



Effect of parietal lobe lesions on saccade targeting and spatial memory in a naturalistic visual search task

Steven S. Shimozaki^{a,*}, Mary M. Hayhoe^a, Gregory J. Zelinsky^b,
Amy Weinstein^c, William H. Merigan^a, Dana H. Ballard^a

^a Center for Visual Science, University of Rochester, Rochester, NY, USA

^b Department of Psychology, State University of New York, Stony Brook, NY, USA

^c Department of Neurology, Strong Memorial Hospital, University of Rochester, Rochester, NY, USA

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Abstract

The eye movements of two patients with parietal lobe lesions and four normal observers were measured while they performed a visual search task with naturalistic objects. Patients were slower to perform the task than the normal observers, and the patients had more fixations per trial, longer latencies for the first saccade during the visual search, and less accurate first and second saccades to the target locations during the visual search. The increases in response times for the patients compared to the normal observers were best predicted by increases in the number of fixations. In order to investigate the effects of spatial memory on search performance, in some trials observers saw a preview of the search display. The patients appeared to have difficulty using previously viewed information, unlike normal observers who benefit from the preview. This suggests a spatial memory deficit. The patients' deficits are consistent with the hypothesis that the parietal cortex has a role in the selection of targets for saccades, in memory for target location.

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1. Introduction

Lesions of the parietal cortex have long been known to cause impairments of visuospatial function. For example, parietal lesions often lead to the syndrome of hemineglect. Occurring predominately with right parietal lesions, hemineglect patients tend to ignore the contralesional (left) side of the environment. Because this syndrome can be distinguished from a loss of visual acuity (hemianopia), hemineglect is considered to be a spatial attention deficit (review Rafal, 1994). It has also been shown that parietal lesions can cause constructional apraxia (a visuospatial deficit in copying and reproducing two- and three-dimensional shapes) (Benowitz, Moya, & Levine, 1990; Benton, 1967; Ruessmann, Sondag, & Beneike, 1988), and deficits in short-term spatial memory (De Renzi, Faglioni, & Previdi, 1977; De Renzi, Faglioni, & Scotti, 1969; De Renzi & Nichelli, 1975).

Neurophysiological studies in primates strongly suggest that another aspect of visuospatial processing involving the parietal cortex is saccadic target selection. The parietal cortex projects to areas primarily responsible for eye movement control, such as the superior colliculus (SC) (Andersen, Asanuma, Essick, & Siegel, 1990; Fries, 1984; Lynch, Graybiel, & Lobeck, 1985) and the frontal eye fields (FEFs) (Andersen et al., 1990; Cavada & Goldman-Rakic, 1989; Schall, Morel, King, & Bullier, 1995). Also, areas in the posterior parietal cortex, such as 7a and lateral intra parietal (LIP), respond both to the anticipation and the execution of a saccade (e.g. Andersen, Essick, & Siegel, 1987; Colby, Duhamel, & Goldberg, 1995; Colby, Duhamel, & Goldberg, 1996; Gnadt & Andersen, 1988; Mountcastle, Lynch, Georgopoulos, Sakata, & Acuna, 1975). Andersen (1995) suggests that the LIP activity preceding a saccade encodes the intention to make a saccade, and Duhamel, Colby, and Goldberg (1992) also found that parietal receptive fields shift in preparation of an intended saccade. Gottlieb, Kusunoki, and Goldberg (1998) found that saccade-related activity in LIP depends on behavioral relevance. They suggest that LIP contains a visual 'saliency' map used in the selection of saccadic targets, as proposed by a number of

* Corresponding author. Present address: Department of Psychology, University of California, Santa Barbara, CA 93106, USA.
Tel.: +1-805-893-3853; fax: +1-805-893-4303.

E-mail address: shimozak@psych.ucsb.edu (S.S. Shimozaki).

computational models of saccades (Findlay & Walker, 1999; Rao, Zelinsky, Hayhoe, & Ballard, 2002; Wolfe, 1994).

Although the attentional deficits caused by parietal lesions in humans have been extensively studied, relatively less is known about the impact of parietal lesions on eye movements. Several previous studies on the effect of parietal lesions on eye movements have focused on hemineglect (e.g. Barton, Behrmann, & Black, 1998; Behrmann, Watt, Black, & Barton, 1997; Chedru, Leblanc, & Lhermitte, 1973; Ishiai, Sugishita, Mitani, & Ishizawa, 1992; Karnath, 1994; Walker & Findlay, 1996). Consistent with the attentional effect of hemineglect, these studies find that saccades of hemineglect patients tend to be biased away from the neglected field (both saccade direction and number of fixations). Studies that have focused more on the eye movements per se, have found that parietal patients have difficulty in a “double-step” saccade task (Duhamel, Goldberg, Fitzgibbon, Sirigu, & Grafman, 1992; Heide, Blankenburg, Zimmerman, & Kompf, 1995; Heide & Kompf, 1998). In this task, the observer must make two successive saccades to two targets flashed briefly and sequentially in the dark before the first saccade can begin. Thus, to make an accurate second saccade, the observer must take into account the spatial displacement of the eye caused by the first saccade. Parietal lesions affected this ability, so that inaccurate second saccades were made despite the presence of accurate first saccades, suggesting an inability to take account of the eye displacement caused by the first saccade. Parietal lesions also caused increased saccade latencies during visually guided reflexive saccades (saccades to sudden onset targets in previously unknown locations) (Heide & Kompf, 1998; Pierrot-Deseilligny, Rivuad, Gaymard, & Agid, 1991a; Pierrot-Deseilligny, Rivuad, Penet, & Rigolet, 1987) and affected saccade latencies and accuracies for memory guided saccades (Pierrot-Deseilligny, Rivuad, Gaymard, & Agid, 1991b). Similar effects were found in normal observers when their posterior parietal cortex was temporarily inactivated by transcranial magnetic stimulation (TMS) (Muri, Vermersch, Rivuad, Gaymard, & Pierrot-Deseilligny, 1996). In addition, several fMRI studies have found activation in the parietal areas during periods of visually-guided saccades, compared to periods of fixation (Corbetta et al., 1998; Darby et al., 1996; Luna et al., 1998; Petit, Clark, Ingeholm, & Haxby, 1997).

Some recent studies suggest a specific role of the parietal cortex in the use of spatial memory in saccade targeting. In an fMRI study, Heide et al. (2001), studied a ‘triple-step’ saccade task, which is analogous to the double-step task described above, except that observers had three successive locations to fixate. They found more activation in the right intraparietal area during the triple-step saccade task, compared to various types of single-step (visually- and memory-guided) saccades that had less demands on spatial memory. Also, some recent studies of parietal hemineglect found a greater number of refixations on the ipsilesional side in a dot-counting task (Zihl & Hebel, 1997), as well as in visual search and cancellation tasks of letters, circles,

and line drawings of objects (Husain et al., 2001). These refixations appear to reflect a deficit in the spatial memory in the ipsilesional field. Of particular interest is the study Husain et al. (2001), in which the neglect patients and the normal observers explicitly stated whether each object had been fixated previously. The hemineglect patients not only refixated objects more often, they also did not remember previous fixations.

This study further explores the effect of posterior parietal lesions on saccades by examining the saccades of four normal observers and two patients with parietal lesions during a visual search task. Unlike what has been more commonly studied, the two parietal patients did not have observable signs of neglect. In a typical visual search trial, the observer is given a target, views a search display that has or does not have the target, and then must indicate the presence of the target in the search display. Also, experiments in visual search often require the observers to hold their gaze, or have briefly presented stimuli, disallowing the use of eye movements (e.g. Palmer, 1994, 1995; Treisman, 1991). If eye movements are allowed, however, observers tend to make several saccades during a visual search task (Findlay & Gilchrist, 1998; Zelinsky & Sheinberg, 1997). Zelinsky and Sheinberg (1997) and Scialfa, Thomas, and Joffe (1994), for example, found that the number of saccades was an excellent predictor of the response times. Another study by Zelinsky, Rao, Hayhoe, and Ballard (1997) found that, during visual search, the accuracy of the saccades to the target location reliably improved from the first to the last saccade of each trial, showing that saccades reflect the dynamic evolution of the search process. Thus, under natural viewing conditions, the process of saccadic target selection is an integral part of visual search. Given the likely role of the posterior parietal cortex in saccadic target selection, the question we wish to address is how parietal lesions affect the saccadic target selection process during visual search.

Another aspect in most visual search studies is that the targets are presented in novel locations on each trial. Thus, the search must be accomplished solely on the basis of the target’s appearance. In the natural world, however, saccadic targets can be selected either on the basis of the target’s appearance (for example, where is the red sweater?) or on the basis of previously acquired information about the target’s location (e.g. the keys are on the table). In these cases, search can be based on the memory of the target’s location as well. A study by Epelboim et al. (1995), for example, showed that spatial memory can affect saccadic performance in a search task. They found that the time taken to tap a specified sequence of colored lights arrayed on a table rapidly decreased as the task was repeated, suggesting that repeated fixations of the locations facilitated the tapping movements. Thus, we were interested to explore saccadic eye movements in both kinds of search process, namely, both in appearance- and spatial memory-based search.

A last feature of the experiments was the use of naturalistic displays. Experiments on visual search typically involve

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