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Distinct anatomy for visual search and bisection: A neuroimaging study

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ABSTRACT

Individuals with spatial neglect following brain injury often show biased performance on landmark bisection tasks (judging if a single item is transected at its midpoint) and search tasks (where they seek target(s) from an array of items). Interestingly, it appears that bisection deficits dissociate from other measures of neglect (including search tasks), and neglect patients with bisection deficits typically have more posterior injury than those without these symptoms. While previous studies in healthy adults have examined each of these tasks independently, our aim was to directly contrast brain activity between these two tasks. Our design used displays that were interpreted as landmark bisection stimuli in some blocks of trials and as search arrays on other trials. Therefore, we used a design where low-level perceptual and motor responses were identical across tasks. Both tasks generated significant activity in bilateral midfusiform gyrus, largely right lateralized activity in the posterior parietal cortex, left lateralized activity in the left motor cortex (consistent with right handed response) and generally right lateralized insular activation. Several brain areas showed task-selective activations when the two tasks were directly compared. Specifically, the superior parietal cortex was selectively activated during the landmark task. On the other hand, the search task caused stronger bilateral activation in the anterior insula, along with midfusiform gyrus, medial superior frontal areas, thalamus and right putamen. This work demonstrates that healthy adults show an anatomical dissociation for visual search and bisection behavior similar to that reported in neurological patients, and provides coordinates for future brain stimulation studies.

Introduction

Spatial neglect is a common consequence of right hemisphere injury, with patients classically failing to respond to information on their left side. Two of the most popular paper-and-pencil methods for assessing this deficit are cancellation tasks (where the participant is asked to mark target items in a cluttered array of distractors) and bisection tasks (where the individual marks the midpoint of a line). While each of these tasks requires exploratory motor movements, similar effects are observed with variants of these tasks that attempt to isolate the perceptual components: the landmark task (where an individual reports if pre-bisected lines are segmented at their midpoint, Harvey et al., 1995) and effortful visual search tasks (where the participant reports if a target item is present or absent in a cluttered display). Despite clear differences in the visual appearance of the test materials as well as in the cognitive demands of performing the tasks, bisection and cancellation tasks are often used interchangeably to assess neglect with considerable success. However, while some patients exhibit biased performance on both bisection and cancellation tasks, many only exhibit biases on cancellation tasks (Ferber and Karnath, 2001). This dissociation has been interpreted as suggesting that some of the regions critical for accurate cancellation performance are not required for unbiased bisection. Support for this notion comes from a series of studies that demonstrate that individuals with bisection deficits have more posterior injury than those without these deficits (Binder et al., 1992; Rorden et al., 2006; Verdon et al., 2010). Our aim was to use neuroimaging in healthy adults to validate this effect and provide a more accurate understanding of the brain regions involved with these tasks.

Brain imaging studies in healthy adults can help identify brain regions involved in perceptual processing. Seminal work by Fink et al. (2000, 2001) demonstrated that landmark tasks activate the posterior parietal cortex (PPC). Çiçek et al. (2009) extended this by demonstrating that both landmark and bisection tasks cause activation in the PPC. In addition, there is clear agreement that visual search tasks engage the PPC (for review, see Corbetta and Shulman, 2002). A study by Himmelbach et al. (2006) identified activity in the superior temporal gyrus (STG) during a visual search task where participants scanned a cluttered array for a very infrequent target (the letter A). One elegant feature of this analysis is that the search was conducted with overt eye movements, similar to the typical tests used with stroke patients, whereas most prior imaging studies have required

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participants to maintain fixation. However, this feature may also explain why Himmelbach and colleagues did not detect any PPC activity: their statistics contrasted active visual search with control tasks where the individuals made similar overt eye movements. Specifically, there is clear evidence that the dorsal attentional network (PPC and FEF) is similarly activated during covert peripheral attention and eye movements (de Haan et al., 2008). Further, Himmelbach et al. did not examine activity related to bisection tasks, so it is difficult to determine if their temporal lobe effect dissociates between the search and bisection tasks.

Our aim was to directly compare activation patterns observed in neurologically healthy adults during landmark and visual search task performance over identical stimulus displays. We specifically chose a 'serial' search task rather than a 'parallel' search task where the targets pop out since this feature is found in all popular cancellation and search tasks used with neglect, and patients with unilateral injury resulting in neglect without additional confounds (such as visual field cuts) as well as patients with simultanagnosia following bilateral injury show remarkably intact performance on preattentive search tasks (Esterman et al., 2000; Karnath et al., 2000). A novel aspect of our paradigm is that we kept the perceptual stimuli and the motoric responses identical between these two tasks. This is important, as it allows us to get a pure measure for task related differences. A second important design decision was to require participants to conduct both tasks without eye movements, in order to rule out the possibility that these tasks might elicit different fixation patterns, which could directly cause different patterns of brain activation.

Based on work with neurologically impaired individuals, we predicted that regions near the superior and middle temporal cortex would show more activation to a visual search task than a bisection task. A second clear prediction was that the bisection task should elicit strong responses in the PPC, though we were agnostic as to whether this region would be task specific: as reviewed, some studies have implicated the PPC in bisection while others have implicated it in visual search, though it is unclear whether these studies refer to the same or different parts of the PPC.

Methods

Participants

Twenty-six young adults (18 female, average age 23.9 years, range 18–38 years) from the Georgia Tech/Georgia State University community participated in the study after giving informed consent following a procedure approved by the local institutional review board. All had normal or corrected-to-normal vision and reported no history of neurological conditions. Data from an additional five subjects was excluded from further analysis due to poor performance on both tasks ($n = 1$), excessive (>3 mm) or stimulus-locked head movement during data collection ($n = 3$), or equipment malfunction (projector focus problems, $n = 1$).

Stimuli

The novel stimuli used in this study enabled us to evaluate the neural correlates of a visual search task and a landmark task using perceptually identical stimuli that required identical motoric responses (see Fig. 1). On each trial, a black bar was presented on a gray background. The bar was 12° of visual angle wide and 3° high. To prevent participants from using the fixation cross as a cue to the center of the bar, the bar was never horizontally centered on the screen but appeared at four equally frequent positions on the screen, with its center positioned 2.5° above and either 1° left, 0.5° left, 0.5° right, or 1° right of the fixation cross. A white line (3° long and 0.13° wide) was positioned vertically to divide the bar into two pieces. The white line divided the bar at the center on 50% of the trials, and appeared 0.4° to the left or right of center on the remaining half of the trials (equally divided). In addition, eight white O or Q-like stimuli were positioned within the black bar on each trial, four to the left of the dividing line and four to the right. Although we did not manipulate set size, previous studies have shown that this stimulus set shows set size effects and requires effortful visual search, with or without eye movements (Zelinsky and Sheinberg, 1997). Each shape was 1° in diameter and was positioned so that it was in one of 22 predetermined positions that were more than 3° but less than 6° from the fixation cross. On 50% of trials, all shapes were Q-like (had a vertical crossbar located at the 12 o'clock position), while on the other 50% of trials, one of the Q-like shapes was replaced with an "O" shape without the crossbar. Half of the time the "O" appeared in one of the eleven positions to the left of the bisecting bar and half the time it was to the right, occurring equally frequently in all positions. The remaining shapes were pseudorandomly assigned to the remaining positions so that four stimuli always appeared on each side of the dividing line and no more than two stimuli were vertically or horizontally adjacent on each side.

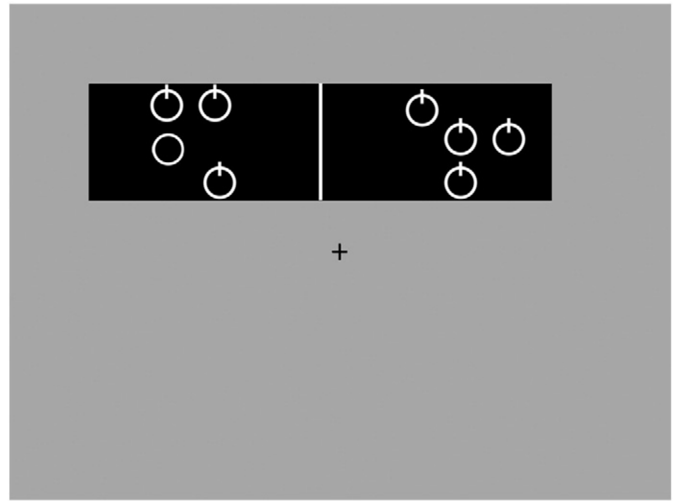

Fig. 1. A typical stimulus display. Identical physical stimuli were used for both tasks. For this display, participants would respond 'centered' if asked to make a line bisection judgment (as the white line is in the middle of the black bar) and 'present' if asked to make a search judgment (as one of the items is an 'O').

On each trial, participants were asked either to judge whether the dividing line was centered or off-center in the bar ("bisection" task) or to judge whether an "O" shape was present or absent among the Q-like shapes ("search" task). Participants reported their judgment by pressing one of two buttons on an MRI compatible button box held in the right hand. 'Present' and 'Centered' responses were mapped to one button and 'Absent' and 'Off-Center' responses were mapped to the other button. Participants were required to make these judgments without moving their eyes from the central fixation cross to control for possible differences in natural eye movement patterns across the two conditions. Within a session, each display (defined by the combination of bar, line, and shape positions) occurred exactly twice, once in the bisection condition and once in the search condition. Counterbalancing ensured that the position of the bisection line (left, center, or right) provided no information about the presence, absence, or position of the "O" shape and vice versa.

Data acquisition

Functional data were collected using a Siemens Trio 3T MRI scanner equipped with a twelve-channel receive-only head coil, using an EPI pulse sequence with the following scan parameters: repetition time (TR) 1920 ms, echo time (TE) 30 ms, flip angle 90°, 64×64