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NOTE

COMPARING THE CEREBRAL HEMISPHERES ON THE SPEED OF SPATIAL SHIFTS OF VISUAL ATTENTION: EVIDENCE FROM SERIAL SEARCH

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Abstract—We compared the speed at which visuo-spatial attention may be shifted from one stimulus to another as a function of the visual hemifield in which the items were displayed in a visual search task requiring serial processing. The increase in response time with the number of items displayed was similar for left- and right-hemifield presentations. This suggests that the rate at which visuo-spatial attention can be shifted from one stimulus to another during visual search does not differ between the cerebral hemispheres.

INTRODUCTION

THE INTEREST of neuropsychology in the processes involved in visuo-spatial attention has centred mainly on the visual hemineglect syndrome. According to many authors, the symptoms that are observed in visual hemineglect originate from a difficulty in orienting attention to the stimuli presented in contralesional space [10, 11, 12, 14, 15, 16, 20]. Visual hemineglect is most often seen in patients with right-brain lesions [1, 3, 4, 5, 8, 9], thus suggesting a specialization of the right cerebral hemisphere for visuo-spatial attention processes.

The present study examines hemispheric specialization for visuo-spatial attention in normal individuals. We shall compare the speed of spatial shifts of attention from one stimulus to another as a function of the visual hemifield in which the items are displayed in a visual search task.

In the visual search paradigm, the subject reports, as rapidly as possible, whether a given stimulus, designated as the target, is present or not within an array made of a variable number of stimuli. When response times (RT's) increase linearly with the number of items displayed, it is usually assumed that visual search is serial, and thus involves the attentional selection of individual items [see 24 for further details]. In this case, it is said that subjects search for the target by sequentially focusing their attention on each stimulus in turn. The rate of increase of RT's as a function of the number of items displayed may be used as a measure of the speed at which attention may be shifted from one stimulus to the next during the visual search task.

The experimental condition we have retained is one in which serial search functions have been observed most consistently, namely the search for a conjunctive target [2, 7, 13, 17, 21, 25, 26, 27, 28, 29]. A conjunctive target differs from distractors by a conjunction of attributes: i.e. it shares one of its attributes with one subset of distractors and another attribute with the remaining distractors. For example, if the target is a *red horizontal* bar, some of the distractors would be *red* vertical bars and the rest would be green *horizontal* bars.

In the experiment reported here, the search displays were lateralized either to the left or the right visual hemifield and the effect of the number of items displayed upon RT's was measured. If both cerebral hemispheres are capable of performing spatial shifts of visual attention but that the right hemisphere is dominant for this function, one may expect that spatial shifts of attention from one stimulus to another would be faster when stimuli fall in the left hemifield than when they fall in the right hemifield. In such a case, the increase in RT's as a function of the number of items displayed should be lower with left-hemifield (right hemisphere) displays than with right-hemifield (left hemisphere) displays.

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METHOD

Subjects

10 normal volunteers (4 men and 6 women) took part in the experiment. All were right-handers, undergraduate or graduate university students, and free from central nervous system impairment. Their age ranged from 19 to 38 years (mean = 25.3 years).

Materials and stimuli

The experiment was controlled by an Amiga microcomputer and stimuli were displayed on an RGB monitor placed at 70 cm from the subject.

The visual search stimuli were horizontal (2.09° wide, 0.30° high) and vertical (0.39° wide, 1.97° high) bars which could either be red (mean luminance of 15.2 cd/m^2) or green (mean luminance of 17.9 cd/cm^2). Using the minimum flicker technique [30], the relative brightness of the colours was set to equiluminance for each individual subject. The stimulus designated as the target was a red horizontal bar, and the stimuli designated as distractors were red vertical and green horizontal bars. This way, the target differed from distractors by a unique conjunction of visual attributes.

In order to control for the locus of ocular fixation before the beginning of each trial, subjects were required to perform a visuo-motor tracking task. In this task, the fixation point (diameter of 0.90°) was white (mean luminance of 85.2 cd/m^2), and it moved up and down (speed of 4.54°/sec) along a vertical axis which was at the centre of the display screen and whose length was 6.35°. The tracking stimulus was a white, empty circle (diameter of 2.10°), whose vertical position was controlled through the computer mouse.

At the onset of a trial, the stimuli used for the visuo-motor tracking task were removed from the display, followed immediately by the visual search stimuli which appeared either to the left or the right of the fixation point. The 2, 4, 6, or 8 stimuli displayed on any given trial were distributed randomly within an eight-position array (2 wide × 4 high). The center-to-center distance between those array positions was of 3.20° horizontally, and of 2.88° vertically. In order to break the regularity of the stimulus display, a small positional shift ranging between ±0.30° horizontally and ±0.23° vertically, whose magnitude was randomly determined, was applied to each individual stimulus. The minimum distance between the centermost stimulus in the display and the vertical axis along which the fixation point moved during the visuo-motor tracking task was 4.31°. The stimulus display remained visible for 150 msec, which ensured that the subject did not shift his or her ocular fixation before the search stimuli disappeared [31].

Procedure

The subject's main task was to indicate, as rapidly as possible while avoiding errors, whether the target (red horizontal bar) was present or not in the display. All subjects responded using their right hand, pressing one button with the index finger on the computer mouse to indicate that the target was present, or a second button with the middle finger to indicate that it was absent.

As mentioned earlier, before the onset of each trial, the subject performed a visuo-motor tracking task which was designed to ensure that his or her ocular fixation was at the center of the display screen. To this end, the fixation point moved up and down at the centre of the screen and the subject's task was to track it with an empty circle whose vertical position was controlled via the computer mouse (see the section *Materials and stimuli*). Trials began only when the subject kept the center-to-center vertical distance between the circle and the fixation point below a maximum of 0.68° for a consecutive duration of 1500 msec. The use of this performance criterion, along with instructions emphasizing the importance of keeping ocular fixation on the fixation point ensured the proper lateralization of the visual search stimulus displays.

The progress of a trial was as follows. The subject performed the visuo-motor tracking task until the aforementioned criterion was reached. This was followed immediately by the disappearance of the fixation point and tracking stimulus, and by the onset of the visual search stimulus display to the left or right of the fixation point. Following the onset of these stimuli, the subject had a maximum of 3000 msec to respond. If the subject failed to respond within this time limit, the trial was terminated. These trials, as well as those in which response time was below 150 msec were rejected and run again later in the session. Following the response, the subject was given an auditory feedback about its accuracy (high pitch sound = correct; low pitch sound = error).

The effect of the three following factors was examined in a factorial design: number of stimuli (4 levels; 2, 4, 6 or 8); hemifield (2 levels; left or right); and target presence (2 levels; present or absent). Trials were distributed randomly within a single experimental session, with the constraint that 15 trials were performed in each condition. Therefore, each subject performed a total of 240 experimental trials. The experiment was immediately preceded by 30 practice trials, for which no data was recorded. The experiment was run in a darkened room.

RESULTS

Correct RT's (Fig. 1) were analyzed with a three-way ANOVA for repeated measures, with number of stimuli, hemifield, and target presence as factors. This analysis shows main effects of the number of items [$F(3, 27) = 42.02$;

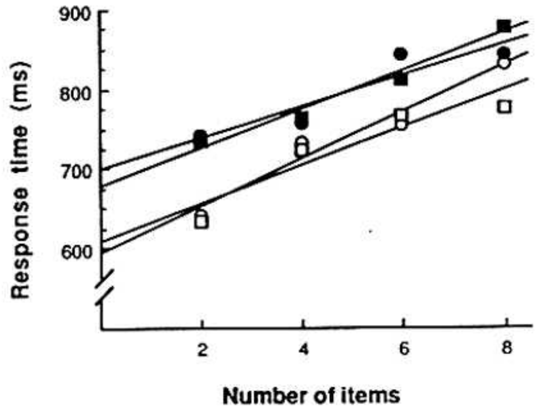

Fig. 1. Mean correct RT as a function of the number of stimuli displayed. Circles, left-hemifield displays; squares, right-hemifield displays; empty symbols, target-present trials; filled symbols, target-absent trials.

$P<0.01$] and of the presence of the target [$F\,(1, 9)=42.21$; $P<0.01$]. No other effect, including, in particular, the number of items × hemifield interaction, reached significance.

Linear regressions of the correct RT's as a function of the number of items displayed were also performed. These linear regressions account for 85 to 97% of the variance due to the effect of the number of items and they all show a monotonic increase of RT's with the number of items displayed. The average slopes of these functions are 24.5 msec/item for left-hemifield displays (29.3 and 19.6 msec/item on target-present and target-absent trials respectively) and 23.6 msec/item for right-hemifield displays (23.4 and 23.8 msec/item on target-present and target-absent trials respectively).

Error rates, which range between 0.7 and 24.0%, correlate positively ($r=0.70$) with RT's, thus showing the absence of a speed–accuracy trade-off. An ANOVA performed on the error rates only revealed a significant main effect of the number of items [$F\,(3, 27)=34.27$; $P<0.001$]. No other main effect or interaction reached significance.

DISCUSSION

The main result of this experiment is that the effect of the number of items upon RT's did not differ between left and right hemifield displays. The most probable interpretation of this observation is that visual search can be controlled within either cerebral hemisphere and the speed at which visuo-spatial attention is shifted from one stimulus to another is similar in both hemispheres. However, this is not to say that no right-hemispheric specialization exists for the processes involved in visuo-spatial attention. Indeed, there have been too many reports that do indicate such a hemispheric specialization to suggest otherwise [see 6 and 23 for a review]. Rather, we propose, along with RATCLIFF [22], that a distinction should be made between low-level (occurring early in visual analysis) and high-level (occurring late in visual analysis) attentional processes. According to RATCLIFF [22], low-level processes are equally represented over both cerebral hemispheres, whereas high-level processes are lateralized to the right hemisphere. As we may reasonably assume that performing spatial shifts of visual attention is a rather low-level capacity, our results are in agreement with this proposal.

Two other aspects of the results are noteworthy. First, data indicating a serial visual search process were observed in conditions that precluded eye movements—no eye movements to individual items were possible in the short display time (150 msec) we used. This finding is in agreement with previous observations which indicated that spatial shifts of visual attention may occur independently of eye movements [18, 19]. Second, the effects of the number of items on RT were similar for target-absent and target-present trials. Such a performance is typically attributed to an exhaustive search process [24]. This result is at variance with the self-terminating search observed in many of the previous experiments that studied visual search of a conjunctive target [7, 21, 25, 26, 28, 29], and in which exploratory eye movements were very likely to occur. From this, we suggest, along with HOUCK and HOFFMAN [13], that the serial self-terminating search of a conjunctive target may be limited to conditions where no eye movements are involved [13, 17].

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