



PAPER

Evidence for intact memory-guided attention in school-aged children

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Abstract

Visual scenes contain many statistical regularities such as the likely identity and location of objects that are present; with experience, such regularities can be encoded and can ultimately facilitate the deployment of spatial attention to important locations. Memory-guided attention has been extensively examined in adults with the ‘contextual cueing’ paradigm and has been linked to specific neural substrates – a medial temporal lobe (MTL)-frontoparietal network. However, it currently remains unknown when this ability comes ‘online’ during development. Thus, we examined the performance of school-aged children on an age-appropriate version of the contextual cueing paradigm. Children searched for a target fish among distractor fish in new displays and in ‘old’ displays on a touchscreen computer. Old displays repeated across blocks of trials and thus provided an opportunity for prior experience with the invariant configuration of the stimuli to guide attentional deployment. We found that over time children searched old displays significantly faster than new displays, thus revealing intact memory-guided attention and presumed function of an MTL-frontoparietal network in 5- to 9-year-olds. More generally, our findings suggest that children are remarkably sensitive to the inherent structure of their visual environment and this enables attentional deployment to become more efficient with experience.

Introduction

Our visual environment is inherently structured and remains relatively stable over time; particular objects tend to co-occur together, often remain in stable spatial layouts, and events unfold in predictable sequences (Bar, 2004; Chun, 2000). If such statistical regularities are encoded into memory, this knowledge can be used to efficiently guide spatial attention to important aspects of complex visual scenes according to expectancies of where and when interesting events will unfold (Carmi & Itti, 2006; Chun, 2000; Chun & Jiang, 1998, 1999; Olson & Chun, 2001; Ono, Jiang & Kawahara, 2005). For example, the stable layout of landmarks on your drive to work can direct attention to relevant locations such as street signs and stop-lights such that they are detected faster and with less effort.

In adults, memory-guided attention has been extensively examined using the ‘contextual cueing’ paradigm (Chun & Jiang, 1998). In this paradigm, participants search for a target among distractors in new displays and in ‘old’ displays that repeat across blocks of trials. Search typically improves over time for old relative to new displays; this ‘contextual cueing effect’ indicates that participants acquire memory traces of the stable configuration of stimuli in old displays and that this

efficiently guides spatial attention to the location of the target (Chun & Jiang, 1998). Notably, functional magnetic resonance imaging (fMRI) and lesion studies suggest that memory-guided attention is mediated by a medial temporal lobe (MTL)-frontoparietal network that supports mnemonic and attentional processes, respectively (Chun & Phelps, 1999; Greene, Gross, Elsingher & Rao, 2007; Manns & Squire, 2001; Preston & Gabrieli, 2008; Summerfield, Lepsien, Gitelman, Mesulam & Nobre, 2006). Additionally, recent fMRI data have revealed a critical role for the entorhinal cortex in contextual cueing (Preston & Gabrieli, 2008).

Little is known about the development of memory-guided attention during childhood. To date, the majority of studies examining the development of selective attention have not considered the role of memory in guiding the deployment of attention, but rather have concentrated on how voluntary (i.e. top-down) and stimulus driven (i.e. bottom-up) influences act on a moment by moment basis to shape attentional selection (Gerhardstein & Rovee-Collier, 2002; Goldberg, Maurer & Lewis, 2001; O’Riordan & Plaisted, 2001; Rovee-Collier, Bhatt & Chazin, 1996; Scerif, Cornish, Wilding, Driver & Karmiloff-Smith, 2004; Schul, Townsend & Stiles, 2003; Trick & Enns, 1998). Indeed, to our knowledge, only one study (Vaidya, Huger,

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Howard & Howard, 2007) has examined memory-guided attention in children using the contextual cueing paradigm and reported that 6- to 13-year-olds failed to display evidence of the contextual cueing effect. Vaidya *et al.* (2007) argued that this provided evidence of immaturity of MTL structures and the mnemonic processes they support. It should be noted, however, that this study employed the standard (adult) paradigm in which participants are required to detect a rotated *T* (the target) embedded among distractor *Ls*. Over the course of 700 trials, participants were exposed to 12 'old' displays, with approximately 24 trials between repetitions of the old displays. It remains possible that this paradigm was inappropriate for children at this age, either because it was not engaging or because it was too difficult. As a result, Vaidya *et al.*'s (2007) null findings should not be taken as definitive evidence for a lack of contextual cueing in children and immaturity of MTL structures.

Evidence from other paradigms suggests that even infants are sensitive to the spatial structure inherent in visual displays. In a study by Fiser and Aslin (2002), for example, 9-month-old infants viewed scenes in which some objects embedded in the scene co-occurred in a fixed spatial relationship with greater probability than other objects. After familiarization with the scenes, infants preferred to look at the objects that had co-occurred with higher probability. This finding indicates that infants rapidly learned something about the structure of the spatial display, and this learning may provide a basis for subsequent use of information about spatial context to influence attentional deployment, enabling it to become more efficient with experience.

Accordingly, the purpose of the present study was to explore the development of contextual cuing in children using a more developmentally sensitive, age-appropriate version of the contextual cueing paradigm. Children between the ages of 5 and 9 years searched for a target fish embedded in a sea of distractor fish in both new displays and old displays that repeated five times during the course of the experiment. The use of colorful fish made the task enjoyable for children, and the use of fewer trials as well as fewer search displays to learn lessened demands on learning capacity. Additionally, the use of a touchscreen computer allowed children to act directly on the target stimulus, further minimizing extraneous cognitive demands.

Experiment 1

Methods

Subjects

Twenty 5- to 9-year-olds ($M = 7.25$, $SD = 1.13$; 10 female) were recruited from a database maintained at

the Child Study Centre at the University of Toronto. Consent was obtained from children's parents prior to testing.

Task and materials

Children sat in front of an ELO infra-red touchscreen computer (monitor dimensions: 24×19 cm) that was custom-mounted into a child-sized desk and were told that they would play a game that would be similar to 'Where's Waldo', except that they would be looking for a special fish ('Frankie the fish') instead of a person. They were told that Frankie the fish would hide by blending in with his fish friends and that the goal of the game was to find Frankie as fast as possible on each round. It was emphasized to children that they should try and take in the whole screen as they searched; this was done on the basis of prior work suggesting that a passive search strategy, such as this, facilitates contextual cueing (Lleras & von Mühlenen, 2004). The search displays comprised the target fish and 15 distractor fish presented on a blue background. Search items were arranged according to an invisible 4×4 grid and each subtended approximately 7.5° (width) \times 4° (height) visual angle from a viewing distance of 40 cm. There were three types of distractor fish that were equally represented in each display (Figure 1). The distractors were randomly assigned to the remaining 15 locations of each display, with the constraint that there must be five of each distractor type. This visual search task was modeled after classic feature conjunction searches (e.g. Treisman & Gelade, 1980) and required children to combine two features (shape and color) to distinguish the target fish from the distractors (Figure 1). Thus, the task was challenging yet enjoyable for the children.

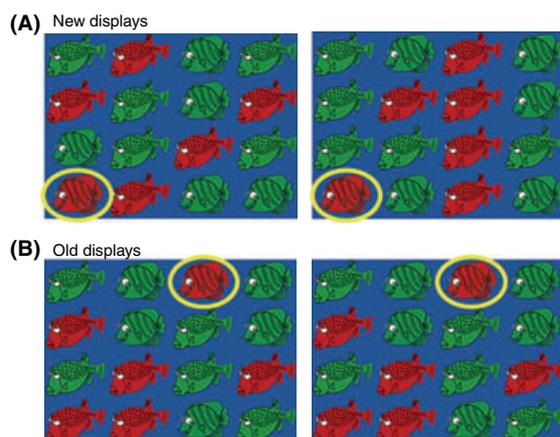


Figure 1 Depiction of new and old visual search displays. The target fish is circled and differs from distractor fish on the basis of a conjunction of shape and color. (A) In new displays, the absolute target location repeats across blocks, but the surrounding context is variable. (B) In old displays, both the absolute target location and the surrounding context repeat across blocks. As such, the invariant context can serve as a cue for where to direct attention according to prior experience.

We generated 48 displays: eight served as old displays that repeated in each of five blocks of 16 trials and 40 served as new displays, eight of which appeared in each block. Eight different spatial locations were chosen as target positions for old displays and the remaining eight positions were used as target positions for new displays. Target positions for old and new displays were specified such that they were evenly distributed across the display to preclude performance differences on the basis of absolute target location. Furthermore, target locations for old and new displays were counterbalanced across children by using two versions of the task (i.e. the target locations for old displays in one version were the target locations for new displays in the other version). Within each block, each of the target positions for old and new displays were used; thus, the absolute location of the targets repeated in every block for both display types. The only difference between old and new displays was that old displays were repeated in every block, providing an invariant context in which the targets were embedded.

It is important to note that in the standard contextual cueing paradigm (Chun & Jiang, 1998), only a subset of potential locations on the search display are occupied with search items on each trial. Thus, the spatial layout of search items is invariant in old displays and is predictive of the target location. In contrast, our task requires a slightly more sophisticated form of associative learning as search items occupy all possible locations on each search display. Thus, old displays are not distinguished in terms of an invariant spatial layout, but rather particular distractors showing up in specific positions. That is, a conjunction of item position and identity is invariant in old displays and is predictive of the target location. All children received the same displays, but in a random order.

Procedure

We had all children place a sticker on their index finger to remind them that it was the only finger they could use to respond and a sticker was also placed on the midpoint of the frame of the touchscreen monitor to serve as children's 'starting position'. Requiring the child to start and return their 'sticker finger' back to the start position after each trial enhanced the consistency of performance within and across children. The experiment began with children being shown Frankie, the fish that they would search for, and then they received four practice trials prior to the experimental trials. Trials commenced with a 3 second countdown followed by the presentation of the search display. The display remained on the screen until children made a correct response, or a maximum of 5 seconds. Correct responses were immediately followed by positive feedback (cheering and a smiley face). If no response was recorded after 5 seconds, a fixation cross appeared and children heard 'oops'. Incorrect choices were recorded, but did not terminate trials; children had the opportunity to correct themselves within the allotted

time. Children simply had to touch the screen in the location corresponding to the target fish, obviating the need to keep arbitrary stimulus-response mappings in mind and reducing the cognitive demands of the task. The child's only job was to find Frankie. There were five blocks of 16 trials; search displays were selected randomly on each trial with the constraint that eight old and eight new displays appeared in each block. At the end of testing, children received a small prize and a certificate of participation.

Statistical analysis

One child's data were removed from analyses due to unusual response times for both old and new displays ($> 2 SD$ from the mean). For each of the five blocks, we computed median reaction times (RTs) for the old and new displays, using correct responses only. Median RTs were submitted to a 2 (display type) \times 5 (block) repeated measures analysis of variance (ANOVA).

To probe potential age-related changes in the magnitude and/or time-course of learning, we used a cueing benefit difference score to provide a measure of a performance benefit for old displays versus new displays at each block relative to the initial exposure. For example, for Block 2, we computed $[(\text{block2}_{\text{new RT}} - \text{block2}_{\text{old RT}}) - (\text{block1}_{\text{new RT}} - \text{block1}_{\text{old RT}})]$. One outlier ($> 2 SD$ from the mean) was removed. To examine the developmental progression of the contextual cueing effect, we then examined whether the cueing benefit score was correlated with age in months at each block.

Results and discussion

Accuracy was very high for old ($M = 97.3\%$, $SD = 7.1\%$) and new displays ($M = 96.5\%$, $SD = 5.5\%$). The RT data revealed a main effect of block [$F(4, 72) = 3.93$, $p = .006$, $\eta^2 = .18$] and a main effect of display type [$F(1, 18) = 7.15$, $p = .02$, $\eta^2 = .28$]. While the overall interaction between display type and block did not reach significance [$F(1, 18) = 1.67$, $p = .17$, $\eta^2 = .09$], an analysis restricted to first block and final block did reveal a significant interaction [$F(1, 18) = 4.43$, $p = .05$, $\eta^2 = .20$]. As Figure 2 illustrates, RTs for old and new displays were nearly equivalent at the first block, but were significantly faster for old relative to new displays at all subsequent blocks, particularly the final block [$t(18) = 3.58$, $p = .002$, $\eta^2 = .42$] ($M_{\text{old block 1}} = 1869.53$, $SD = 497.13$; $M_{\text{new block 1}} = 1831.18$, $SD = 369.09$; $M_{\text{old block 5}} = 1629.54$, $SD = 377.88$; $M_{\text{new block 5}} = 1791.76$, $SD = 426.45$). Thus, experience with the invariant configurations of old displays conferred a clear benefit on children's attentional deployment, making search more efficient.

The blockwise correlations between age in months and cueing benefit scores revealed a negative, but non-significant, relationship at each time point following Block 1 (Block 2: $r = -.17$, $p = .50$; Block 3: $r = -.25$,

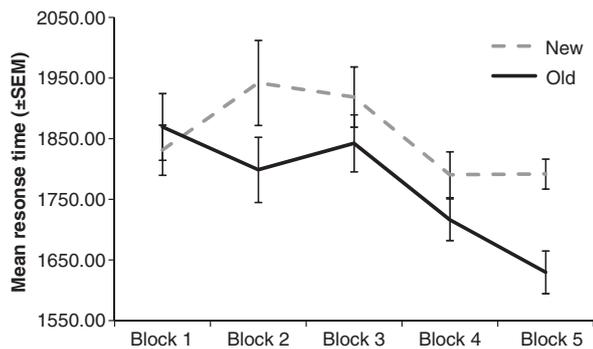


Figure 2 Mean response times as a function of display type at each block. The data reveal a minimal difference in response times for old and new displays at block 1, but significantly faster response times for old displays at all subsequent blocks. Error bars reflect ± 1 SEM based on a within subjects design (Loftus & Masson, 1994).

$p = .31$; Block 4: $r = -.09$, $p = .73$; Block 5: $r = -.39$, $p = .11$), suggesting a trend for younger children to display the largest benefit from the repeating displays. Younger children may have had the most room to reduce their target search time and demonstrate a greater benefit from learning.

We found that with repeated exposure to the old search displays, school-aged children located the target fish significantly faster in old than in new displays. This demonstrates that, with experience, children encoded the invariant configurations of the old displays and these representations adaptively guided spatial attention to the location of the target.

Experiment 1A

An intriguing question is whether awareness of the task structure could modulate the contextual cueing effect. We modified the contextual cueing paradigm (Olson & Chun, 2001) to provide a stronger test of awareness, by presenting only old displays in the first set of blocks and then a subsequent block of new displays. Old and new displays utilized *identical* target locations, so an increase in RT during the new block would indicate whether the predictive (invariant) configuration of the old displays facilitated the deployment of spatial attention to the target during the old blocks. This modification allowed us to probe whether children were aware of the invariance of the configuration; following the task, we presented children with pictures of search displays in a yes/no recognition memory task to probe their awareness for the repeating displays.

Methods

Twelve 6- to 9-year-olds ($M = 7.3$, $SD = 1.2$; five female) participated and were recruited through the Child Study Centre at the University of Toronto.

Contextual cueing task

The task instructions and trial requirements were identical to Experiment 1. However, in this version, there were six blocks of old displays followed by one block of new displays. The same eight old displays were used and each appeared once per block in a random order. Search time to the target was hypothesized to improve across the six blocks of old displays if children are sensitive to the predictive nature of the spatial configuration. Eight new displays were created and each appeared once during the final block. In contrast to Experiment 1, these new displays used the same eight target locations that were used in the old displays but the distractor items surrounding the target were arranged in a new configuration. It was expected that the new configuration would fail to efficiently guide attention to the target, resulting in longer search times; longer search times during this final block would indicate attention to the change in context and suggest that any improvement across blocks of old displays could be attributed to contextual cueing.

Recognition memory task

Stimuli: We created laminated $8.5 \times 11''$ color pictures of four old displays, four new displays that never appeared during the contextual cueing task, and four individual fish (Frankie the target fish, a green distractor fish, and two fish that children had never seen before). The locations of the target fish in the old and new displays were the same to prevent children from basing their choices on whether the absolute location of the target was familiar.

Procedure: Children were told that they would see pictures of fish displays and that the goal of the game was to tell the experimenter whether they had seen the display before or whether they had never seen it before, using a yes/no response. Children were told that this would be challenging and were encouraged to guess if they were not completely sure about a display. The experimenter individually presented each of the four old and four new displays in a random order and asked: 'Have you seen this display before?' Children were given as much time as they needed to respond. Afterwards, children were shown the pictures of the individual fish and asked: 'Have you seen this fish before?' We expected the individual fish questions to be simple for the children and, therefore, they allowed us to determine whether children properly understood the instructions for the memory task and whether they were trying their best to answer correctly.

Statistical analysis: Children's recognition memory was assessed in terms of the percentage of responses answered correctly for the old and new displays overall, and also in terms of the relative hits and false alarms for old displays. Performance on the individual fish questions was calculated separately.

Results and discussion

Contextual cueing: Accuracy was very high for both old displays ($M = 97.9\%$, $SD = 2.2\%$) and new displays (97.9% , $SD = 3.9\%$). Search time (RT to locate the target fish) dramatically decreased across the six old blocks and then substantially increased during the final new block, when the display configurations were no longer predictive of the target's location (Figure 3). Contrasting RTs for block 6 (the last old block) with block 7 (the new block) confirmed that children became significantly slower during the new display block [$F(1, 11) = 6.78$, $p = .03$, $\eta^2 = .38$], indicative of a contextual cueing effect (Olson & Chun, 2001). Given that the same target locations were used in old and new displays, these data suggest that the predictive (invariant) configurations of the old displays facilitated children's ability to locate the target during the old blocks, and the removal of the predictive relationships among search items during the new block impaired performance.

Recognition memory: Children performed very well on the simple recognition memory questions for individual fish ($M = 97.7\%$, $SD = 7.5\%$), indicating that they understood the requirements of the memory task and were trying to answer the questions correctly. Consistent with the adult literature (e.g. Chun & Jiang, 1998; Manns & Squire, 2001), recognition memory scores for search displays were not different from chance [$t(11) = 1.81$, $p = .10$, $\eta^2 = .23$] and the hit rate and false alarm rate for old displays were not different [$t(11) = 1.67$, $p = .122$, $\eta^2 = .20$]. The mean recognition score was 59.4 ($SD = 18.6$): mean hits for old displays was 62.5 ($SD = 34.5$) and mean false alarms for old displays was 43.8 ($SD = 32.2$). Interestingly, recognition memory performance demonstrated no relationship with age in months ($r = -.14$, $p = .66$) or the magnitude of the contextual cueing benefit ($r = -.16$, $p = .62$).

Experiment 1A replicated the finding of a contextual cueing effect in school-aged children, indicating that

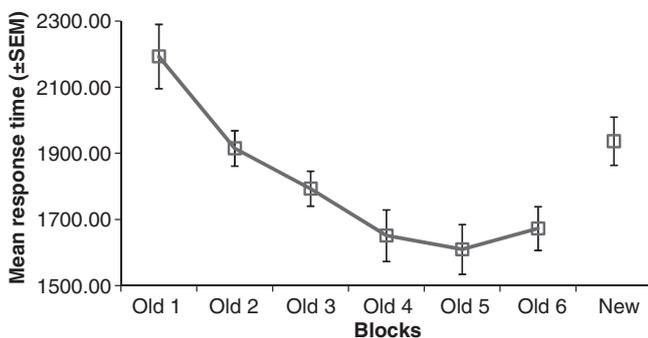


Figure 3 Mean response times for the six blocks containing only old displays followed by the block containing only new displays for Experiment 1A. The data demonstrate an improvement in performance across the six old blocks, followed by a significant slowing during the new block. Error bars reflect ± 1 SEM based on a within subjects design (Loftus & Masson, 1994).

memory-guided attention is indeed operational from an early age, and it also yielded data consistent with the suggestion that children's memory-guided attention is not driven by explicit awareness to the repetition of the old displays, at least in this form of contextual cueing. Critically, even with this relatively small sample, the effect size for the contextual cueing effect was similarly large compared to Experiment 1 and the effect size for explicit awareness was commensurately small. Correspondingly, the magnitude of the contextual cueing effect was unrelated to the level of awareness, and explicit awareness was not greater in the older relative to the younger children. These findings suggest that the learning that drives the contextual cueing effect is not carried by explicit memory, similar to findings with adults (Chun & Jiang, 1998, 2003; Chun & Phelps, 1999; Manns & Squire, 2001; Preston & Gabrieli, 2008).

Discussion

We devised an age-appropriate version of the contextual cueing paradigm (Chun & Jiang, 1998) in order to examine the development of memory-guided attention. In two experiments we found a reliable contextual cueing effect in 5- to 9-year-olds (i.e. faster search times to locate a target fish embedded in repeated, old relative to new search displays). Thus, with exposure to the old displays, children were able to acquire the invariant relationships between particular objects and locations and this information facilitated the efficient deployment of spatial attention to the target's location. Prior work with adults (Brady & Chun, 2007) suggests that the contextual cueing effect does not require learning the entire configuration of the old displays, but rather, can result from the formation of associations between the target and a few local distractors. Sensitivity to invariant properties of our visual world is highly adaptive as it allows experience to 'tune' mechanisms of selective attention, facilitating more efficient interaction with the environment (Chun, 2000). Our findings suggest that attentional deployment in childhood (similar to adulthood) is able to benefit from experience.

Our findings stand in contrast to those of Vaidya *et al.* (2007), who did not find evidence of contextual cueing in children, and therefore highlight the importance of using age-appropriate tasks to assess children's cognitive abilities; doing so allows an opportunity to observe age-related differences that may be obscured by extraneous factors such as inappropriate learning requirements, strategy use, interest/engagement in the task, or prior knowledge (cf. McDermott, Pérez-Edgar & Fox, 2007).

Our findings are consistent with a growing body of evidence suggesting that human beings come into the world equipped with sophisticated learning mechanisms that can exploit statistical regularities present in the

world. For instance, after a brief learning experience, infants are sensitive to the probability that particular speech sounds (Saffran, Aslin & Newport, 1996) or objects (Kirkham, Slemmer & Johnson, 2002) will be presented sequentially, and can extract and generalize rules that define the structure of sentences (Marcus, Vijayan, Rao & Vishton, 1999). The study by Fiser and Aslin (2002) also demonstrated that infants quickly become sensitive to the spatial structure inherent in the scenes they viewed. On the basis of these and related findings, it has been suggested that a domain general statistical learning mechanism is operational from very early in life and helps infants make sense of their world (Kirkham *et al.*, 2002). Our findings are a natural extension of this work and indicate that acquisition of statistical regularities – such as the likely location of particular objects – shapes attentional deployment during childhood, enabling it to become more efficient with experience.

A fundamental question concerns the nature of the statistical learning observed in children in the present study and prior work. Using a recognition memory task we demonstrated that contextual cueing did not appear to be driven by explicit memory in children, similar to adults (Chun & Jiang, 1998, 2003; Chun & Phelps, 1999; Manns & Squire, 2001; Preston & Gabrieli, 2008). Importantly, individual differences in children's level of awareness of the task structure were not related to the magnitude of the contextual cueing effect or to children's age. For both forms of the age-appropriate contextual cueing paradigm, there was a negative, but nonsignificant, relationship between age and the magnitude of the contextual cueing effect. This trend suggests that our tasks may have given younger children more room to demonstrate a benefit from the invariant old displays and improve their search time with experience.

It remains possible that given a more demanding task, older children could show a more robust contextual cueing effect, but caution should be drawn from Vaidya *et al.* (2007), who failed to demonstrate evidence of the contextual cueing effect in children potentially because of using an age-inappropriate task. Future studies that incorporate a wider age range, and a task that is equally challenging for older children, may clarify the developmental progression of memory-guided attention. Given that the contextual cueing effect may occur via forming associations between the target and only a few local distractors (Brady & Chun, 2007), increasing the perceptual difficulty of the task rather than the size of the search display may be the more effective method in challenging older children.

Functional neuroimaging and lesion studies with adults suggest that memory-guided attention is mediated by a MTL-frontoparietal network (Chun & Phelps, 1999; Greene *et al.*, 2007; Manns & Squire, 2001; Preston & Gabrieli, 2008; Summerfield *et al.*, 2006). The MTL includes the hippocampus and surrounding

entorhinal, perirhinal, and parahippocampal cortices, and plays a central role in associative/configural memory encoding and retrieval (Eichenbaum, 2004; Eichenbaum & Bunsey, 1995; Giovanello, Schnyer & Verfaellie, 2004) even when learning occurs implicitly (Rose, Haider, Weiller & Büchel, 2002). With respect to contextual cueing, the MTL – in particular the entorhinal and perirhinal cortices – may support encoding of the old displays into memory by integrating elements of the old displays into fused configural representations (Preston & Gabrieli, 2008). Our findings suggest that these MTL structures may be mature enough to support contextual learning at an early age, paralleling their structural integrity (Alvarado & Bachevalier, 2000; Diamond, 1990; Giedd, Vaituzis, Hamburger, Lange, Rajapakse, Kaysen, King, Vauss & Rapoport, 1996; Gogtay, Giedd, Lusk, Hayashi, Greenstein, Vaituzis, Nugent, Herman, Clasen, Toga, Rapoport & Thompson, 2004; Nelson, 1995). Our findings are corroborated by prior work revealing successful performance of infants and children on tasks sensitive to the MTL such as delayed non-matching to sample (Diamond, 1990), deferred imitation (Collie & Hayne, 1999; Meltzoff, 1988), spatial relational learning (Overman, Pate, Moore & Peuster, 1996), and transverse patterning (Rudy, Keith & Georgen, 1993), and are further bolstered by a recent fMRI study of declarative memory that found mature activation of MTL regions in children (Ofen, Kao, Sokol-Hessner, Kim, Whitfield-Gabrieli & Gabrieli, 2007). Although there is also some evidence for protracted development of MTL function (e.g. Casey, Thomas, Davidson, Kunz & Franzen, 2002; Paz-Alonso, Ghetti, Donohue, Goodman & Bunge, 2008), at least some circuits within the MTL appear to be functional early in life (Alvarado & Bachevalier, 2000; de Haan, Mishkin, Baldeweg & Vargha-Khadem, 2006; Nelson, 1995), and these circuits may contribute to the ability of infants and children to detect structure in their environment.

Frontoparietal regions including the intraparietal sulcus and frontal eye field represent the salience of objects and locations (Bisley & Goldberg, 2003; Thompson, Bichot & Schall, 1997), and they support a top-down attentional control network (Corbetta & Shulman, 2002; Yantis & Serences, 2003). Accordingly, visual search for a pre-specified target is reliant upon these regions (Nobre, Coull, Walsh & Frith, 2003; Shulman, McAvoy, Cowan, Astafiev, Tansy, d'Avossa & Corbetta, 2003). Thus, during the contextual cueing task, interactions between MTL and frontoparietal regions would allow acquired configural representations (i.e. memories of old displays) to adaptively guide ongoing visual search; the salience of particular locations would be modulated by prior experience allowing attention to be rapidly deployed to the known location of the target. Although there is abundant evidence of protracted structural (Gogtay *et al.*, 2004; Huttenlocher, 1990; Sowell, Thompson, Holmes, Jernigan & Toga, 1999) and functional development

(Bunge, Dudukovic, Thomason, Vaidya & Gabrieli, 2002; Chugani, Phelps & Mazziotta, 1987; Crone, Wendelken, Donohue, van Leijenhorst & Bunge, 2006; Durston, Davidson, Tottenham, Galvan, Spicer, Fossella & Casey, 2006) of frontoparietal regions, it has come to be appreciated that such regions are not silent, but rather are functional during infancy and childhood – although perhaps in a limited capacity (Johnson, 2000; Bell & Fox, 1992; Diamond, 2002). Moreover, a study of selective attention using a feature conjunction search task (similar to the present study) found similar frontal and parietal regions to be active in adults and children (Booth, Burman, Meyer, Lei, Trommer, Davenport, Parrish, Gitelman & Mesulam, 2003).

Taken together, the evidence suggests that early maturation of an MTL-frontoparietal circuit may mediate the intact contextual cueing exhibited by school-aged children in the current study. Irrespective of the precise neural underpinnings, the findings presented here provide evidence that mnemonic and attention systems begin interacting early in life, consistent with a *neuroconstructivist* view of functional brain development that proposes that brain regions develop interactively – each region may shape the development of others (Westermann, Mareschal, Johnson, Sirois, Spratling & Thomas, 2007).

In sum, our findings demonstrate evidence of intact contextual cueing in young school-aged children. Children were significantly faster to detect a target stimulus when it was embedded in a repeated, as opposed to a new, context. Our findings support the idea that young children are remarkably sensitive to statistical regularities intrinsic to their visual environment and this allows efficient attentional deployment with experience. Future research should explore more directly the extent to which efficient memory-guided attention in children is mediated by interactions between MTL and frontoparietal regions.

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