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SPATIAL DISTRIBUTION OF VISUAL ATTENTION: SPLITTING OR SINGLE GRADIENT?

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ABSTRACT

In the present work we investigated whether visual attention could be allocated to noncontiguous regions of the visual field, without covering the area between them. We used a probe procedure in which we measured simple reaction times in response to two spatially separate targets (1.2° and 15.6° of visual eccentricity, respectively) presented, in random order, in the same visual quadrant (condition of lower spatial predictability). On one randomly chosen trial during the presentation of the last 11 trials in an experimental block (consisting of a total of 41 trials), a probe was presented at a location halfway between the targets (7.2°). The reaction times in response to both probe and targets were measured and compared to reaction times collected during another experimental session in which probe and targets were steadily presented, in separate blocks, at their respective spatial location (condition of higher spatial predictability). The present experimental design allowed us to uncouple the influence of visual attention (manipulated by means of the stimulus' spatial predictability) from the sensory effects conveyed by the stimulus' eccentricity. When the eccentricity effects were taken into account, we observed a shorter reaction time in response to the probe in comparison to reaction times in response to the targets. These results agree with a unitary focus of visual attention distributed over the visual field according to a gradient model.

Several models of visual spatial attention have been proposed in the last decades. In most of them it is assumed that attention enhances the efficiency of visual processing. Posner (1980) proposed the *spotlight metaphor*, in which the focus of attention is conceived as a beam that illuminates the region of the visual field chosen to receive enhanced processing. The spotlight metaphor had been previously employed by James (1950/1890), Descartes and probably by the ancient Greeks (see Neumann, 1996; Cave & Bichot, 1999). Eriksen and colleagues (Eriksen & St. James, 1986; Eriksen & Yeh, 1985) proposed a variation of this metaphor: the *zoom lens model*, in which a scale adjustment was added. According to this model, there is an inverse relationship between the size of the attentional focus and the processing efficiency, although the resource distribution is uniform inside the focus. An important point of both models is that they assume the view of a unitary focus of visual attention that cannot be split between noncontiguous locations in visual space.

An alternative metaphor is the *gradient model* (Downing & Pinker, 1985; LaBerge and Brown, 1989). Here, like the zoom lens model, the focus size is variable but the attentional resources are concentrated in the center of the attended area and gradually decrease with the distance from the center. Evidence for this model was also found in eletrophisiological studies

(Mangun & Hillyard, 1995). Although such an attentional gradient could cover a large area, some defenders of this model assume that attention can be divided over the visual field. LaBerge and Brown (1989) stated that the attentional gradient could assume two peaks formation, corresponding to two stimuli locations. Indeed, previous studies (Shaw & Shaw, 1977) indicated the possibility of attentional allocation simultaneously to distinct locations of the visual field in order to optimize performance. An attentional switching could, however, account for those results. Participants could be focussing only on a single location on each trial and switching between the two locations on a trial-by-trial basis (Cave & Bichot, 1999).

In order to test the hypothesis that visual attention can be divided, Castiello and Umiltà (1992) performed a series of experiments employing a variation of Posner's procedure (1980). Reaction time (RT) measures were made for targets that appeared inside two empty boxes (which served as cues) located bilaterally in the horizontal hemifields. They interpreted their data as indicating a splitting of the attentional focus. However, McCornick and colleagues (McCornick *et al*, 1998) pointed out that Castiello and Umiltà's results could be accounted for either by a single attentional focus that encloses both cued locations or by the switching of the attentional focus between these two locations. McCornick and colleagues (1998) found that when the two boxes were simultaneously presented as cues, the RTs in response both to targets (presented inside the boxes) and to probes (halfway between the boxes and the fixation point) did not differ significantly. These data suggest a single focus of attention that includes both cues and the region in between. Because they did not find any difference between RTs in response to the targets and to the probes, they concluded that their results were consistent with the zoom lens model, in which the distribution of resources inside the attentional focus is uniform.

In the present study we attempted to further examine whether visual attention can be allocated to noncontiguous regions without covering the area between them. By means of RT measures, we assessed the latency of manual responses to two flashing stimuli separated by 14.4 degrees of visual angle (targets), under two different conditions of spatial predictability. The use of a probe stimulus allowed the measure of RTs in response to visual stimulation in an area located between the two targets, leading to a qualitative evaluation of the spatial profile of attentional distribution.

METHOD

Eight naïve volunteers participated in these experiments, which were reviewed and approved by the Committee on Research Involving Human Subjects, Institute of Biomedical Sciences, University of São Paulo. All volunteers had normal or corrected-to-normal vision. They were seated in front of a computer screen, in a sound-attenuated, dimly lit room, and instructed to maintain stable eye position at a central fixation point during the task. To maintain stable head position, a chin and forehead rest was used so that the distance from the observer's eyes to the screen was kept constant at 57 cm. Eye position was monitored by a video camera.

On each trial, a fixation point (FP) was presented in the center of the screen. After a random interval between 800-1800 ms, a stimulus (a full square subtending 0.3° of visual angle and luminance of 21.4 cd/m^2) appeared at one of three eccentricities: 1.2° or 15.6° (targets) and 7.2° (probe). There were two experimental conditions rendering two levels of predictability. On the first condition (RANDOM) the target appeared, during each block, at two possible eccentricities (either 1.2° or 15.6°) randomly chosen from trial to trial (leading to a condition of lower spatial predictability). After the 30th presentation, a probe was presented, at an eccentricity of 7.2°, in one trial randomly chosen among the next 11 trials. In the second experimental condition (FIXED), probe and targets were steadily presented, in separate blocks, at their respective spatial location (leading to a condition of higher spatial predictability). The 4 visual quadrants were tested in separate sessions (6 sessions each quadrant). In all experimental trials, the observer had to fixate on the FP and respond as fast as possible to the stimulus presentation by pressing an optic key with the dominant index finger (Fig. 1).

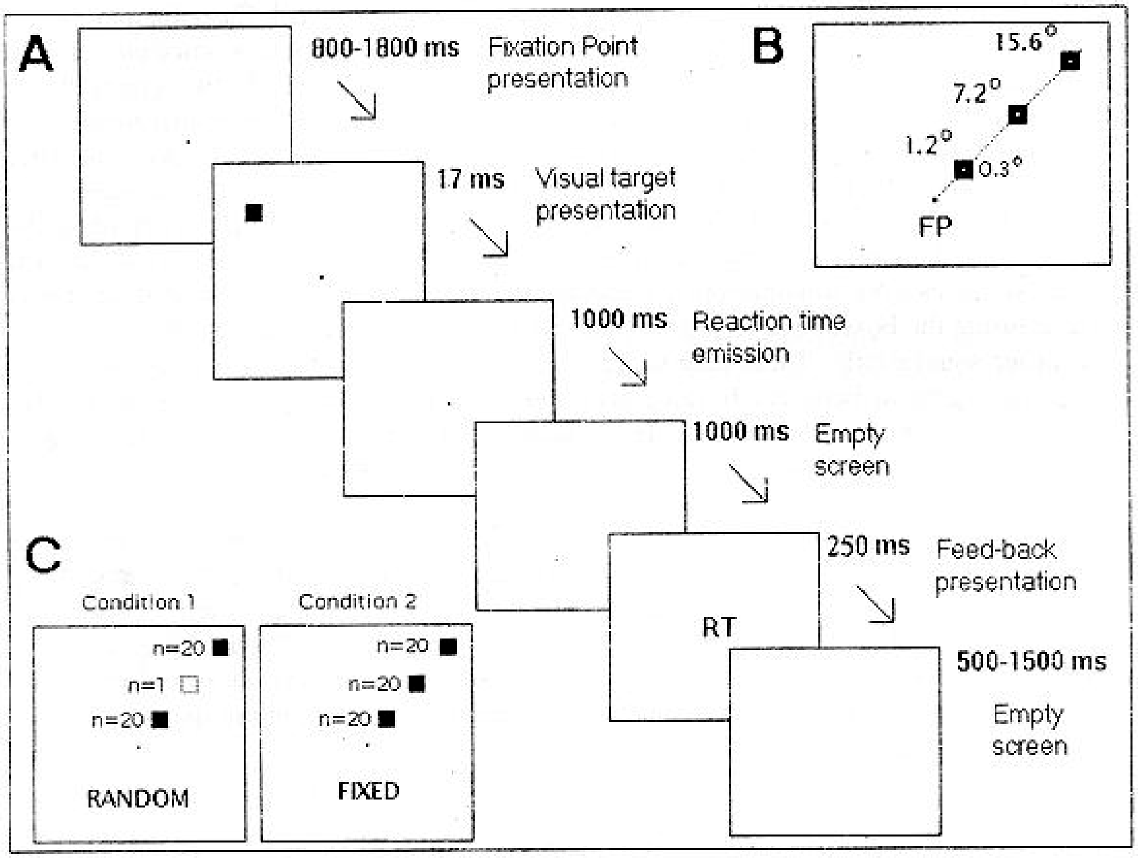

Figure 1. (A) Temporal sequence of events. (B) Spatial display of fixation point (FP) and target (only one target was presented in each trial). (C) Predictability conditions. In Condition 1 (RANDOM) the target appeared in one visual quadrant at two possible eccentricities (1.2° and 15.6°). After the 30th presentation, a probe appeared at 7.2° of eccentricity in one trial randomly chosen among the next 11 trials. In Condition 2 (FIXED), target and probe appeared always at the same position during the block.

RESULTS AND DISCUSSION

The median of RTs was calculated for each experimental condition and each participant. These values were entered into a two-way repeated-measures analysis of variance with factors *Predictability* (FIXED and RANDOM) and *Eccentricity* (1.2°, 7.2° and 15.6°). The analysis was followed by pairwise comparisons (Tukey's HSD test), with significance level set at 5%. The ANOVA showed a main effect for both factors [*Predictability*: $F(1,7) = 18.33$, P =

0.0036; *Eccentricity*: $F(2,14) = 13.48$, $P = 0.0005$], and a significant interaction between them [$F(2,14) = 12.95$, $P = 0.0006$]. Despite the fact that both predictability conditions (FIXED and RANDOM) shared a very similar sensory setting, a significant difference between them was found, possibly related to the different levels of attentional resources assigned to these two conditions. Therefore, the presentation of the targets at randomly chosen locations apparently had the effect of changing the spatial allocation of visual attention, leading to an increase of the RTs (Fig. 2A).

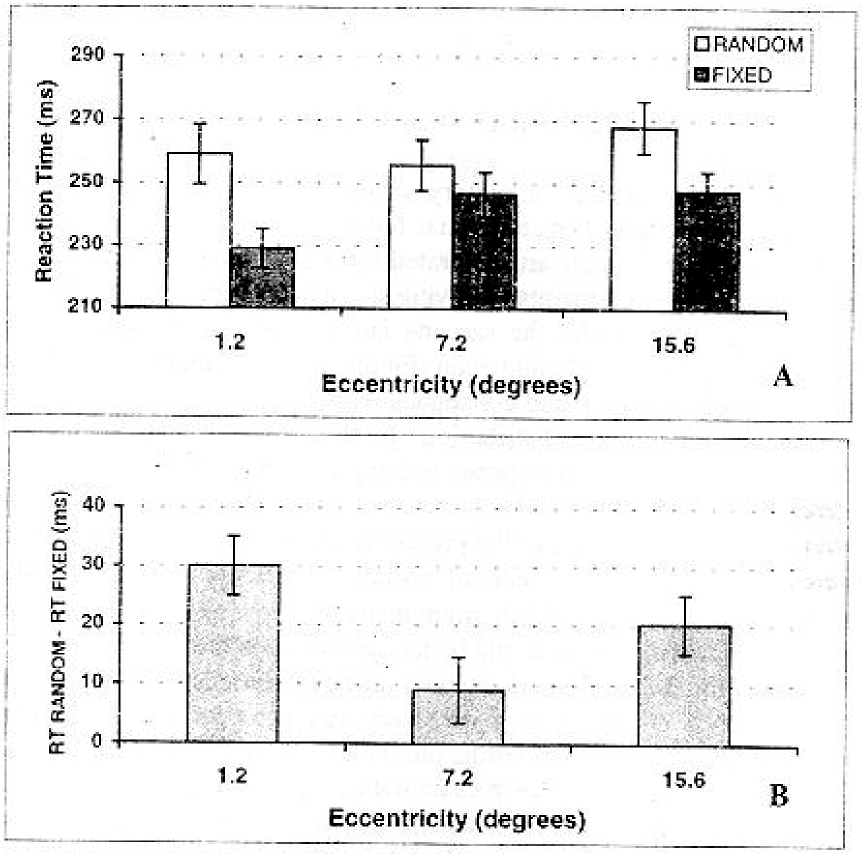

Figure 2. (A) Mean reaction times (± s.e.m.) in response to targets (1.2° and 15.6°) and probe (7.2°) for both predictability conditions (Random and Fixed). (B) Values of ΔRT obtained by subtracting the RTs measured in the FIXED condition from RTs measured in the RANDOM condition, for each eccentricity separately.

In order to account for the influence of the eccentricity on the RTs, we subtracted the values obtained in the FIXED condition from the values obtained in the RANDOM condition, for each eccentricity separately. An additional one-way ANOVA compared the differential RTs ($\Delta RT = RT_{RANDOM} - RT_{FIXED}$), which represent the specific contribution of the stimulus' spatial predictability. We found a main effect of Eccentricity [$F(2,14) = 12.95$, $P = 0.0006$], and the post-hoc analyze showed that the ΔRT observed at 7.2° (probe's eccentricity) was significantly shorter ($P < 0.05$) in comparison to the other two eccentricities (1.2° and 15.6°). The mean ΔRT in response to the probe was shorter in comparison to the targets even though the observers did not expect the presentation of a stimulus at the probe's location (Fig. 2B).

To test the possibility that participants might be learning the probe's appearance and location, leading to a change in the observer's attentional set, we analyzed the temporal profile of RTs in response to the probe throughout all sessions. A one-way ANOVA, followed by a Tukey's HSD test, did not show any significant difference between the RT in response to the presentation of the first probe and the RTs in response to the following 23 probe presentations ($P > 0.918$). Additionally, a linear regression applied to the same data set resulted in a slope not significantly different from zero ($P > 0.10$), meaning that no decrease in RTs in response to the probe presentations was observed.

GENERAL DISCUSSION

These results clearly suggest a unitary focus for the spatial distribution of visual attention. According to this view, the attentional focus cannot be split in two noncontiguous regions, even when the visual targets are separated by a large intermediate area. Evidence of this fact can also be found in experiments involving saccadic eye movements. When two targets are presented in the same hemifield, the saccade lands at an intermediate position between them, leading to the "*global effect*" phenomenon (Findlay, 1982; Findlay & Gilchrist, 1997).

Differently from McCornick and colleagues' conclusions, our results point out in favor of a gradient model of attentional distribution. In their experiments, they did not find a significant difference between RTs in response to the probe and RTs in response to the targets. This led them to conclude that attentional resources were uniformly distributed inside the focus, as is assumed in the zoom lens model. In the present findings, the mean ΔRT in response to the probe, after taking into account the effects of visual eccentricity, was shorter than the mean ΔRT in response to the targets. This result strengthens the view of a gradient model, in which the peak of the attentional distribution would be located between the targets.

Castiello and Umiltà (1992) work favored an object-based view of visual attention. In their words, "the presence of objects is a necessary condition for allowing control over the width of the attentional focus. In other words, observers can focus attention on objects but not on empty regions of space" (p. 847). The present data suggest the opposite. The probe location was an empty region of space, and nonetheless encompassed the peak of the attentional distribution. It is conceivable that the visual attention might be split only between locations that lie in opposite hemifields, because the possible existence of two independent attentional mechanisms located in opposite cortical hemispheres (Ladavas, Petronio & Umiltà, 1990). This possibility would not be in contradiction with the present findings, and further work should to be done to clarify this issue.

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