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The development of organized visual search

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ABSTRACT

Visual search plays an important role in guiding behavior. Children have more difficulty performing conjunction search tasks than adults. The present research evaluates whether developmental differences in children's ability to organize serial visual search (i.e., search organization skills) contribute to performance limitations in a typical conjunction search task. We evaluated 134 children between the ages of 2 and 17 on separate tasks measuring search for targets defined by a conjunction of features or by distinct features. Our results demonstrated that children organize their visual search better as they get older. As children's skills at organizing visual search improve they become more accurate at locating targets with conjunction of features amongst distractors, but not for targets with distinct features. Developmental limitations in children's abilities to organize their visual search of the environment are an important component of poor conjunction search in young children. In addition, our findings provide preliminary evidence that, like other visuospatial tasks, exposure to reading may influence children's spatial orientation to the visual environment when performing a visual search.

1. Introduction

Many of us can recall misplacing a well-used item in our childhood, perhaps a favored toy or a missing article of clothing. For example, consider a small child that has lost one of his shoes. His mother instructs him to go to his room and find the missing shoe. No matter how hard he looks, he cannot find his missing shoe. Concluding his unsuccessful search of the shoe's whereabouts, he tells his mother, "I can't find it, I looked *everywhere*." Despite his assertion to the contrary, his mother insists that the shoe is located in his room. To his surprise, his mother quickly locates the missing shoe after briefly searching his room. From children finding their lost shoe in their messy room to adults locating their car in a crowded parking lot, visual search plays an important role in guiding behavior. As in our example, young children have more difficulty than their older counterparts with visual search (Donnelly et al., 2007; Trick & Enns, 1998). However, the underlying developmental processes responsible for poor visual search in children remain unclear. In the present paper, we investigate the development of children's ability to organize their visual search of the environment (search organization skills) and assess whether developmental changes in search organization skills contribute to developmental limitations in children's visual search accuracy.

1.1. Visual search

Visual searches can be directed at targets that have distinct features or are made of conjunctions of features (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Trick & Enns, 1998). In feature search, distinct low-level object features "pop-out" when a unique object is amidst distractors (e.g., Fig. 1a; Treisman & Gelade, 1980). The distinct low-level perceptual features of the target, relative to distractors, can be registered, coded, and processed in parallel across the visual field, resulting in quick location of the target (Treisman & Gelade, 1980). In contrast, when targets and distractors share common features (e.g., Fig. 1b), parallel processing of the environment is insufficient (for an alternative view, Guided Search, see Wolfe, Cave, & Franzel, 1989). Rather, conjunction search requires participants to search serially (i.e., from object to object) the visual environment for the target containing the conjunction of features distinguishing it from distractors (Duncan & Humphreys, 1989).

Behaviorally, feature searches are quicker and more accurate than conjunction search (e.g., Carrasco, Giordano, & McElree, 2006; Gibson

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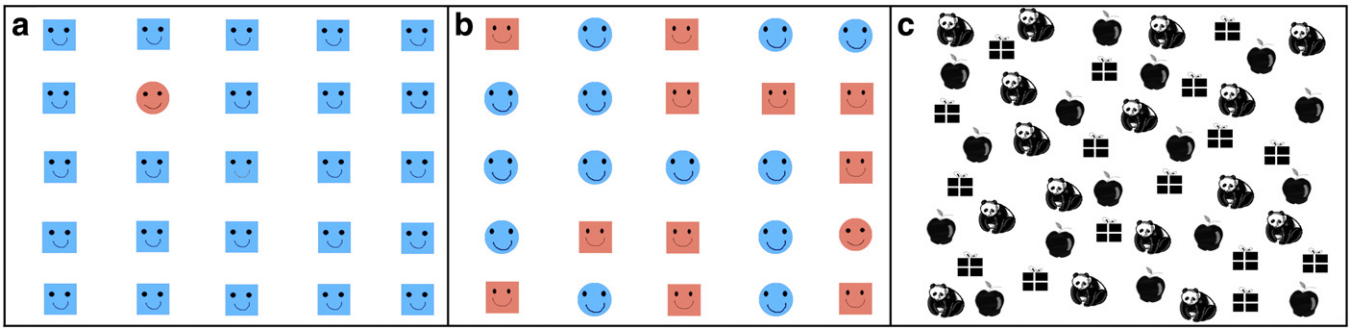

Fig. 1. Behavioral tasks. a) An example of the feature search task, b) an example of the conjunction search task, c) the apple cancellation test. Participants were instructed to search for the red circle in both feature and conjunction search tasks. Participants were instructed to cancel (or mark out) each of the apples in the apple cancellation test.

& Jiang, 1998; Treisman & Gelade, 1980; Treisman & Sato, 1990; etc.). Feature search relies on feature-based mechanisms of attention to quickly cue attention to unique features in the visual environment (for a review see Carrasco, 2011). In contrast, conjunction search relies upon moving spatial attention between locations and perceptually binding two or more features, as well as working memory processes that assist in remembering locations previously searched (Bernstein & Robertson, 1998; Humphreys, Cinel, Wolfe, Olson, & Klempen, 2000; Luria & Vogel, 2011; Robertson, 2003; Treisman & Gelade, 1980).

Although both forms of visual search can fail, the ability to accurately search the visual environment serially significantly improves from childhood to adolescence, peaking in young adulthood (Donnelly et al., 2007; Thompson & Massaro, 1989; Trick & Enns, 1998). In contrast, most studies do not report changes from childhood to adolescence in feature search performance (Gerhardstein & Rovee-Collier, 2002; Thompson & Massaro, 1989; Trick & Enns, 1998, also see Donnelly et al., 2007 for an alternative discussion). Consistent with our 'lost shoe' example, Donnelly et al. (2007) found that 6–7 year olds performed more poorly than adults on a conjunction search task. Furthermore, in a cross sectional study across the lifespan (ages: 6, 8, 10, 22, & 72), Trick and Enns (1998) also demonstrated that young children perform conjunction search tasks less accurately than young adults and seniors. Both Donnelly et al. (2007) and Trick and Enns (1998) propose that age-related effects on conjunction search tasks result from children's inability to appropriately plan and execute an organized serial search of the environment. Unfortunately, the cognitive processes underlying children's ability to plan and execute organized visual search remain unclear. Furthermore, the pattern of development for this skill, organizing visual search, remains uncharted.

1.2. Executive function and search organization

The ability to plan and execute an organized pattern of behavior is most often associated with "executive functions." The term 'executive function' refers to complex cognitive processing that requires coordination of several sub-processes to adapt behavior to the demands of the environment (Elliot, 2003; Funahashi, 2001). These sub-processes include motor/action planning, working memory, inhibitory control, and mental flexibility. The dorsolateral prefrontal cortex (DLPFC) is a critical brain structure affiliated with maturation of executive functions (Baird et al., 2002; Diamond & Goldman-Rakic, 1989; Elliot, 2003; Funahashi, 2001; Moriguchi & Hiraki, 2009). Executive functions instantiated in the DLPFC continue developing well into young adulthood, fully maturating around the mid-twenties (e.g., Baird et al., 2002; Diamond & Goldman-Rakic, 1989; Giedd, 2004; Giedd et al., 1999; Lenroot & Geidd, 2006; Moriguchi & Hiraki, 2009; Sowell, Thompson, Tessner, & Toga, 2001).

Executive processes play important roles in several aspects of conjunction search. For instance, working memory is important for preventing return to a previously searched location, and plays a key role in guiding spatial attention in conjunction search tasks (Boot, McCarley, Kramer, & Peterson, 2004; Emrich, Al-Aidroos, Pratt, & Ferber, 2009; Peterson, Beck, & Vomela, 2007, Peterson, Kramer, Wang, Irwin, & McCarley, 2001). Furthermore, processes like motor/action planning and inhibitory control contribute to the generation, initiation, and inhibition of goal-directed behaviors, an important aspect of serial search (e.g., Muggleton, Chen, Tzeng, Hung, & Juan, 2010). Developmental limitations in working memory and other executive processes do not influence feature search performance, a task relying on lower-level mechanisms of vision and feature-based attention. In contrast, limitations in executive processes, like working memory, may severely hamper children's abilities to plan and execute an organized serial search of the environment (Donnelly et al., 2007; Han & Kim, 2004; Luria & Vogel, 2011; Trick & Enns, 1998). However, the development of children's abilities to organize serial visual search behavior, a skill we will refer to as 'search organization,' remains relatively unexplored.

Studies typically infer search organization based on the relationship between reaction time and the number of distractors in the visual environment (i.e., search slope) — as the number of distractors in a conjunction search task increases, reaction time also increases (i.e., a steep search slope; Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe et al., 1989). In contrast, the number of distractors does not significantly influence reaction time on feature search tasks (i.e., a flat search slope; e.g., Treisman & Gelade, 1980). Steeper conjunction search slopes signify more disorganized, or inefficient, search as seen in children compared to adults (Donnelly et al., 2007). Search slope methods in visual search, however, do not necessarily tap exclusively into search organization skills (Trick & Enns, 1998), as reaction time is an indirect marker of information processing speed associated with many aspects of human behavior (e.g., general cognitive function, aging, quality of living, etc.; Deary & Der, 2005; Jakobsen, Sorensen, Rask, Jensen, & Kondrup, 2011). Furthermore, general age-related improvements in processing speed from childhood to late adolescence make the interpretation of reaction time data unclear for cross-sectional developmental studies (e.g., Anderson, Starck, Rosin, & Svensson, 1984; Coyle, Pillow, Snyder, & Kochunov, 2011; Philip, 1934). Visual search organization measurements unrelated to reaction time would add to understanding of the development of children's search organization skills and how search organization influences visual search performance.

Accuracy is a measure of visual search performance, but is uninformative in adults because of near ceiling performance (i.e., 100%). However, visual search accuracy, particularly for conjunction search, is variable in children and provides an informative measure of visual search performance. Mark and colleagues recently demonstrated a valid non-reaction time based measure of search organization skills in healthy adults and adult patients with brain injury (Mark & Woods, 2003; Mark, Woods, Ball, Roth, & Mennemeier, 2004; Woods & Mark, 2005, 2007; Woods, Mark, & Mennemeier, 2004). Mark and Woods administered a cancellation task that required participants to locate and mark out (or cancel) 56 identical target objects amongst a field of 127 pseudo-randomly arrayed distractors. While participants canceled targets, the investigators