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Spatial ranking strategy and enhanced peripheral vision discrimination optimize performance and efficiency of visual sequential search

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Abstract

Visual sequential search might use a peripheral spatial ranking of the scene to put the next target of the sequence in the correct order. This strategy, indeed, might enhance the discriminative capacity of the human peripheral vision and spare neural resources associated with foveation. However, it is not known how exactly the peripheral vision sustains sequential search and whether the sparing of neural resources has a cost in terms of performance. To elucidate these issues, we compared strategy and performance during an alpha-numeric sequential task where peripheral vision was modulated in three different conditions: normal, blurred, or obscured. If spatial ranking is applied to increase the peripheral discrimination, its use as a strategy in visual sequencing should differ according to the degree of discriminative information that can be obtained from the periphery. Moreover, if this strategy spares neural resources without impairing the performance, its use should be associated with better performance. We found that spatial ranking was applied when peripheral vision was fully available, reducing the number and time of explorative fixations. When the periphery was obscured, explorative fixations were numerous and sparse; when the periphery was blurred, explorative fixations were longer and often located close to the items. Performance was significantly improved by this strategy. Our results demonstrated that spatial ranking is an efficient strategy adopted by the brain in visual sequencing to highlight peripheral detection and discrimination; it reduces the neural cost by avoiding unnecessary foveations, and promotes sequential search by facilitating the onset of a new saccade.

Introduction

Understanding the sequence of an event and acting upon a serial order lead to the acquisition of voluntary actions at the basis of intelligent behaviors such as language and logical thinking. (Rizzolatti & Arbib, 1998). Visual sequential search (VSS) is the capacity of looking at objects in a specific order; its successful execution requires the optimization of the perceptual resources of foveal and extrafoveal vision. Formerly learned sequential procedures (particularly numeric and alphabetic sequences) may optimize the VSS performance (Hikosaka *et al.*, 1998, 1999). Nevertheless, the acquisition of visual information across parts of the retina with different spatial resolution has critical consequences (Anton-Erxleben & Carrasco, 2013). Indeed, outside the fovea, which ensures the best resolution, discrimination abilities decrease sharply (Curcio *et al.*, 1990). To overcome this limit, the brain must select relevant locations of the visual field for enhanced processing (Desimone & Duncan, 1995). Spatial attention selects these locations overtly with an eye movement or covertly without eye movements (Deubel & Schneider, 1996). Covert attention collects global information of the scene in parallel processing and enhances visual perception at the attended target locations (Posner, 1980; Bundesen, 1990; Carrasco & McElree, 2001; Carrasco, 2011).

Even though basic attributes of the scene may pre-attentively influence visual search (Deubel *et al.*, 1998; Godijn & Theeuwes, 2003), the properties of covert attention may be used actively in gaze strategies adopted to accomplish complex tasks. One strategy, called spatial pooling, is clustering explorative fixations in locations that enhance peripheral information (Findlay, 1982; Findlay *et al.*, 2001; Cohen *et al.*, 2007). This strategy is supposed to be adopted by the visual system when the saccade landing point is uncertain due to crowded or competing targets. Indeed, uncertainty about target choice needs to be solved by pooling pieces of information of the scene collected extrafoveally in favor of one among several options (Bahcall & Kowler, 2000). However, in the case of logical sequential search, the choice of the next target to be looked at is related not only to the spatial features of the image, but also to the necessity of respecting the sequential logical order. Therefore, a gaze strategy (spatial ranking that expands peripheral vision discrimination) should be more active than simply pooling spatial information of the image for further

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