish among features of the distracter subsets would likely be ineffective in producing contextual cueing effects.

Supplemental analyses

Comparisons across experiments

To provide a more complete test of our tentative conclusions, we reanalyzed our data across the two experiments. The first analysis was conducted on the mean response times. This analysis was conducted to assess whether or not contextual cueing effects as measured in terms of the difference between repeated and control displays were preserved in the cross-experiment analyses. The second analysis was conducted on the POF scores. The purpose of the POF analysis was to examine group differences in contextual cueing while taking into account differences in overall RTs.

The analysis of mean response times was a four-way ANOVA with age (younger children, older children, or adults), distracter similarity (dissimilar or similar), block (Block 5 or Block 10), and predictability (repeated or control) as the independent variables. The analysis revealed a significant effect of age, $F(2, 57) = 44.917$, $p < .01$, $\eta_p^2 = .612$, with RTs decreasing with increasing age. There was also a main effect of distracter similarity, $F(1, 57) = 16.931$, $p < .01$, $\eta_p^2 = .229$, with RTs being faster in the dissimilar condition (Experiment 1) than in the similar condition (Experiment 2). The main effect of block was significant, $F(1, 57) = 51.792$, $p < .01$, $\eta_p^2 = .476$, with RTs being faster in Block 10 than in Block 5. Finally, the main effect of predictability was significant, $F(1, 57) = 15.978$, $p < .01$, $\eta_p^2 = .219$, with RTs being faster in the repeated displays than in the control displays, indicating significant contextual cueing effects overall. There were three significant or marginally significant interactions associated with predictability: Age × Predictability, $F(2, 57) = 2.788$, $p = .07$, $\eta_p^2 = .089$, Distracter Similarity × Predictability, $F(1, 57) = 3.289$, $p = .075$, $\eta_p^2 = .065$, and Block × Predictability, $F(1, 57) = 6.033$, $p = .017$, $\eta_p^2 = .096$. Taken together, the analyses indicate that contextual cueing effects were significant overall. However, the magnitude of contextual cueing varied as a function of distracter similarity (larger contextual cueing effects were observed when unpredictive distracters were dissimilar from the target), block (larger contextual cueing effects were observed following more exposure to the repeated displays), and age (adults and older children exhibited larger contextual cueing effects than did younger children).

The POF analysis was a three-way ANOVA with age (younger children, older children, or adults), distracter similarity (dissimilar or similar), and block (Block 5 or Block 10) as the independent variables. In general, the analysis of POF scores produced results that were essentially the same as those for the mean RT analyses. There was a significant effect of age, $F(2, 57) = 6.286$, $p < .01$, $\eta_p^2 = .181$, with adults exhibiting greater facilitation than both groups of children (both *p*s < .05 using Tukey HSD [honestly significant difference]) and children not differing significantly from each other. There was also a main effect of block, $F(1, 57) = 7.139$, $p < .01$, $\eta_p^2 = .111$, with greater facilitation being observed for Block 10 than for Block 5 (6% vs. 2%, respectively). There was also a marginal effect of distracter similarity, $F(1, 57) = 3.33$, $p = .07$, $\eta_p^2 = .055$. Overall, less contextual cueing was observed when the nonpredictive distracters were similar to the predictive distracters (as well the target) than when the nonpredictive distracters were dissimilar from the predictive distracters (3% vs. 5%, respectively). None of the interaction effects was significant.

The cross-experiment results provide only modest support for several of our tentative conclusions. The observation of the two significant main effects of age and distracter similarity in the absence of an interaction of group and distracter similarity seems to indicate that the contextual cueing effects observed for the children in Experiment 1 were relatively weak in comparison with those observed for the adults. Even though the younger children did exhibit significant contextual cueing, it simply was not as robust as that of the adults, and the null finding of Experiment 1 should be viewed with some caution. In addition, the results suggest that contextual cueing effects in each age group may have been smaller when distracter similarity was increased. Thus, these results worked against the finding of a significant interaction with age associated with the manipulation of distracter similarity. Nevertheless, two important trends emerged from the cross-experiment analyses. First, it appears that the acquisition of contextual cueing effects improves with age under conditions in which only half of the distracters predict the location of the target. Although we did find a significant contextual cueing effect with our youngest participants in Experiment 1, based on the cross-experiment analysis, we must conclude that the effect is not as strong for children relative to adults even when the predictive distracters are more similar to the target than the nonpredictive distracters and are searched as a byproduct of the task. Second, distracter similarity affects the acquisition of contextual cueing effects. More specifically, contextual cueing effects are more robust when the predictive distracters are more similar to the target and it is easier to distinguish between the predictive and nonpredictive distracters.

Explicit memory test

After completing both experiments, a memory test was presented to a sample of the adult and older child participants. The purpose of the memory test was to evaluate explicit memory for the target locations. In total, 18 adult participants and 8 older child participants finished the explicit memory test. Two adult participants did not complete the memory test due to a technical problem. We assumed that if adults could not explicitly remember the repeated displays, children could not either.

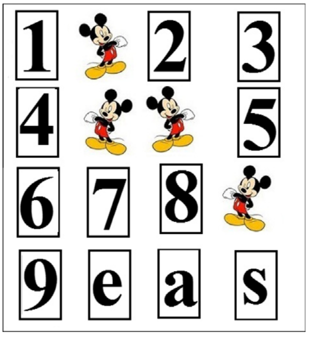

Fig. 6. Recognition test display. Only the locations of predictive Mickey distracters of the repeated displays were presented. This example is for Fig. 2A.

However, to test this assumption, we also conducted the explicit memory test with 8 randomly selected older children. The adult participants were shown displays in which only the four predictive distracters were presented, with all of the other locations occupied by numbers and letters (see Fig. 6). They were asked to indicate where they thought the target Mickey should be if he was in the picture by pressing the number or letter corresponding to that location. After responding to each display, they were also asked how confident they were regarding their judgment on a scale of 1 to 6 (with 1 indicating *just guessing* and 6 indicating *absolutely certain*). They viewed a total of eight of the repeated displays intermixed randomly, four from each experiment. Child participants were also shown the same eight repeated displays and asked to indicate where the target Mickey should be, but they did not provide confidence judgments.

Participants selected which of 12 possible locations they thought the target would be based on the locations of the four predictable distracters. Chance performance in this task was 1 of 12 over the eight explicit memory items (0.67 overall). The adult participants made on average 0.72 correct responses ($SD = 1.18$), which did not differ significantly from chance, $t(17) = 0.12$, *ns.* When we counted the responses in the same quadrant as correct responses to assess whether participants learned the general but not specific location of the target, the adults made an average number of 2.28 correct responses ($SD = 1.41$). This also did not differ significantly from the chance level of 2.25, $t(17) = 0.08$, *ns.* The average confidence score associated with their responses was 2.14 ($SD = 0.95$) of 6.0, indicating that they were not confident in their responses. Older children made on average 1.0 correct responses ($SD = 1.06$) when judging exact target location and on average 2.63 correct responses ($SD = 1.18$) when judging the same quadrant. Neither differed significantly from chance level performance, $t(7) = 0.87$, *ns,* and $t(7) = 0.89$, *ns,* respectively. Therefore, we concluded that neither the adult participants nor the older child participants explicitly learned even the relative locations of the targets in the repeated displays. We assumed that the younger child participants did not explicitly learn the target locations if the adults and older children did not.

General discussion

The results of our study add to the growing body of evidence that young children can exhibit contextual cueing effects under a variety of conditions (Couperus et al., 2011; Dixon et al., 2010; Merrill et al., 2013). Specifically, children as young as 6 years can demonstrate contextual cueing effects that are comparable in many ways to those of 10-year-old children and young adults. Because contextual cueing is generally considered to be an implicit phenomenon (Chun & Jiang, 1998) and the results of the explicit memory test of the current study indicated that participants were not consciously aware of the covariations in the repeated displays, our data are also consistent with the long established notion that implicit learning is generally independent of age (Don, Schellenberg, Reber, DiGirolamo, & Wang, 2003; Reber, 1992; Vinter & Perruchet, 2000). One of the key brain regions responsible for contextual cueing is the medial temporal lobe, including the hippocampus (Burgess, Maguire, & O'Keefe, 2002; Chun & Phelph, 1999; Greene, Gross, Elsinger, & Rao, 2007; Manns & Squire, 2001). Although many functional aspects of the medial temporal lobe continue to develop through early childhood and into adolescence (see Chiu, Schmithorst, Brown, Holland, & Dunn, 2006; Menon, Boyett-Anderson, & Reiss, 2005; Paz-Alonso, Ghetti, Donohue, Goodman, & Bunge, 2008), those that support the expression of contextual cueing as a form of implicit associative memory appear to be early developing (for evidence of structural maturity, see Seress & Abraham, 2008). This conclusion is also supported by explicit studies of place learning (Townsend, Richmond, Vogel-Farley, & Thomas, 2010) indicating that 6-, 8-, and 10-year-olds are able to learn and remember spatial relations between a target and its related visual cues.

We did find that children as young as 6 years can selectively attend to a subset of predictive distracters and ignore nonpredictive distracters during exposure to contextual cueing displays when the predictive distracters shared important features with the target. However, the cross-experiment analyses indicate that this ability might not be as robust for young children as it is for young adults. This ability to acquire contextual cueing effects when predictive distracters share one or more key features with the target reflects what we have called feature-based selective attention and reflects how the relation between selective attention and contextual cueing is commonly studied (e.g., by manipulating a feature such as color or size; see Conci and von Mühlenen 2011; Couperus et al., 2011; Goujon, Didierjean, & Mareche, 2007; Jiang & Chun, 2001; Rausei, Makovski, & Jiang, 2007). Using the guided search model (Wolfe, 1994, 2007) of visual search as our framework, we assumed that participants were able to restrict search to items in the display that were similar to the target. Because attention is effectively limited to the predictive distracters in this procedure, their value can be learned and used by even young children. This is consistent with Couperus and colleagues (2011), who also found that 10-year-old children could engage selective processing during exposure to contextual cueing displays. Our studies revealed that children as young as 6 or 7 years were also able to do this, although perhaps not as easily as young adults. We also observed that our child participants exhibited contextual cueing when the ratio of predictive and nonpredictive distracters was 50:50, whereas Couperus and colleagues found contextual cueing effects only when the ratio was 75:25. Taken together, our results and those of Couperus and colleagues indicate that children are able to engage selective processing of distracters that are similar to the target in support of contextual cueing. However, children's expression of this ability is likely to be influenced by variables that affect overall signal-to-noise power. Subjectively, this may include type and overall number of stimuli in each display (e.g., a small number of cartoon characters may have encouraged greater attention per item than a larger number of offset Ls). Objectively, this may also include the ratio of predictive and nonpredictive distracters in each display and the proportion of repeated and control displays presented during initial exposure to the contextual cueing displays. Manipulating signal-to-noise power also influences the expression of contextual cueing in young adults (Jungé, Scholl, & Chun, 2007), so it is not surprising that it would influence the performance of children even more.

We also found that increasing the similarity between predictive and nonpredictive distracters in Experiment 2 reduced the magnitude of contextual cueing for the three groups. In Experiment 2, we created experimental stimuli in which the predictive and nonpredictive distracters shared features with the target and also with each other. Therefore, feature-based selective attention was initially disabled because participants could no longer direct attention to the predictive distracters by virtue of looking for items that were like the target. All of the distracters were like the target. Hence, the deployment of selective attention needed to involve expectancy-based attention as a byproduct of learning rather than as the precursor of learning. Through multiple exposures to the repeated displays in which locations of one subset of distracters spatially co-occur with the location of the target, participants develop the expectation that this subset predicts the target location. It does appear that all of our participants were negatively affected by this manipulation.

It is not clear from our data whether or not age-related differences in the robustness of contextual cueing were increased by the manipulation of distracter similarity. In Experiment 2, the adults clearly demonstrated that they were able to exhibit significant contextual cueing effects even when the predictable and unpredictable distracters were similar to each other. In contrast, the younger children did not exhibit significant contextual cueing effects in Experiment 2. In fact, their pattern of performance was actually opposite what would be expected for contextual cueing. Hence, it does not appear that the younger children were able to develop expectancy-based selective attention without the help of feature-based attention mechanisms. However, the failure of the interaction between age and similarity (or experiment) to reach significance in the statistical analyses of the POFs across two experiments suggests caution in interpreting the results from the individual experiment analyses alone. Nevertheless, it is reasonable to consider the lack of contextual cueing in Experiment 2 by the younger children to reflect a qualitatively different type of performance from that observed for the adults. This is in contrast to the quantitatively smaller contextual cueing effects observed for the younger children relative to the older children and the adults in Experiment 1. Still, it will be necessary to examine this possibility more closely before more definitive conclusions can be reached.

Conclusions

This study demonstrates that both children and adults can use regularities in the context to guide attention to target locations even when those regularities are embedded in noise. When visual search for a target can be restricted on the basis of identifiable features in the environment to which the participants are drawn, the mechanisms of contextual cueing can work efficiently at a very young age even in the presence of irrelevant nonpredictive distracters. That said, it is still likely that the efficiency of this feature-based selective search process will be influenced by the specific conditions of learning that are present, as evidenced by the differences between the current study and Couperus and colleagues (2011). When feature-based visual search and selective attention processes are not available, younger children experience greater difficulty in identifying relevant aspects of the environment that can facilitate attentional guidance. Several questions about the relation among age, contextual cueing, and visual search and attention remain to be addressed. For example, if the problem exhibited by younger children is the result of inefficiencies in perceptual learning, then it may be that expectancy-based attention in children can be enhanced by sensitizing them to the distinguishing characteristics of the predictive versus nonpredictive distracters prior to exposure to the contextual cueing procedure. In addition, it would be valuable to systematically manipulate the degree to which the predictive and nonpredictive distracters differ to see to what extent feature-based selective attention is essential for contextual cueing to occur for children and adults. Moreover, although we focused on the interactions among age, contextual cueing, and selective attention in terms of distracter similarity, it is clear that other factors, such as timing of the presentation (e.g., preview search; Goujon, 2011) and signal-to-noise ratio as demonstrated by Couperus and colleagues (2011), can influence the expression of contextual cueing by young children as well.

We generally view the products of implicit spatial learning to be complementary to those of explicit learning. First, implicit knowledge should be able to facilitate later explicit learning, for example, in the case of navigation. Implicit knowledge of the general spatial layout of a neighborhood should make it easier to explicitly learn directions to a new friend's house in that neighborhood. Second, implicit knowledge allows us to keep track of the location of important signals in the environment when our explicit processes are otherwise engaged (e.g., we can find "EXIT" signs in a new theater even though we have not explicitly learned their locations). Our research identifies age-related differences in these abilities. We specifically focused on learning conditions in which some, but not all, of the context predicts the target location because the environment often has objects that change (e.g., cars and furniture may move) as well as objects that are stationary. Our research indicates that despite general similarities in implicit spatial learning, children and adults may differ in the amount and kind of irrelevant unpredictable distracter information they can tolerate without serious impact on learning. We hope that these data may ultimately provide information relevant environmental engineering that promotes learning of important danger/safety signals in the environment of younger children.

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