Inhibition Effect of Spatial Attention on Surroundings in Discrimination Task

Linyan Xue, Kun Liu, Shipeng Zhang, Kun Yang*

ABSTRACT

The cue size effect which is characterized as a reverse relationship between the cue size and the detection speed is regarded as a proof for adjustment of the attentional field according to the cue size. This effect was mainly found in detection experiments. As several studies have shown that cues had discrepant effects in visual detection and discrimination task, it's natural to ask whether cue size effect still exist in discrimination task. The probability exists that the influence of cue size differ in these two basic types of behavioral tasks. To solve the problem, we assessed the interference of surrounding ring on discrimination at its center with a multiple cuing design. The results show that in distributed neutral condition when no single place gains overwhelming advantage from attention, ring size has a positive correlation with the discrimination speed. However, when the exact place of impending target is cued and spatial attention takes effect, variance in surrounding ring size makes no difference on discrimination. This type of result pattern doesn't depend on what is discriminated (orientation or brightness) or how the spatial attention is induced (by peripheral ring cue or central symbolic line cue). Our findings add evidence to the view that detection and discrimination should not be considered as the same. We also propose that with sufficient time, attention suppresses the impact from the vicinity.

Key Words: Cue Size Effect, Multiple Cues, Discrimination, Peripheral Vision, Crowding

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Introduction

Our eyes are flooded with numerous information which exceeds the limit that our brain can handle. Attention is a crucial mechanism of the brain to select important information for further processing. The spatial extent of attention, known as attentional field, can be adjusted according to the task requirement and the environment just like a zoom lens.

According to this widely accepted zoom lens metaphor (Eriksen *et al.*, 1986), the smaller the attentional field, the higher the processing efficiency. As cues of various sizes can be used in experiment, if small cue induces attentional scope of small range, it should lead to more benefits from attention than a big cue does which provokes much more diluted attentional field. Based on this idea, several previous studies (Turatto *et al.*, 1998; Castiello *et al.*, 1990; Turatto *et al.*, 2000; Umiltà, 1998) used differently sized spatial cues to indicate the possible position of an impending target stimulus, then measured the subjects' reaction time (RT) to detect the target. They found an inverse relationship between size of the cue and subsequent RT of target detection, which they named as 'cue size effect' and claimed as empirical support for zoom lens model. Some studies compared patients with normal people using similar paradigms, and revealed that cue size did not have same effect in these two groups (Facoetti *et al.*, 2003; Facoetti *et al.*, 2000; Mizuno *et al.*, 1998). However, a later research (Panagopoulos *et al.*, 2006) adopted three mea sures (simple RT, search RT and Temporal Order)

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to examine the cue size effect. The study found that the influence of cue size depended heavily on the experiment design and the cue-target stimulus onset asynchrony (SOAs), thus the cue-size effect was not a robust phenomenon.

This revealed cue size effect is quite appealing with an implication that spatial range of attention can be manipulated by merely varying cue size, especially when some latest work demonstrated that the spatial scope of attention was a key factor to determine how attention modulates contrast processing and perception (Herrmann *et al.*, 2010; Itthipuripat *et al.*, 2014; Reynolds *et al.*, 2009). Unfortunately, until now, whether the 'cue size effect' is a true strong effect of attention modulation is still on debate. Its origin also hides in shadow.

Besides, detection and discrimination are two fundamental visual functions. Many psychophysical investigations involved both detecting and discriminating stimuli found discrepancies in performance between these two types of tasks (Lubbe *et al.*, 1985; Smith *et al.*, 2004). An electrophysiological research even proved that detection and discrimination of visual motion were based on different populations of neurons (Hol *et al.*, 2001). However, the important distinction between detection and discrimination was not fully considered in previous studies on cue size effect.

On account of all mentioned above, systematically research is needed to investigate whether the cue size effect can be generalized to other type of tasks, particularly discrimination, and to explore its contributing factors. Furthermore, given the reported differences between discrimination and detection, it's also necessary to examine whether the discrepancy of task types can be reflected on the cue size effect.

In the current study, we used a multiple cuing paradigm to assess the effect of cue size in discrimination tasks Comparisons between different conditions (Distributed Neutral & Cue) and different cue sizes (small & big) were carefully conducted. Unlike the cue size effect reported in former simple detection tasks, the results revealed that varied cue size had no significant impact in focused attention condition. However, under neutral condition, there was an influence related to cue size: discrimination speed was faster after a big cue in contrast to the slow rate after a small cue, The robustness of key findings was verified in three experiments by applying two types of stimulus (Gabor and flash disk) and two ways of inducing attention (peripheral ring cue and central symbolic line cue).

Methods

Experiment 1

Subjects

Seven subjects (age 22–33 years, 5 male, 2 female) participated in this experiment. All had normal or corrected-to-normal vision and provided informed consent. Experiments were conducted according to the ethical recommendations of the Declaration of Helsinki. All subjects except one author are naïve to the purpose of the experiment.

Apparatus

The stimuli were gen erated by Matlab and the Psychotoolbox software (Brainard, 1997; Pelli, 1997) and presented on a gamma-corrected 24'' monitor (BenQ xl2411t,100Hz). Mean luminance of the screen was 52.61 cd/m2. With head stabilized by a chin rest, subjects sat in a dark room and viewed the stimuli binocularly at a distance of 57cm.

Stimuli and procedure

Subjects should fix at the black cross (0.3°×0.3°; Figure 1) at the center of the screen while performing the task. The fixation cross kept on the screen throughout the whole experiment. Appearance of eight white circles represented the beginning of a trial. The circles had evenly separated centers located at the same eccentricity of 8º. Their diameters alternated between 6ºand 2º. After 400ms of fixation, one of the rings (Cued) or all rings (Distributed Neutral) changed color to red as visual cue. The red's luminance was equal to the luminance of the white. The cue lasted for 300ms then the changed color went back to white. After an interval of 300ms, a stimulus appeared at the center of one of the circles for 50ms. If the cue showed before was one red ring, the stimulus was always presented at the center of the ring that the cue referred to. Hence, the 'Cue' cue was 100 percent valid to make sure subject locate their attention into that region. The stimulus was a Gabor patch (2º×2º, Gaussian window s.d.0.2º) tilted 10ºor -10º to the vertical with 100% contrast. The stimulus and the background circles disappeared simultaneously. The participants were asked to report whether the stimulus was tilted clockwise or counterclockwise to the vertical as fast as possible via corresponding keys.

Another trial began after an ITI randomly chosen from an average probability distribution from 500 to 1500ms with every circle changing its diameters to the value different from last trial, e.g., the circle had a diameter of 6º in this trial if its diameter in last trial was 2º and vice versa.

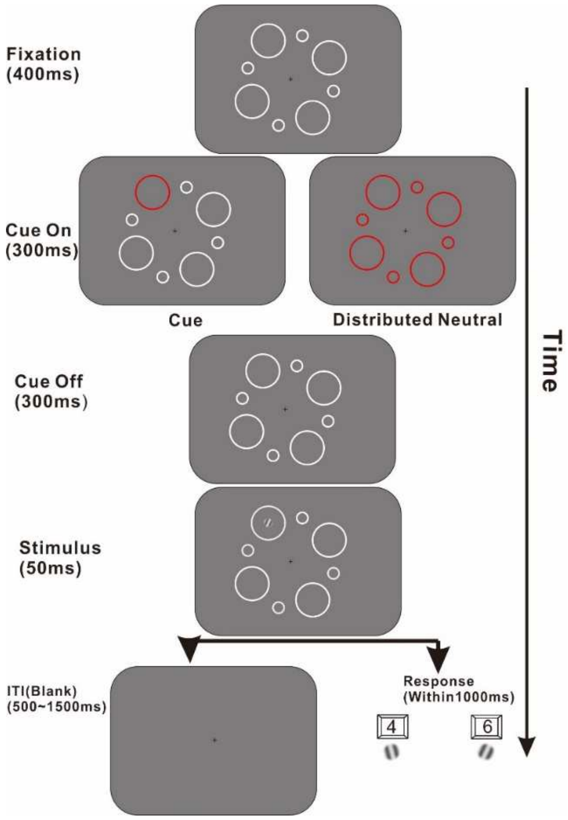

Figure 1. Time sequence of a typical trial

Each trial began with the presence of eight evenly placed iso-eccentric peripheral white circles with diameters alternating between 6º(big) and 2º (small). After the fixation, one circle (Cued) or all rings (Distributed Neutral) turned to red as visual cue. The cue in 'attention in' condition was 100 percent valid in terms of the location of the upcoming tilted Gabor. The participant performed a 2AFC orientation discrimination task on the Gabor patch. For each trial, every circle changed its diameter to the value dissimilar with the one used in the last trial.

Each subject completed five or six blocks (lasting about 1 hour). Each block, the subject should correctly completed 64 trials including different cue types and different ring size with random order. Those trials that had fixation breaks or reaction times longer than 1s or shorter than 150ms were considered as incorrect and were repeated at the end of the block. Only RTs from correct trials were used for later analysis.

Data analysis

Attention modulation index (AMI) was used to evaluate the effect of attention modulation, which was the mean RT difference between Distributed Neutral and Cue trials for a given sized cue, divided by the average of mean RTs of Distributed neutral and Cue:

$$AMI= (RT_{\text{Distributed Neutral}} - RT_{\text{Cue}})/((RT_{\text{Distributed Neutral}} + RT_{\text{Cue}})/2) \quad (1)$$

We calculated cue size effect index (CSEI) as the mean RT difference between big and small sized cue in trials for a given condition (Distributed Neutral or Cue), divided by the average of the mean RTs of the two sized cue and regarded CSEI an indicator of cue size effect:

$$CSEI= (RT_{\text{Small}} – RT_{\text{Big}})/((RT_{\text{Small}} + RT_{\text{Big}})/2) \quad (2)$$

We also recalculated AMI and CSEI divided by the mean RT of all of a specified subject's trials, and got same conclusion (data not shown).

Statistics

Within-participant nonparametric randomization tests (Grubb *et al.*, 2014; Yuval-Greenberg *et al.*, 2014) were used to compute the p values of the differences between conditions or varying sizes. For example, to establish the significance of attention modulation in a given cue size, all correct trials of each subject with this cue size were chosen at first, then the condition labels were shuffled ("Distributed Neutral" and "Cue"). After the shuffling, we calculated within-participant paired difference between these two conditions on the shuffled data. Subsequently, these paired differences across participants were averaged. This procedure repeated 1000 times to obtain a null distribution for mean within-participant changes. At last, the actual mean difference value was compared with the null distribution. The proportion of the null distribution greater than the measured value was reported as the one-tailed p value.

Results and discussion

Errors including eye movements were less than 10 percent of the total trials and were not analyzed.

An individual subject's profile of the RTs in experiment 1 is presented in Figure 2a. Figure 2b shows the averaged population data (Figure. 2b). RTs with attention are significantly smaller than those in Distributed Neutral condition regardless of cue size (population data, $p<0.001$). No difference in RTs is found between the two cue sizes in Cued condition. Conversely, RTs in Distributed Neutral condition show an obvious cue size influence. RTs of small cue (2º) are significantly longer than the RTs of big cue (6º) (population data, $p<0.05$).

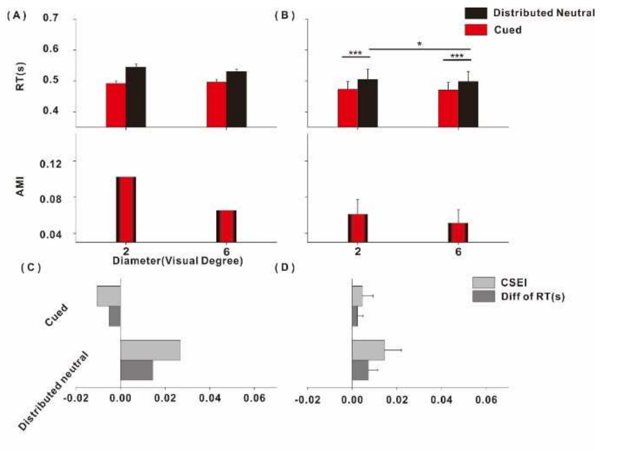

Figure 2. RT, AMI, CSEI and corresponding RT differences in Gabor orientation discrimination task

(A)(C), data from an individual subject. (B)(D), population average data from 7 participants. (A)(B), RT profile and corresponding AMI. (C)(D), CSEI and corresponding RT difference. Short vertical bars represent the SEM.

The RT differences and corresponding AMIs between Distributed Neutral and Cued conditions of two cue sizes (Fig 2a, individual subject, Fig 2b, population) indicate that compared with big cue, small cue leads to larger RT change and attention modulation.

The RT difference between small cue and big cue in Cued condition is smaller than the value got in Distributed Neutral condition. The same trend is kept in the corresponding CSEIs of the two conditions (Fig 2c, individual subject, Fig 2d, population). Notice that for this subject used as an example, the RT difference between the two sizes of cues in Distributed Neutral condition has a positive value as the difference is negative in Cued condition.

Experiment 2

Experiment 2 was conducted in purpose to make more direct comparison to preceding studies which asked subjects to detect the appearance of small disk, and to examine whether the findings found by the discrimination task for Gabor orientation can be reproduced in the discrimination task for disk brightness. And we didn't do any adjustment to make these two types of tasks have same difficulty.

Subjects

Six subjects (age 22–33 years, 4 male, 2 female) participated in this experiment. All had normal or corrected-to-normal vision and provided informed consent. Experiments were conducted according to the ethical recommendations of the Declaration of Helsinki. All subjects except one author are naïve to the purpose of the experiment.

Stimuli and procedure

All settings were identical to those used in experiment 1, except that the target was a flash disk with 0.4º diameter either brighter or darker than the background with equivalent amount. The observers answered whether the target was brighter or darker than the background with corresponding key press.

Results and discussion

Left column and right column of Figure 3 shows separately the data of an individual participant and the data of the averaged population in experiment 2.

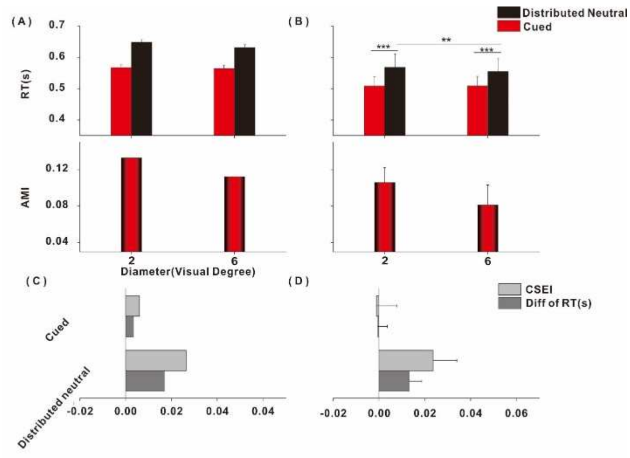

Figure 3. RT, AMI, CSEI and corresponding RT differences in flash brightness discrimination task with peripheral ring cue

Significant differences are found between RTs in Cued condition and RTs in Distributed Neutral condition in both cue sizes (population data, p<0.001). In Cued condition, RTs between the two cue sizes have no difference. In Distributed Neutral condition, RTs from two cues sizes have great difference (population data, p<0.01), showing a RT decrease with the increase of cue size. The AMI of small cue and corresponding RT difference exceed their counterparts of big cue. CSEI in Cued condition and corresponding RT difference are less than their counterparts in Distributed Neutral condition.

(A)(C), data from an individual subject. (B)(D), population average data from 6 participants. (A)(B), RT profile and corresponding AMI. (C)(D), CSEI and corresponding RT difference.

Experiment 3

The form of the influence of ring size in neutral condition was not as same as it was in Cue condition. The cause could lay in the different stimuli patterns in cuing period of the two conditions: all peripheral rings changed color versus only one ring changed color. If that supposition was true, replacing the peripheral ring cue with central symbolic line cue would generate a dissimilar result pattern. The aim of experiment 3 was to examine whether changing the way of could lead to modification of result form.

Subjects

Eight subjects (age 22–33 years, 6 male, 2 female) participated in this experiment. All had normal or corrected-to-normal vision and provided informed consent. Experiments were conducted according to the ethical recommendations of the Declaration of Helsinki. All subjects except one author are naïve to the purpose of the experiment.

Procedure

All settings were identical to those used in experiment 2, except for the cuing period: in neutral conditions, instead of all the rings turning red, we replaced the center cross with a white dot; In Cue condition, there was also no color change but the presence of a short line near to the center cross pointing to the place where the target would appear.

Results and discussion

Left column and right column of Figure 4 shows separately the data of an individual participant and the data of the averaged population in experiment 3.

(A)(C), data from an individual subject. (B)(D), population average data from 8 participants. (A)(B), RT profile and corresponding AMI. (C)(D), CSEI and corresponding RT difference.

Significant differences are found between RTs in Attention In and RTs in neutral condition in both cue sizes (population data, p<0.001). In Cued condition, RTs between the two cue sizes have no difference. In Distributed Neutral condition, RTs from two cues sizes have great difference (population data, p<0.001), showing a RT decrease with the increase of cue size. The AMI of small cue and corresponding RT difference exceed their counterparts of big cue. CSEI in Cued condition and corresponding RT difference are less than their counterparts in Distributed Neutral condition.

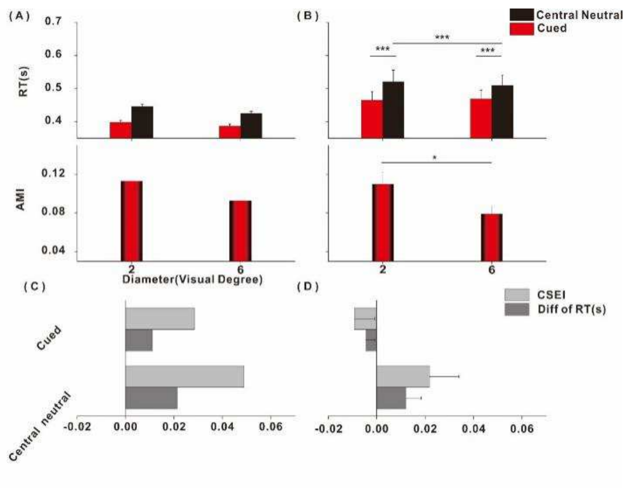

Figure 4. RT, AMI, CSEI and corresponding RT differences in flash brightness discrimination task with central symbolic line cue

General discussion

In the present study, we showed that in typical discrimination tasks, reaction time of discrimination was significantly shortened by focused attention. In the meantime, attention also neutralized the difference of reaction time which was caused by the variance of cue size and was evident in neutral condition. The findings were confirmed by using different types of stimuli and different attention inducing methods.

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Existence of strong attention modulation

As previous studies (McMains *et al.*, 2004) have proved, instead of being a unitary spotlight, attention can be split and distributed to several separated places simultaneously. With the increase of the number of attending locations, processing efficiency at a single location decreases (McMains *et al.*, 2005). So the division of attention cannot be infinite. According to a recent study (Ester *et al.*, 2014), only a small number of discrete locations can be focused on at an instant. The present results are consistent with those findings: there is significant RT reduce from Distributed Neutral condition to focused attention condition in all three experiments. The circles in periphery defined eight separated spots where the subsequent stimulus could appear. In Distributed Neutral condition, subjects needed to keep alert to changes at all these locations at the same time. In the contrary, noticing the state of one place was sufficient in Cued condition. The RT difference between these two conditions represent the benefit of focused attention and the cost of distributed attention.

Strong impact of ring size in distributed neutral condition

The noticeable ring size influence in neutral condition is intriguing. That means occurrence of interaction between surrounding rings and stimuli. The peripheral circles provided no certain information about where the impending stimulus would appear under neutral condition, Hence their function as cues to direct spatial attention deployment was attenuated which made them act more like ordinary objects in peripheral vision. And in peripheral vision, the discrimination of an object can be greatly degraded by its surroundings. This well-known phenomenon, called crowding or lateral masking or lateral interference, was proved to get ameliorated with the increase of the space between the target and the distractors (Bouma, 1970; Pelli *et al.*, 2004). Ring, as a special surrounding, has shown to impair the letter recognition performance although the purpose for using it was to attract attention within a letter string (Averbach *et al.*, 1961). In accordance with those former studies, the RT reduction with the enlargement of surrounding ring in neutral condition existing in the present research indicated the corresponding weakening process of crowding effect.

No impact of ring size in cue condition

Our study shows that when attention is focused, the influence of surrounding circles on discrimination is negligible. We suggest it's caused by the adjustment of attention area, shrinkage of the attentional field to the target location, to be specific, which filtered out the interference of adjacent circles for the discrimination. This explanation is supported by many pas t findings. Previous study (Yeshurun *et al.*, 1998) found spatial resolution was improved by exogenous attention and thought the basis of this promotion was a smaller area for information processing selected by attention. Neurophysiological studies also found the contraction of the cell's receptive field around the attended stimulus(Anton-Erxleben *et al.*, 1985). The furthermost distance between the target and distractors for the crowding effect to take place, termed as critical distance was shown to be shortened by attention (Yeshurun *et al.*, 2010).

Some previous work saw the interference of surrounding ring in focused attention condition. Studies on paracontrast masking revealed that with different SOA or polarity or spatial separation between the target and the ring, a single preceding ring could have varied influence on later judgment of brightness or contours (Breitmeyer *et al.*, 2006; Kafaligönül *et al.*, 2009). It also showed that changing the brightness of circle cue could alter its influence on contrast perception (Schneider, 2006), which should be explained by paracontrast masking, a sensory interaction between the circle and the stimulus instead of by attention modulation (Ling *et al.*, 2007). But we don't think paracontrast masking played an important role in our experiment. First, the effect of paracontrast masking largely depends on SOA and can only last up to 450 ms, much shorter than the SOA (600 ms) used in present research. Second, paracontrast masking produces prolonged inhibition on visibility. Yet, comparison between the neutral condition and Cue condition in our study found no inhibition.

Cue size effect

Previous researches on cue size effect (Castiello *et al.*, 1990; Castiello *et al.*, 1992; Turatto *et al.*, 2000; Umiltà, 1998) mainly concentrated on tasks which required participants to detect whether a single element appeared. The position of the target was always at the center of a cue. Turatto *et al* (Turatto *et al.*, 2000) claimed that by adding a second cue after the first cue but before the present of the target, they found cue size effect in letter discrimination task which expressed as a reverse correlation between the respond speed and the size of the second cue. (See their experiment 2). No second cue existed in our design. And the SOA between the cue and the target in our study was 600ms, however the time interval between appearance of the second cue and the target was 304 ms in their setting. These discrepancies can lead to unlike findings on account o f the fact that cue size effect is not a long lasting phenomenon (Turatto *et al.*, 1998; Panagopoulos *et al.*, 2006). In single target detection task, the effect arose when the SOA between the cue and the target was no less than 66ms and vanished when the SOA was longer than 500ms. Combining our results and previous findings, it's apparent that given enough time, attention can be narrowed towards behavioral relevant place to achieve better performance, meanwhile other items including cues are disregarded. This assumption reconciles with earlier findings which showed the flexibility of endogenous attention and its capability of optimizing performance in texture segmentation task (Yeshurun *et al.*, 2008).

Conclusions

This study investigated the influence of surrounding ring size in discrimination task. When attention was not spatially located in advance, we found a positive correlation between ring size and discrimination speed which is quite different from previous cue size effect. Spatial attention shielded the interference from the vicinity, and promoted the process efficiency.

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