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Distracted by relatives: Effects of frontal lobe damage on semantic distraction

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ABSTRACT

When young adults carry out visual search, distractors that are semantically related, rather than unrelated, to targets can disrupt target selection (see Belke, Humphreys, Watson, Meyer, & Telling, 2008; Moores, Laiti, & Chelazzi, 2003). This effect is apparent on the first eye movements in search, suggesting that attention is sometimes captured by related distractors. Here we assessed effects of semantically related distractors on search in patients with frontal-lobe lesions and compared them to the effects in age-matched controls. Compared with the controls, the patients were less likely to make a first saccade to the target and they were more likely to saccade to distractors (whether related or unrelated to the target). This suggests a deficit in a first stage of selecting a potential target for attention. In addition, the patients made more errors by responding to semantically related distractors on target-absent trials. This indicates a problem at a second stage of target verification, after items have been attended. The data suggest that frontal lobe damage disrupts both the ability to use peripheral information to guide attention, and the ability to keep separate the target of search from the related items, on occasions when related items achieve selection.

1. Introduction

In visual search tasks participants are asked to decide whether a pre-specified target is present on the screen. Many theories assume that search is guided to a target by an "attentional template" held in working memory. Evidence for such a template comes from a number of sources. Chelazzi, Miller, Duncan, and Desimone (1993) trained monkeys to make a saccade to an item in a search display that matched a stimulus held in working memory (using a match to sample task). They found that cells in the inferior temporal lobe responding to the cued item maintained their activity during the interval between the cue and the search display, with the cells showing an enhanced rise in activation when the cued item re-appeared in the search display. Chelazzi et al. proposed that the activity maintained during the interval between the cue and the display represented a template that biased activity in earlier cortical regions to favor features consistent with the target.

Evidence for effects of top-down guidance on human search comes from a number of sources. For example, several investigators have reported asymmetries in visual search, with search tasks varying in difficulty according to which item is the search target and which is the distractor (e.g., a large target versus small distractors generates efficient search, whereas a small target amongst large distractors generates inefficient search; Wolfe (1998)). Hodsoll and Humphreys (2001) showed that this search asymmetry was modulated by fore-knowledge of the target: the asymmetry was larger when participants knew what they were searching for relative to when they searched for a target that was the odd one out (see also Hodsoll & Humphreys (2005), for similar evidence from orientation search asymmetries). Hodsoll and Humphreys proposed that the search asymmetry was partially dependent on the match between the stimulus and the search template (some stimuli are matched more quickly than others) and not just on bottom-up differences between the stimuli.

Moores et al. (2003) provided other evidence for a template by assessing the effects of semantic distractors on search. They asked participants to search for a familiar target object (e.g., motorbike) and, on some trials, presented semantic distractors in the display (e.g., motorbike helmet). They found that reaction times were slowed on trials when semantic distractors were present. On target-absent trials in particular, the first eye movement tended to go to the semantically related distractor rather than to unrelated distractors. These data suggest that activation of a memory template for a target also excites the re-presentations of related items, which can then guide search to matching (but in this case, distractor) stimuli. In the present paper, we use data from patients with frontal-lobe lesions to probe-apart the different processes involved in guiding search to targets. In particular, using the procedure of

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Moores et al. (2003) we examine whether, in addition to any effects of related distractors on the initial stages of selection, there are effects at later stages in which any selected stimuli are compared with target-related templates. At what stage(s) can semantic information about the stimuli be accessed to influence target selection and how is this affected by damage to the frontal lobes? We present data suggesting that although there are effects of target-distractor relatedness at both stages and across patient and control groups, frontal lobe damage alters: (i) the initial gathering of peripheral information that guides the first stages of target selection (which is independent of target-distractor relatedness) and (ii) the later process of target identification following the orienting of attention to a stimulus (which is affected by target-distractor relatedness).

2. Effects of frontal lobe damage on search

Adequate functioning of the frontal lobes is necessary for visual search (De Fockert, Rees, Frith, & Lavie, 2004; for reviews see Corbetta & Shulman, 2002; Kanwisher & Wojciulik, 2000). In an fMRI study of healthy participants, Donner et al. (2000) found that the frontal eye fields (FEF) showed increased activation during conjunction search when compared to feature search. FEF activation was linked to the selection of search targets. The necessary involvement of the FEFs in search is supported by results using rTMS. Muggleton, Juan, Cowey, and Walsh (2003) found that, compared to a no-stimulation baseline, TMS over the FEF led to more false positive errors during conjunction search. No differences were found between the TMS and no TMS conditions for a feature search task, and intermediate differences in error rates occurred for an interleaved feature search task where target and distractor items varied across trials. It was concluded that the FEFs were necessarily involved in visual search, playing a particularly strong role when the target was not very salient.

The control of visual search is not restricted to the FEF, however. A wider requirement of the frontal lobes has been implicated in singleton search using fMRI and in experiments examining the interplay between visual selection and working memory. In their fMRI experiment, Lavie and de Fockert (2006) found evidence for increased dorsolateral frontal activity during search for a target in the presence (relative to the absence) of an irrelevant singleton distractor. They linked frontal lobe involvement to the requirement to suppress the salient distractor. Converging evidence comes from neuropsychological studies. Kumada and Hayashi (2006) studied a patient with frontal–temporal lobe brain damage, YW, and compared his results to normal controls. Participants either searched for a color or orientation-defined target amongst non-targets (no singleton condition) or for targets in the presence of a singleton distractor (differing in color or orientation from the other items present). YW's search RTs increased abnormally for the singleton compared to the no singleton condition. Kumada and Hayashi argued that YW's ability to select the target over the singleton was impaired due to poor top-down 'weighting' of the stimulus properties defining the target. Under these conditions singleton distractors competed strongly with targets and sometimes won the competition for selection.

Zihl and Hebel (1997) also reported problems in the planning of scan paths across dot patterns in patients with frontal damage and linked this to a working memory deficit. Problems in task control based on the active maintenance of working memory re-presentations could impact on search in various ways. For example, there might be less top-down control from a template of a target held in working memory, or there may be an impaired re-presentation of previously inspected locations so that search becomes more generally disorganized.

However, the requirement of frontal lobe functioning for competent search has not been observed universally. For example, Humphreys, Hodsoll, and Riddoch (2009) reported no difference between patients with frontal-lobe lesions and age-matched controls when search slopes were examined for feature and conjunction search tasks. They used brief presentation conditions, where working memory load may be reduced. The data suggest that search can be relatively normal when working memory is not loaded (see also Walker, Husain, Hodgson, Harrison, & Kennard, 1998).

The relation between WM and visual search through small arrays was examined by Soto, Humphreys, and Heinke (2006). They found increased effects of irrelevant objects held in working memory on search in frontal patients compared with age-matched controls. They had participants hold an item in memory prior to carrying out a search task. The search task required participants to point to a tilted line target amongst vertical line distractors, and an irrelevant shape surrounded each line. Control participants were slowed in initiating saccades to the target when the memory item re-appeared surrounding a distractor in the search display, and the likelihood that the first saccade went to the target, rather than the distractor was also reduced. Soto et al. reported that these effects were equivalent in frontal patients and controls, indicating that the influence of the working memory on the initial stages of selection was relatively normal. Nevertheless, the patients made more errors when the memory item re-appeared around a distractor, and they were then slower to point to the target, when compared to the controls. This last mentioned result suggests that frontal lobe damage affected the ease of disengaging attention from a distractor, once it was selected. Soto et al. proposed that frontal patients had difficulty maintaining separate the template for the target from other information held in working memory. The patients were thus confused about whether they should respond to a selected item, even if it was a distractor.

Quite similar results to this, but based on the presence of new related distractors rather than the re-presentation of items from working memory, were reported by Belke et al. (2008). They had healthy participants hold a working memory load prior to searching for a target and examined the effects on search of presenting a related distractor in the search display (cf. Moores et al., 2003). Though effects on the initial saccades in search were unaffected by cognitive load, participants were delayed in responding due to the time taken to reject related distractors that were selected. To the extent that the working memory task made a demand on frontal lobe structures (Lavie & De Fockert, 2006), these results point to the role of the frontal lobes in rejecting distractors once they are selected. This was tested more formally here, when we examined the effects of new, related distractors on search in frontal patients and age-matched controls. Following the results of Soto et al. (2006) we predicted that: (i) effects of the semantic distractor on the initial selection of stimuli should be unaffected by the lesion, and (ii) there should be impaired disengagement from a semantically related distractor, once selected. Thus the patients should not differ from age-matched controls on first fixation behavior, but reactions may be slower, fixation durations longer and more errors may arise when the patients make an orienting response to semantic distractors.

3. Materials and methods

3.1. Participants

The patient group comprised of nine right-handed patients with a range of lesions, but all including damage to the frontal cortex (see Fig. 1 and Table 1). There were four patients with unilateral right hemisphere damage (JQ, AS, TT and PW), and two with unilat-