Center of mass attracts attention

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Using the spatial cueing technique, this study demonstrates that the center of mass (centroid) of a visual scene has a special ability to attract attention even when there is no object presented at this location. Four boxes formed an imaginary square and were presented to the left or right hemifield. After the cueing in one box, a target appeared in one of the four boxes and, in addition, at centroid. Fastest reaction times were observed at centroid, irrespective of whether this centroid was also occupied by a box. Reaction times at the uncued locations varied according to their relative positions to centroid and fixation. No inhibition of return effect was observed when the cue was at centroid. *NeuroReport* 17:85–88 © 2006 Lippincott Williams & Wilkins.

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Introduction

In a typical picture of our galaxy, our attention can be involuntarily summoned to the center of the galaxy, where most stars seem to congregate. Salient objects or features in the visual field may capture attention [1–4]. By measuring the effect of inhibition of return (IOR) in spatial cueing [5,6], we demonstrate that the center of mass (centroid), which is composed of several objects, has a particular ability to attract attention, even when there is no object presented at the center itself. This 'empty' center functions like an invisible star, its gravity attracting attention across visual space.

In most studies of attention, the center of a visual field is occupied by stimulus or by an eye fixation sign. The attraction of centroid and its attentional effect on stimulus processing are confounded by object-based attention [7,8] or by the hypothesized effect of fixation, which assumes that attention tends to return to the fixation location after it is released from capture by a salient peripheral stimulus. Several studies, however, suggest that the center of a visual field has a special status in eye movement, with saccades often landing near the 'center of gravity' [9–17]. Zelinsky *et al.* [17], for example, examined fixation patterns in a simple search task using natural images of objects. Surprisingly, most initial saccades were directed toward the center of the scenes even though no objects ever appeared there. This pattern of performance was attributed to the averaging of visual signals across the scene [16]. Given that attention shift and eye saccade are closely coupled and may share a common functional network in the brain [18–20], one might predict that the center of gravity may also function in a special way in attracting attention.

In fact, one study on unilateral visual neglect in patients [21] suggested that this may indeed be the case. The patients' performance in detecting a target presented to the neglected left visual field was worse when the target was accompanied by distractors presented to the right visual field than when it was presented alone. If the target was accompanied by distractors in the peripheral region of the neglected hemifield, however, the patients' performance improved. This finding suggests that distractors presented in the neglected hemifield partially attract attention to that field and this shifts centroid of the stimulus array towards the left, making centroid closer to the target. As centroid attracts attention, target detection is thus facilitated.

This study examines directly whether centroid has a special status in attracting attention. To achieve this aim, it is crucial to separate the potential effect of center-based attention from other effects, such as those produced by eye fixation. Therefore, we put objects (boxes) at the four corners of an imaginary square but presented the square on either the left or the right side of fixation. To measure the effect of centroid on attention in this global configuration, we took advantage of the IOR effect in spatial cueing [5,6], presenting the cue and target at the same or different locations. The IOR effect refers to the finding that responses to the target at a precued location are slower than responses to the target at an uncued location if the stimulus onset asynchrony between the cue and the target is longer than 250 ms. It is hypothesized that attention, having recently been removed from the periphery, is subsequently inhibited from returning there [5,6]. In this study, the differences in reaction times (RTs) to the target presented at uncued boxes and at centroid were taken as measures of the efficiency of attentional orienting. Target detection should be the fastest when it is presented at centroid, if centroid is special in attracting attention.

Overview of the experiments

Two sets of experiments were conducted, one (experiments 1A and 1B) with the four boxes at corners while the other (experiments 2A and 2B) had an additional box at centroid. The purpose of running the latter experiments was to rule out the possibility that the potentially fastest RTs at centroid in experiment 1 were because of the lack of masking or crowding between the box and the target at this location. The location of fixation sign was manipulated such that it was either in the middle between boxes at the midline of the visual field (Fig. 1a) or 2.9° away from this middle point (Fig. 1b). We hypothesized that there is a general tendency of attention moving back to fixation after it is released from capture by the cue at a location away from fixation (i.e. box C or D). Moving the fixation sign away from the middle point would make the box near fixation (i.e. box B) closer to the path of attention momentum [22] than the diagonal box (e.g. box A). Thus, if RTs to the target in the diagonal box were faster than RTs to the target in the box near fixation, it was not simply because the target in the former case received more attention owing to the attraction of fixation than the target in the latter case.

Given that fixation could exert a strong influence on attention shift across space, we differentiated the cued location in experiment 1 into two types, one near fixation (boxes A and B) and one away from fixation (boxes C and D). If a cued box was near fixation, the attention shift to the diagonal box was against the hypothesized attraction of fixation; if the cued box was away from fixation, the attention shift to the diagonal box was generally congruent with the attraction of fixation.

In all the experiments, the location of the target could not be predicted by the cue. In experiment 1, the cue could appear in one of the four corner boxes while the target could appear in equal probability in these four locations plus centroid. The cue in experiment 2 could also appear at centroid, which was occupied by a box. If centroid is indeed special in attracting attention, we should be able to demonstrate directly its impact on target processing – by observing the fastest RTs at this location. Moreover, this effect should not change according to whether there is an object presented at centroid.

Method

Participants

A total of 75 undergraduate students at Peking University were tested, with 16, 18, 21, and 20 each for the four experiments. They had normal or corrected-to-normal vision and gave their informed consent to participate in the study.

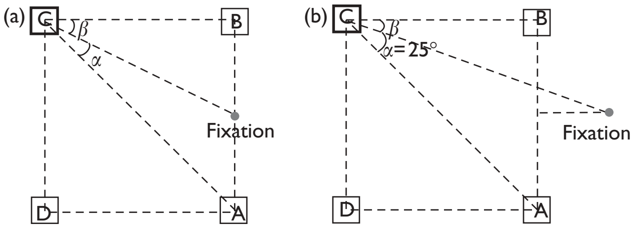

Fig. 1 Presentation of a stimulus array on the left hemifield. Boxes A and B are near fixation and boxes C and D are away from fixation. The thickened box C represents a cue while the target appears, in equal probability, at C (cued), B (the uncued location near fixation), A (the diagonal location), D (the location away from fixation) or at centroid. Fixation sign is in the middle between boxes at the midline of the visual field (a) or is 2.9° away from this middle point (b). Dashed lines and letters were not presented in actual experiments.

Design and procedures

The two sets of experiments had similar designs with two within-participant factors. The first factor was cue location, with the cued boxes either near fixation or away from fixation. The second factor was the location of the target, which was either in the cued box (e.g. box C in Fig. 1), the uncued box near fixation (box B), the diagonal box (box A), the box away from fixation (box D), or at centroid. Experiments 2A and 2B had an extra cue location at centroid. Each experiment consisted of a single practice block and four test blocks. Each test block had 160 critical trials and 40 catch trials in experiments 1A and 1B and 200 critical trials and 50 catch trials in experiment 2A or 2B. Cue location, target location and visual hemifield were balanced in each block. Catch trials were identical to critical trials except that no targets were presented and participants were supposed to withhold response.

Each trial consisted of a series of displays on a black background. Participants were first presented with a fixation sign at the center of a computer screen for 600 ms, accompanied by four (or five in experiment 2) empty boxes presented at the left or right side of fixation. The outlines of one of the boxes became thicker and brighter for 100 ms. After 400 ms, a target (a '+' sign) appeared in one of the five target locations. The stimulus onset asynchrony of 500 ms between the cue and the target was selected so that the IOR effect could be observed in spatial cueing. The target remained on the screen until a detection response was made or until 2000 ms elapsed. No target would appear in catch trials and participants were supposed to withhold responses. Each box measured 1° of visual angle at a viewing distance of 57 cm. The center-to-center distance between two adjacent boxes was 6°. The target '+' subtended 0.5°.

Participants were tested individually in a dimly lit room and were instructed to press a response button as quickly as possible when the target appeared. They were asked to keep their eyes fixated at the central fixation sign although fixation was not objectively monitored. The detection task we used, however, typically does not involve saccadic eye movements [23]. Moreover, many previous studies monitoring eye movement and discarding the contaminated trials find that the pattern of IOR effects was not affected [23]. Furthermore, the less (experiments 1A and 2A) or more (experiments 1B and 2B) lateral presentation of visual stimuli, which were less or more likely to involve eye movement, produced identical patterns of cueing effects (see below), indicating that eye movement was not responsible for the patterns of effects we observed.

Results

One participant each in experiments 2A and 2B was excluded because of excessive false responses to catch trials. For each of the remaining participants, the median RT was calculated for each experimental condition. Preliminary analyses of data showed that the four experiments had identical patterns of cueing effects. Group mean RTs for different experimental conditions, collapsed over visual hemifield, experiment set and fixation distance, are reported in Fig. 2. An omnibus ANOVA was first conducted for RTs, with experiment set and fixation distance as two between-participant factors and cue location and target location as two within-participant factors.

A highly significant main effect of target location [F(4,276)=124.59, $P<0.001$], with target detection much slower at the cued location (357 ms) than at the uncued locations (331, 328, 338 and 316 ms) was observed. This was the typical IOR effect. Importantly, the interaction between target location and cue location was significant [F(4,276)= 30.08, $P<0.001$], suggesting that patterns of cueing effects were different for cues near or away from fixation. Separate ANOVAs were then conducted for the two types of cues.

For cues near fixation, the main effect of target location was significant [F(4,276)=77.44, $P<0.001$]. Bonferroni-corrected pairwise comparisons showed that the overall mean RT at the cued location (355 ms) was significantly slower ($P<0.001$) than RTs at the uncued location near fixation (325 ms), the diagonal location (333 ms), the location away from fixation (342 ms) and centroid (315 ms). Importantly, comparisons between RTs at the four uncued locations all showed significant differences ($P<0.001$ or $P<0.005$). This pattern of cueing effects did not vary significantly over the experiments, although the interaction between target location and fixation distance was marginally significant [F(4,276)=2.28, $0.05<P<0.1$].

For cues away from fixation, the main effect of target location was also significant [F(4,276)=125.18, $P<0.001$], with slower RTs at the cued location (360 ms) than at the uncued locations ($P<0.001$). Further pairwise tests showed that, at the four uncued locations, RTs at the location near fixation (338 ms) and the location away from fixation (335 ms) were equally fast ($P>0.1$). Both of them, however, were slower ($P<0.001$) than RTs at the diagonal location (323 ms) and at centroid (317 ms). Importantly, the difference between RTs at the two latter locations was also significant ($P<0.05$).

Analyses of RTs to the target were also conducted for cues at centroid in experiment 2. An eccentricity effect was found, with RTs at the location away from fixation (353 ms) slower than RTs at centroid (344 ms, $P<0.05$) or at the location near fixation (340 ms, $P<0.001$). The latter two did not differ from each other ($P>0.1$). Thus, there was no IOR effect when the cue was at centroid.

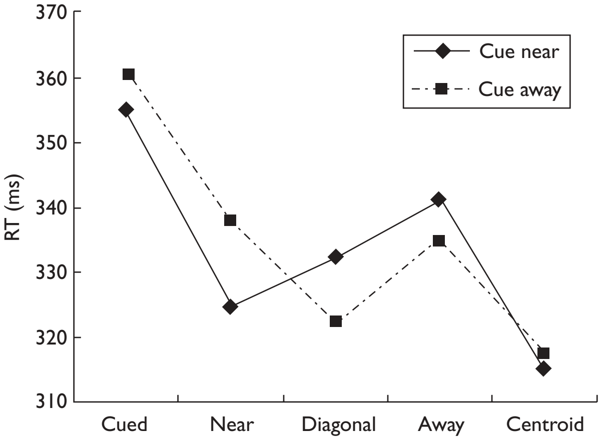

Fig. 2 Mean reaction times (RTs) (ms) collapsed over the four experiments.

Discussion

When the cue was at the location away from fixation (e.g. box C in Fig. 1), target detection at uncued locations showed a clear advantage for the diagonal location than the location near fixation or away from fixation (Fig. 2). Moreover, target detection at centroid was the fastest compared with all other locations. This pattern of effects did not change with respect to the fixation distance and the presence or absence of an object at centroid. Clearly, these effects cannot be explained simply by the distance between the cue and the target or between fixation and the target, as locations with the same distance could have different RTs, and locations with the shortest and longest distances could all have the fastest RTs. Instead, they suggest that the centroid of a visual field has a special ability in attracting attention, facilitating the processing of stimulus presented there. Moreover, the attraction of centroid and the attraction of fixation interact to help the shift of attention across space.

When the cue was at the location away from fixation (e.g. box C in Fig. 1), attention was naturally pulled by two forces after it was released from capture by the cue: centroid and eye fixation. These two forces were largely congruent as the directions of their attention momentum paths from the cue were similar. Centroid produced the fastest RTs to the target, and it helped to produce the second fastest RTs at the diagonal box (e.g. box A). Eye fixation could have also played a role in attracting attention along the direction. This role became apparent as RTs were faster at the location near fixation (e.g. box B) than at the location away from fixation (e.g. box D). The faster RTs at the diagonal location than at the location near fixation also demonstrated the effect of centroid, which was *on* the path from the cue to the target. Both centroid and fixation could produce some kind of 'gravitational sling-shot', accelerating attention movement from the cue to the target if centroid or fixation is on or near the path, just like the gravity of Jupiter accelerated the speed of the spacecraft Cassini on its way to Saturn. This idea of 'gravitational sling-shot', however, needs further, independent tests.

When the cue was at the location near fixation (e.g. box B), the attraction of centroid and attraction of fixation were largely incongruent, that is, with large angels between the paths of attention momentums from the cue to centroid or fixation. The fastest RTs at centroid demonstrated again the strength of centroid in attracting attention. The second fastest RTs were now at the location near fixation (e.g. box A) rather than at the diagonal location (e.g. box C), suggesting that when both fixation and centroid are on their respective attention momentum paths, fixation could play a stronger role in accelerating attention movement.

The finding of no IOR effect when the cue was at centroid is consistent with the argument that centroid is special in attracting attention. It is possible that, compared with other locations, attention is more likely to dwell here and/or to return to this location after the cueing. This would reduce or eliminate the inhibitory effect.

A question is why centroid should have such an inherent advantage in attracting attention. To account for the saccadic data concerning centroid, it is commonly assumed that in programming the landing positions of saccades, visual signals from given objects or regions are pooled and the eye is initially directed to configurations of objects rather than individual items [16,17]. Thus, the entire search display is grouped and encompassed in this initial parallel processing and the averaging of signals makes centroid particularly salient. The same principle may be applied to covert attention. As the target could appear in equal probability in one of the five locations over the whole field, these objects and the regions covered could be perceptually grouped, and form a coherent configuration. Averaging signals from these locations highlights centroid in the saliency map [24], prompting it to capture attention. Given that salient objects or features *are* typically put in the center of the visual field for closer inspection, attending to centroid has an evolutional and biological advantage, just as the development of IOR in visual orienting [5,6].

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