A DIFFERENTIAL EFFECT OF EXOGENOUS AND ENDOGENOUS ORIENTING ON THE SPATIAL DISTRIBUTION OF VISUAL ATTENTION

BY

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Abstract

The location-precuing paradigm establishes two distinguishable forms of spatial cueing: an endogenous cue, a centrally presented indicator, that directs attention to a peripheral location in a goal-driven fashion; and an exogenous cue, a peripheral onset stimulus, that draws attention in a stimulus-driven fashion. Attention gradients, a phenomenon that attention effects on the unattended locations decline with increasing distance from the attended location, is found whether exogenous or endogenous cues are administered under different experimental settings. However, it is argued from the perspective of limited capacity that there may be a differential effect of exogenous and endogenous cues in the allocation of spatial attention. Using EOG electrodes to monitor eye movements, the allocation of spatial attention is measured with response times to recognition of the targets that are presented at different locations following a cue. The results showed that as opposed to endogenous orienting, there was no distance effect found in exogenous orienting.

Keywords: spatial attention, endogenous orienting, exogenous orienting, attention gradient

1. INTRODUCTION

Information abounds in our surroundings; information-processing capacity is, however, limited for the brain. Limited capacity is a sufficient reason for perceptual systems to select which object and/or region of space to process first (Tsotsos, 1997). The general purpose of selectivity is to protect the brain's limited capacity system from informational overload (Allport, 1989). If the brain's capacity were sufficient to process all information that arises from every sense organ at one time, then attention would not be necessary. Therefore, the function of attention is to decide which information will be selected for high-priority processing and further to control the availability of the brain's capacity.

Experimental evidence gathered from different paradigms, such as visual search, response competition, and location-precuing paradigms, has suggested that the algorithm of spatial selection is to enhance the processing of relevant locations and/or to inhibit the processing of irrelevant locations (Yeshurun, 2019). In the location-precuing paradigm (Posner, 1978), two sources of spatial selection—exogenous and endogenous cues—are used to direct covert orienting which refers to the allocating of attention to a

peripheral location without concomitant eye movements. Subjects' attention is directed to one specific location at either left or right of a fixated point by an arrowhead cue presented at the fixated point, which indicates the likely target location, or by an abrupt brightening of a peripheral location. Hundreds of milliseconds after the cue, a target appears either in the cued location (a valid condition) or its opposite location (an invalid condition). The baseline condition is when a cross is presented at the fixated point, serving as a warning signal and not indicating any target location (a neutral condition). It has been well established that reaction times (RTs) to the target are faster in a valid condition than in a neutral condition. This RT difference is called the benefit of precuing, and it results from enhancement of cued locations. In contrast, RTs are slower in an invalid condition than in a neutral condition. This RT difference is called the cost of precuing, and it results from inhibition of uncued locations. The differences between exogenous and endogenous orienting lie in the selective mechanism and time courses.

An endogenous cue is a symbolic indicator (e.g., an arrowhead or a line) presented at the center of the display (also referred to as a central cue), indicating the very likely location of the forthcoming target in the periphery. The facilitation effect of the valid cue on the target detection must be ascribed to the perceptual goal generated endogenously because the target never appears at the center of the stimulus display. In contrast, an exogenous cue is an abrupt brightening of the outline of one location in the periphery (also referred to as a peripheral cue), which is randomly associated with the target location. The shift of attention and processing benefits for the cued location may be initiated by the sudden stimulus onset because subjects are given no reason to expect the target at the cued location.

In addition, the endogenous cue needs to be perceived and decoded to determine which location it indicates, whereas no such translation or decision process is required for the exogenous cue. This distinction may result in the difference between central and peripheral cues in the time course of their facilitation effect on task performance. For example, Cheal and Lyon (1991) found that an exogenous cue produced an optimal performance on the target discrimination when the interval between the onset of the cue and the onset of the target (stimulus onset asynchronies; SOAs) was within 100 ms, whereas an endogenous cue required approximately 300 ms to produce an optimal performance.

The theoretical and empirical distinctions indicate that the determining force of selection can be goal-directed or stimulus-driven (Egeth and Yantis, 1997). In stimulus-driven attention, selection is determined by the properties of the stimulus itself even if they are irrelevant to the current goal of the tasks. In goal-directed attention, observers' knowledge and goals determine where and/or what to select. It is also implied that exogenous orienting is an automatic process (or a bottom-up process), whereas endogenous orienting is a voluntary process (or a top-down process).

A question of interest arising from this distinction is: what is the differential effect of exogenous and endogenous cues on the processing of uncued portions of the visual field? A general approach to this question is that following the cue, a target is then presented at different spatial separations from the cued location. The allocation of spatial attention is measured with response times to recognition targets at different locations. For example, Posner, Nissen, and Ogden (1978) found that response times to the stimulus in an expected position were faster than to the same stimulus at an unexpected position. It seemed that directed attention was focused in a spatially restricted region (less than 1°). Hughes and Zimba (1985) adopted this precuing method to explore how wide attentional focus could be across the visual field. In contrast to Posner et al.'s (1978) finding, they proposed the meridian boundary model. According to this model, rather than 15 restricted locations, attention was directed to large regions of the visual field, where regions were visual hemifields or visual quadrants defined in terms of the vertical and/or horizontal meridians. In their study, subjects were required to direct their attention by following a central cue to the locations at either a 2° or a 6° visual angle from fixation. The subjects made a simple

response to a probe (a luminance onset) occurring at either the cued location 89% of the time, the opposite location across the vertical meridian, or several other locations along the horizontal meridian within the same or different hemifield of the central cue. Hughes and Zimba believed their results showed that directed attention could not be allocated to a specific location; rather, it would activate the whole visual hemifield.

However, since the cost and benefit of RTs for each probe location was based on the ratio of RTs for uncued trials over RTs for cued trials, this index might not be sensitive enough to show the RT difference over spatial distance separated from the expected location. In addition, they didn't present catch trials, so that subjects tended to anticipate responses and thus had very quick response times (most of data were below 300 ms). Therefore, the data may not have enough sensitivity to reveal the difference of attention effects on each probe location.

Klein and McCormick (1989) tested the meridian boundary model. They precued subjects endogenously to attend to one of the corners in an imaginary square centered at fixation. Suppose an arrow cue pointed to the upper left of the square. An invalid location could be one of the following three types: (A) the lower left that was within the same hemifield as the cued location (across a horizontal meridian), (B) the upper right that was within a different hemifield from the cued location (across a vertical meridian), and (C) the lower right that was the opposite location diagonally across from the fixation point. If an entire visual hemifield was activated, as Hughes and Zimba (1985) had proposed, then a simple reaction time to a luminance increment in location A would be similar to valid RT and faster than that in location B and C, both of which should be equivalent. The results showed that all three invalid locations behaved similarly. This pattern strongly contradicted the hemifield activation hypothesis. Further, Klein and McCormick proposed a midlocation placement strategy to explain what they found in an experiment in which they fixed the invalid location in one block of trials.

The midlocation placement strategy assumes that locating attentional focus depends on the angular difference between valid and invalid locations. If valid and invalid locations are in the same direction (e.g., above or left), then attention focus is located in the middle location between the two. When an invalid location is moved towards the diagonal opposite of a valid location, attentional focus would be moved towards the valid location and further away from the invalid location (C). Because invalid location A or B is fixed in one block of trials, subjects might just attend to a midlocation between the cued and potentially invalid locations. According to this hypothesis, it was predicted that the benefit for the valid location would be reduced and the RTs for invalid location A would be equivalent to the RTs for invalid location B, but faster than invalid location C. The results were consistent with the prediction of the mid location placement hypothesis that attentional focus could be located at the mid location no stimulus was located.

Unlike the mid location placement hypothesis, the attentional gradient model proposes that attention is distributed like a gradient

centered at the attended location (or precued location). Accordingly, the effects of attention on response performance decline with increasing distance from the attended location. It is also referred to as the distance effect. Obviously, the distance effect has been found in Klein and McCormick's results. Downing and Pinker (1985) first demonstrated the conceptualization of attention gradients. In one experiment, subjects had to detect a luminance increment that occurred in one of ten boxes located at either left or right of the fixated point on the horizontal meridian. The eccentricity of boxes varied from 1.25° to 11.25°. A digit cue (from 1 to 10) presented at fixation identified one of ten boxes as a high-probability location and the remaining nine boxes served as low-probability locations. Downing and Pinker found that the magnitude of RT costs on the unexpected locations was a function of the distance separating the expected from unexpected locations. They suggested that the allocation of attention to a spatial location produced a gradient of attention whose peak was centered at the expected location. Recently, Klatt and Memmert (2021) found that the spatial attention was distributed along its horizontal, vertical, and diagonal meridians to a larger extant.

Henderson and Macquistan (1993) examined exogenous orienting. In their study, the stimulus display had eight possible target locations arranged around an imaginary octagon with a radius of 9° visual angle, in which any two adjacent locations have equal distance (7° visual angle). After a peripheral flash was presented, subjects had to complete a letter discrimination task ("X" or "0"). The cost for each invalid location was based on a reference to neutral trials. The results showed that performance in the cued location was the fastest (and the most accurate), followed by the closer invalid location (whether they were inside- or outside-quadrant locations), and worst at the farthest invalid location (diagonal invalid). As they suggested, the findings supported the gradient model of attentional allocation.

The only shortcoming in the study is that they did not monitor subjects' eye movements instrumentally. Although the interval between cue onset and target offset was only 150 ms, during which subjects probably could not have gained any advantage by executing a saccade to the cued location (entailing more than 200 ms), it is still not certain whether subjects moved their eyes or not during the trial. When eye movements are not controlled, subjects tend to move their eyes to the peripherally flashed location. If so, the pattern of the attentional gradient can possibly be revealed merely by the visual acuity effect because as the target location is farther away from the cued location (assuming eyes are moved to the cued location), it is more peripheral to the foveal acuity. Therefore, it is very probable that this gradient is due to confounding of the target location with retinal acuity.

Handy, Kingston, and Mangun (1997) recorded subjects' EOGs and discarded the trials that contained eye movements or blinks to study the attention distribution across the visual field. In their study, subjects directed their attention to one location by following an arrow cue presented at the fixation point and then responded to a luminance onset. There were six possible target locations arranged along an imaginary semicircle in the upper visual field, 6.0° visual angles from fixation. Both accuracy and reaction times were measured. The analysis of RT cost and benefit for the target detection in each location showed that attention was very narrowly focused on the specific cued location. If the data point of the valid-cued location was excluded, the rest of curve did not indicate that RT costs increased monotonically with increasing target distance from the cued location. It appeared that beyond 2.5° from the attended location, there was little or no modulation in target detection latency.

In summary, the findings from different tasks and stimulus displays seem to be inconsistent, but most researchers generally agree that the effects of attention on response performance decline with increasing distance from the attended location. This conclusion is based on the reaction times as a dependent measure. On the other hand, the distance effects (indexed by response times) may result simply from the change of the response criterion because the response criterion varies inversely with the likelihood of the target location (Shaw, 1984).

According to the signal detection theory, there are two stages of information processing involved in the target detection. First, sensory evidence in one channel is accumulated regarding the presence of the target. Second, observers adopt a decision criterion, whether it is liberal or conservative, to determine whether this evidence is sufficient for the detection response. Compared to the uncued locations, the decision criterion will be more liberal towards the cued location because the target is most likely to occur at that location. As a result, the response to the target at the cued location will be faster relative to other uncued locations because less sensory evidence needs to be accumulated from the cued location. Instead of simply measuring reaction times, the distance effect of spatial selection in perceptual sensitivity has also been observed. In Downing's (1988) experiment, twelve possible target locations marked by boxes were arranged along on an imaginary circle with a 7° diameter. After an arrow cue pointed to one location, subjects were randomly probed to perform a detection task in which the stimulus could occur at one of four locations including the expected location. The performance was indexed by perceptual sensitivity (d') according to the signal detection theory. The results showed that sensitivity was maximally enhanced at the expected location and gradually decreased with increasing distance from that location. In addition, from electrophysiological evidence, Mangun and Hillyard (1988) also found that the amplitudes of the PI 35 and N190 brainwaves decreased progressively as attention was directed to locations increasingly distant from a lateral stimulus. Also, the spatial gradients of Pl/Nl amplitudes were paralleled by changes in d' scores. Because the modulations of PI/Nl components index an early attentional process that regulates the amount of sensory information flowing to higher perceptual centers (e.g., visual cortex), the distance effects in spatial selection may reveal a mechanism operating (filtering or gating) at the early stage of visual information processing.

Although the distance effects reviewed previously are all revealed from the location precuing paradigm, in which the target appears without accompanying any distracting stimulus, it is reasonably assumed that the closer to the attended location the distracting stimulus is, the more interference it will cause. Many studies using

the response competition paradigm have also supported this assumption. For example, Eriksen and St. James (1986) proposed a zoom lens model, in which the attentional focus was enlarged to include all precued locations, but the speed of response decreased as the precued area expanded. They found that the disruptive effect of incompatible noise letters decreased progressively as the noise letter was located from 0.5 to 1.5 of visual angle from the edge of the cued area. In addition, this gradient pattern of attentional processing at the border of the focal area was invariant regardless of the size of the precued area.

Pan and Eriksen (1993) suggested an ellipse as the appropriate metaphor for the attentional focus, rather than a spotlight or a zoom lens. In their study, they manipulated the size of the focal area by means of requiring subjects to compare two letters which were separated by 0.5°, 1.0°, or 2.0° visual angles vertically or horizontally. The two to-be-compared letters were flanked by a distractor that could be 0.25°, 0.5°, or 1.0° away from the major axis of the two targets. They found that for 0.5° separation between two targets, only the 0.25° distractor had a significant response-competition effect, and the 1.0° distractor did not cause any response interference. On the other hand, for 2.0° separation between two targets, the attentional field seemed to be expanded and any distractor within 0.5° had a significant interference effect. They suggest that rather than being a circle, the shape of the attended area seems to be elliptical. The principal axis is defined by the spatial separation of the locations of the targets and the minor axis is proportional to the principal axis. Around the attended area is an inhibitory field. The spatial extent revealed from the response-competition effects resulted from the inner limits of an inhibitory field, rather than from the outer limits of the attended field. When targets are only 0.5° apart, the 0.5° distractor is excluded from attentional focus and thus inhibited; when targets are 2.0° far apart, the 0.5° distractor is included in attentional focus and thus not inhibited because the attentional window has been expanded. Similarly, Müller et al. (2005) found that spatial attention was distributed like a shape of Mexican hat.

In summary, converging evidence from the response-competition paradigm suggests that the distance effect is quite robust in spatial attention, and its underlying mechanism may be via inhibition of unattended locations. Nonetheless, an attention set should be established endogenously prior to the target display in this paradigm, so evidence from the response-competition paradigm does not necessarily support a distance effect in spatial attention following the exogenous cue, which directs the distribution of attention via the property of a stimulus itself. It is speculated that there may not be a distance effect following the exogenous cue. This hypothesis is supported indirectly by studies of visual search. Visual search refers to the task in which observers search for a target item embedded in some number of distractor items. When the distractors are all identical and the difference between target and distractor is in a single feature, such as color or orientation, the search time is independent of the display size. In other words, no matter how many distractors surround the target, the distractors will not interfere with the target detection. For example, Treisman and Gormican (1988) found that when targets contained a unique

distinguishing feature relative to the neighboring distractors, the number of distractors did not affect the reaction times of the observers' search for targets. In one experiment, they tested the feature of line orientation. Subjects were required to detect a tilted line among vertical lines which were scattered randomly in an area subtending 7.8° x 6.8°. The results showed that detection time was equally fast when the number of vertical lines was zero, five, or eleven. On the one hand, this result can be accounted for by a parallel search process (bottom-up process), in which the target feature is singled out of the distractor feature without involving focal attention. On the other hand, this also implies that stimulus-driven selection induces a restricted allocation of attention over the target location. Therefore, the distractors do not have any power to distract attention and thus cause no interference.

The deployment of attention in response to the exogenous cue is also in a stimulus-driven fashion, which suggests that attention may be allocated narrowly to the cued location when the exogenous cue is used. Thus, there may be no distance effect in spatial attention following the exogenous cue. This prediction makes ecological sense. The exogenous cue, such as a sudden movement or an abrupt flash, usually has a survival value, either signifying a potential danger (predator) or food (prey), so it would be worthwhile to focus attention fully on it.

In the past studies of spatial attention, the general conclusion is that attentional effects on response performance decrease with increasing spatial separation between attended and unattended locations. The distance effect in the allocation of attention seems to be a parallel between exogenous and endogenous orienting, despite the fact that exogenous and endogenous orienting can be differentiated by automatic vs. voluntary processes. However, there are three reasons to speculate that there may be a differential effect of endogenous and exogenous cues on the spatial distribution of attention. The first reason is that attention orienting in response to an exogenous cue is automatic, whereas attention orienting in response to an endogenous cue is voluntary. The directionality of an endogenous cue needs to be interpreted and decoded into working memory before attention is directed, whereas no such translation process is required for an exogenous cue. The notion of limited capacity assumes that the total of attentional resources is fixed. If the decoding process takes less resources, there should be more left for allocating to the possible target locations. Based on this reasoning, following an exogenous cue, the uncued locations may still be attended slightly. Following an endogenous cue, the unexpected locations nonetheless may be ignored and have no allocation of attention at all because the location-coding process will consume some resources. Therefore, it is reasonable to think that the RT costs for the uncued locations may be larger in endogenous orienting than in exogenous orienting. The second reason for positing a differential effect is that the deployment of attention via an exogenous cue is stimulus-driven, whereas the deployment of attention via an endogenous cue is goal-directed. Indirect evidence from the visual search paradigm showed that in the feature search task, the time to detect a target with a distinctive feature was not affected by the number of the distractors surrounding the target (Treisman and Gelade, 1980). This suggests

that no matter how distant the distractors are from the target, they will be ignored and thus will not interfere with the target detection. Because stimulus-driven selection is involved in the feature search task, this also implies no distance effect in stimulus-driven selection. In contrast, evidence from the response competition paradigm showed that responses to a pre-designated target letter were interfered with by surrounding irrelevant letters associated with the wrong response, and more importantly, this interference effect decreased as the noise letters were moved farther away from the target. This implies a distance effect in goal-directed selection. The third reason is that exogenous orienting is a bottom-up process, whereas endogenous orienting is a top-down process. According to the CODE theory by Logan (1996), the representation of a location is distributed across the space in a Laplace distribution. The distribution also represents the probability of sampling features in one item within the location. The CODE surface refers to the summation of all distributions representing different items located in the space. Perceptual grouping is formed by applying a threshold to the CODE surface. The items (or locations) located in the same above-threshold region of the CODE surface will belong to the same perceptual group. Therefore, when one item (or location) is selected, its proximate items (or locations) may also be selected in part if that part is within the above-threshold region of the surface.

The CODE theory further assumes that attention samples the features that are available within the above-threshold region. The probability of sampling features is called feature catch. Either top-down or bottom-up processes can influence the size of feature catch for each location. Bottom-up processes will reduce the variability of the feature distribution so that the feature catch of the proximate items (or locations) will decrease within the above-threshold region. It is implied that the attentional focus will be narrower following an exogenous cue. On the other hand, top-down processes, instead of changing the shape of the surface, will lower the threshold level, so that the feature catch of the proximate items (or locations) will increase within the above-threshold region. It is implied that the attentional focus will be broader following the endogenous cue. This implication is consistent with the previous reason.

Taken together, there are two empirical predictions derived from the above reasons.
First, as opposed to an exogenous cue, the RT costs of uncued locations following an endogenous cue should be significantly larger. Second, the distance effect will be found in endogenous orienting, whereas the RT costs for the uncued locations may show a uniform pattern in exogenous orienting, i.e., no distance effects.

Attentional effects can be confounded by two other factors: eye movements and visual acuity. First, the relationship between attention and eye movements is very complicated. Observers may move their eyes to where they are attending; this is called "overt orienting" as opposed to "covert orienting", which will be explored in this study. Without controlling eye movements, observers will spontaneously move their eyes to the cued location and wait for the target. Therefore, the dependent measurement of reaction times will simply reflect the duration of time during which the eyes move

from the cued location to the target (saccadic movements). The distance effect will simply reflect the spatial separation between the cued location and the target. To exclude this confounding, we monitor subjects' eye movements using EOG (electro-oculograms) electrodes. Second, targets in foveal vision are always recognized more quickly than in peripheral vision. This is called the visual acuity effect. As the location is farther away from fixation, it is more peripheral to the foveal acuity. Therefore, if each location had a different distance to the fixated point, the visual acuity effect might confound the attentional effects. The gradient of attention can be due to confounding of the target locations with retinal acuity. To avoid this confounding, the stimulus display is arranged along an imaginary semicircle in which each possible target location is equally distant from the fixation center.

Much previous research into spatial attention has been more or less contaminated by the two confounding factors described above. The worst is that the confounding can lead to the most important conclusion in this line of research, which is the distance effect in the spatial distribution of attention. This study aims to control confounding and answer the following questions. Is there a differential effect of exogenous and endogenous cues on the processing of uncued portions of the visual field?

2. Method
The purpose of this study was to test those predictions by directly comparing exogenous and endogenous cues under the same experimental settings. The stimulus display (see Figure 1), adapted from Handy et al. (1997), included six boxes arranged along a semicircle in peripheral vision, 5.7° distant from the fixation center so that each box had the same visual acuity. A line presented at the fixated point served as an endogenous cue, predicting the upcoming target with a likelihood of 70%. The outline of one of the six boxes was brightened abruptly to serve as an exogenous cue. In this experiment, only two locations could be precued, which were the rightmost and the leftmost boxes. The reason is that only a few observations (24% of the trials) can be made for all uncued locations in endogenous cueing and thus collecting a sufficient number of data points at any single uncued location requires an extremely long experiment. Therefore, subjects' attention was only directed to two of six possible locations and allowed enough observations to be made at each uncued location within one hour and a half. To ensure that covert attention shift, not overt movements of eyes, was responsible for performance, eye movements were monitored using EOGs electrodes. EOGs were recorded from three sites, i.e., a horizontal EGG recorded from the left outer canthus and a vertical EGG recorded from the sites inferior and superior to the left eye. All electrodes were referenced to the right outer canthus.

2.1 Participants
Fifty-two college undergraduates participated in a single 1 to 2 - hour session, in partial fulfillment of an introductory psychology class requirement. All had normal or corrected-to-normal visual acuity. Twenty-six participants were randomly assigned to endogenous and exogenous cueing sessions, respectively. Two

participants in the exogenous cueing session were discarded from the analysis, because of frequent eye movements.

2.2 Apparatus

Stimulus displays were presented on a ViewSonic 4E 14" color monitor driven by a PC equipped with a Cirrus Logic SVGA graphic card. Participants sat in a comfortable chair in a sound-attenuating and dimly lit booth. The monitor was placed at eye level on a table. The viewing distance measured from the surface of the monitor to the subjects' eyes was fixed at approximately 65 cm. Subjects responded by pressing keys on a terminal keyboard. EOGs were collected via an analog-to-digital converter, amplified (via Grass/Model 12) with a gain of 5000, and digitized at a sampling rate of 200Hz. A voltage criterion of 20 μV shift within 30-50 ms was set for defining eye movements. Any trials with eye movements or blinking detected were discarded and rerun later in the experiment.

2.3 Stimuli

The stimulus display included six boxes outlined in black color against a gray screen background (13-foot Lamberts; fL), arranged along a semicircle in the upper visual field. A small white square (0.31° tall x 0.22° wide) placed at the center of the display served as the fixation point. Each box was 1.32° tall x 1.14° wide, 5.7° from fixation, and equally spaced, 2.64° center to center, from its neighbor. Two most lateral boxes were positioned 1.76° above the horizontal meridian. The stimulus display was symmetric about the vertical meridian, with three boxes in each visual hemifield. A white straight line (1.32° long x 0.04° wide) was presented at fixation, serving as a central cue. The outline of any one box was brightened (33 fL) for 100 ms, serving as a peripheral cue. The target was either the letter "P" or "B" (0.79° long x 0.35° wide) placed in the center of a box. The possible farthest target location was 9.3° away from the cued location.

2.4 Procedure

In the endogenous cueing session, a fixation square, along with six boxes, was first presented. Subjects were instructed to fixate the square throughout the trial. After 900 ms a cue appeared at fixation for 150 ms. On 80% of the trials, the cue was a white line pointing either to the leftmost or the rightmost box. The cue predicted the upcoming target with 70% validity. On 20% of the trials, a neutral cue with six lines pointed to every box. The interval between the offset of the cue and the onset of the target (inter-stimulus interval; ISl) varied from 300 to 500 ms. A target, either the letter "P" or"B", was presented for 90 ms in either the cued box 70% of the time or in any one of the uncued boxes 6% of the time. Finally, a pattern mask followed. Subjects determined whether the target was "P" or "B" and responded by pressing the period key (.) with their right index finger if the letter "B" appeared and the semicolon key (;) with their middle finger if the letter "P" appeared. The next trial automatically started two seconds later. Eye movements were monitored from the fixation display to the target offset. If subjects moved their eyes during that period, a warning message would appear on the screen. Then the next trial would not proceed until the space bar was hit. Subjects were instructed to use this period to rest their eyes. The procedure for the exogenous cueing session was identical to that for the endogenous cueing session, except for

the following. The cue was an abrupt brightening of the outline of one of six boxes, on 80% of the trials. The ISl between cue and target varied from 50 to 150 ms, instead of 300 to 500 ms. The reason for this change is to avoid"inhibition of return", a finding that a previously cued location is inhibited if a target appears more than 300 ms after a peripheral cue (Posner and Cohen, 1984). However, this phenomenon does not exist in endogenous orienting. A target appeared in any one of six boxes with equal probability (i.e., 1/6 = 16.7%). On 20% of the trials, all six boxes were brightened simultaneously for 100 ms to serve as a neutral cue. Different from the endogenous cueing session, two additional locations could be precued to avoid the possibility that participants might actively suppress the abrupt flash because the flash tended to elicit blinking responses naturally. If only two most lateral locations could be flashed, participants were very likely to suppress their responses to the flash intentionally.

2.5 Design

A 2 x 2 x 6 design was used. Two within-subjects variables were cueing locations (leftmost/rightmost)' and target locations (0°, 2.6°, 4.9°, 6.5°, 8.1°, and 9.3° distant from the cued location). One between-subjects variable was cueing type (endogenous vs. exogenous). The central cue pointed to either side equally often. A total of 496 trials was divided into 4 blocks of 124 trials each. The task was forced-choice letter discrimination of "B" and "P" that were randomly chosen. Subjects were encouraged to follow the central cue and to prepare for the upcoming target while maintaining fixation at the center of the display. The peripheral cue also appeared in two most lateral locations equally often. A total of 360 trials was divided into 3 blocks of 120 trials each. Subjects were told that the peripheral brightening has nothing to do with the upcoming target location.

2.6 Data analysis

To eliminate the trials in which subjects did not respond to the target until after an unusually long delay or prematurely respond to the target, reaction times slower than 1500 ms or faster than 200 ms were considered errors and discarded from the analysis (Handy, et al., 1997). There were three types of trials in this experiment. A valid trial is one in which cue and target locations are matched. An invalid trial is one in which cue and target locations are not matched. Neutral trials are those with a neutral cue. The RT benefit (a negative) was computed by subtracting the mean RT of neutral trials from the mean RT of valid trials. The RT cost (a positive) was computed by subtracting the mean RT of neutral trials from the mean RT of invalid trials. Analysis of variance (ANOVA) was based on the RT benefit/cost calculated for each participant.

3. Results

The results are graphed in Figure 2. First of all, data from exogenous and endogenous cueing were analyzed separately. The RT costs and benefits were analyzed in an ANOVA with a within-subjects factor, which was cueing laterality. There was no significant effect of laterality in either endogenous cueing or exogenous cueing, $F_{(l, 25)} = 2.13$, $p = .157$, and $F_{(l, 24)} < 1$, respectively. There was no significant interaction of laterality x target locations, in either endogenous cueing or exogenous cueing,

$F(5, 125) = 1.47$, $p = .2$, and $F(5, 120) < 1$, respectively. In other words, no matter which visual field the cue occurred in, the RT patterns across all target locations were similar to each other. Therefore, we combined the data from two symmetrical cued locations for the further analysis. Data from endogenous cueing. A repeated measures ANOVA on RT costs and benefits was then conducted, with target locations as the only factor. There was a significant effect of target locations, $F(5, 125) = 5.28$, $p < .01$, indicating that there was a significant RT benefit when the probe happened at the cued location (valid trials) relative to the uncued locations. In order to examine whether the attentional effect was only isolated to the valid location, a contrast analysis among means was performed. The results showed that there was a significant difference between 2.6° and 4.9° distant invalid locations, $F(l, 25) = 4.46$, $p < .05$. It appeared that spatial attention was spread as a gradient within 4.9° distant from the expected location. On the other hand, there were uniform RT costs when the target happened in the locations 6.5°, 8.1°, and 9.3° distant from the cued location. This pattern of uniform RT costs suggested an inhibitory component in endogenous orienting. Data from exogenous cueing. Results from exogenous cueing (see Figure 2) were similar to but somewhat different from those described above. An ANOVA on RT costs and benefits showed that there was a significant effect of spatial separation, $F(5, 115) = 2.52$, $p < .05$, indicating that there was a significant RT benefit when the probe happened at a cued location, relative to uncued locations. However, if the valid location was excluded, the other uncued locations had uniform RT costs, which seemed to be smaller than those found in endogenous cueing. This result suggested that spatial attention was narrowly focused within 2.6° distant from the cued location.

A mixed analysis. A split-plot ANOVA was performed with cueing type (endogenous vs. exogenous) as a between-subjects factor and spatial separation as a within-subjects factor. We found that the interaction of cueing type and spatial separation was not significant, $F(5, 240) < 1$. However, the main effect of cueing type was close to the significant level, $F(l, 48) = 3.69$, $p = 0.06$, and the main effect of spatial separation was significant, $F(5, 240) = 6.96$, $p < .01$. This suggests that both endogenous and exogenous cues induce a very similar pattern of RT costs and benefits. That is, attention orienting, following the cue, generated RT benefits to recognition of the target in the cued location, and generated uniform RT costs to recognition of the target in most uncued locations. In addition, the endogenous cue tended to induce larger RT costs to recognition of the target in the uncued locations. A similar split-plot ANOVA, except for excluding the valid and 2.6° invalid locations, found that only the main effect of cueing type was significant, $F(l, 48) = 5.1$, $p < .05$. This suggests that generally in endogenous cueing the costs of the uncued locations distant beyond 2.6° were larger than those found in exogenous cueing.

In endogenous cueing, the overall error rate was 10.1%. Accuracy was analyzed in a repeated measures ANOVA with cued locations and target locations as factors. Only the main effect of target locations was significant, $F(5, 125) = 3.32$, $p < .01$, indicating that accuracy was higher when the target occurred in the rightmost location than in any other locations, no matter which visual field

was cued. There was no significant difference in accuracy between the two visual fields because neither the effect of cued locations nor interaction of cued locations and target locations was significant. In addition, there was a positive correlation (.57) between error rate and mean response times across all combinations of cued and target location, indicating no strong speed/accuracy trade-off. In exogenous cueing, the overall error rate was 23% and the correlation between error rates and reaction times was .24, also indicating no problem of speed/accuracy trade-off. Accuracy was analyzed in a repeated measures ANOVA with cued locations and target locations as factors. None was significant, indicating that accuracy patterns in the left and right visual fields were similar to each other.

4. Discussion

There are two differences between endogenous and exogenous cuing. First, a gradient of attention is found in endogenous cueing, although the spatial extent of the gradient is not larger than 4.9° visual field surrounding the cued location. In exogenous cueing, attention is, however, focused narrowly at the cued location and the RT costs for the uncued locations are not mediated by distance. Second, for those uncued locations beyond 4.9° distant from the cued location, the RT costs in endogenous cueing are larger than in exogenous cueing. In sum, these results have corroborated our predictions. There is a distance effect in endogenous cueing, while no such effect is manifested in exogenous cueing under the stimulus display of this experiment.

Spatial selection seems to involve two aspects of attention: facilitation and inhibition (Müller et al., 2005). Undoubtedly, processing in the cued location is enhanced, so that performance on that location is the fastest in both types of cueing conditions. On the other hand, processing in uncued locations is more strongly inhibited in endogenous cueing than in exogenous cueing. Obviously, the spotlight metaphor (Posner, 1980) cannot explain the distance effect because information can either be enhanced in the area of spotlight or be ignored out of the spotlight. There are no various degrees of processing within the spotlight. The zoom lens metaphor (St. James and Eriksen, 1986) may be able to explain the differential degrees of processing within the spotlight by adding the parameter of variable resolution in the different area of the spotlight. However, the zoom lens model may not explain the inhibitory area outside of the attentional focus. Other metaphors, such as an attentional window or gating (Pan and Eriksen, 1993), may explain the inhibitory operations in the uncued locations, but they lack an 'adjustable' window to explain the distance effect in the area of window. Finally, the variable and permeable filters metaphor (Cheal, 1997) may explain the results well by using as many filters of mixed excitation and inhibition as necessary. Two different groups of filters will be needed to explain the different spatial distribution of attention in response to exogenous and endogenous cues. However, this metaphor seems to create another problem—how one attention system in the brain reconciles with two different systems of filters.

Based on the clear pattern of RT costs and benefits across the visual field, it is believed that spatial selection is realized by

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enhancing processing of the relevant locations, as well as by inhibition of the irrelevant locations. As Tsotsos (1993) suggested, the attentional"beam" includes both facilitatory and inhibitory zones which operate in the brain map, not simply like a spotlight shining on the two-dimensional visual space. The facilitatory zone defines a group of excitatory connections between neurons. The inhibitory zone defines a group of inhibitory connections between neurons. The gradient pattern of RT costs and benefits is caused by the intersection between two zones. Because attentional facilitation is cancelled out by inhibition within the intersection zone, performance in this area will be in the intermediate level of the scale of costs and benefits. As a result, the curve of RT benefits and costs will reflect a gradient pattern surrounding the cued location. It is worth noting that exogenous cueing has revealed a different pattern with no distance effect and a less stiong inhibitory component. It is hypothesized that this may result from the difference between bottom-up and top-down processes in deciding which connections should be selected or inhibited.
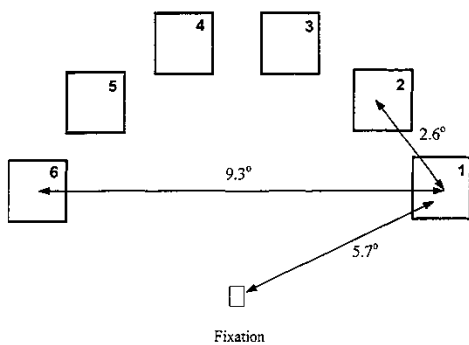

Figure 1. Spatial arrangement of stimulus display used in Experiments 1 and 2. Each possible target location was labeled by the number in the upper right-hand comer of each box. In the text, each display location was referenced to these numbers which were not included in the actual experimental display. The distance was measured as the shortest line between the center of any two locations. The longest distance between cued and target locations could be 9.3°.
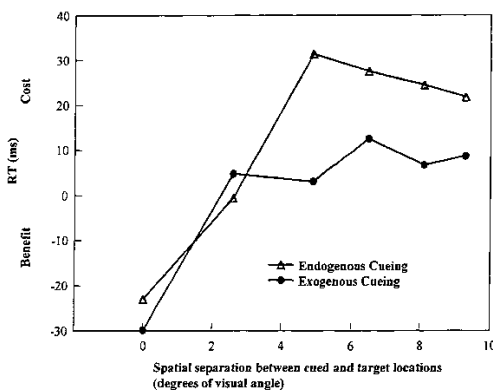

Figure 2. The results of experiment in which either the rightmost or the leftmost location is precued. Targets appear at a 0°, 2.6°, 4.9°, 6.5°, 8.1°, or 9.3° distance from the cued location. The reaction time (RT) cost/benefit to identification of the target is a function of

the distance between cued and target locations. The validly cued location is represented by a visual angle of 0°.

Reference

1. Allport, A. (1989). Visual attention. In M. I. Posner (Ed), *Foundations of cognitive science* (*pp.* 631-682). Cambridge, MA: MIT Press.
2. Cheal, M. L. (1997). Understanding diverse effects of visual attention with the VAP- filters metaphors. *Consciousness and Cognition: An International Journal, 6,* 348- 362.
3. Cheal, M. L., & Lyon, D. R. (1991). Central and peripheral precuing of forced-choice discrimination. *Quarterly Journal of Experimental Psychology, 43A,* 859-880.
4. Downing, C. J. (1988). Expectancy and visuospatial attention: Effects on perceptual quality. *Journal of Experimental Psychology: Human Perception & Performance, 74,*228-241.
5. Downing, C. J., & Pinker, S. (1985). The spatial structure of visual attention. In M. I.
6. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (*pp.* 171-188). Hillsdale, NJ: Erlbaum.
7. Egeth, H. E., & Yantis, S. (1997). Visual attention: Control, representation, and time course. *Annual Review of Psychology, 48,*269-297.
8. Eriksen, C. W., & Hoffinan, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. *Perception & Psychophysics, 14,* 155-160.
9. Eriksen, C. W., & ST. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40,* 225-240.
10. Handy, T. C., Kingstone, A., & Mangun, G. R. (1997). Spatial distribution of visual attention: Perceptual sensitivity and response latency. *Perception & Psychophysics, 58,* 613-627.
11. Henderson, J. M., & Macquistan, A. D. (1993). The spatial distribution of attention following an exogenous cue. *Perception & Psychophysics, 53,*221-230.
12. Hughes, H. C., & Zimba, L. D. (1985). Spatial maps of directed visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 11,*409-430.
13. Klatt, S., & Memmert, D. (2021). Studying spatial visual attention: The attention-window task as a measurement tool for the shape and maximum spread of the attention window *Frontier in Psychology, 12*, 1-13.
14. Logan, G. D. (1996). The CODE theory of visual attention: An integration of space-based and object-based attention. *Psychological Review, 103,*603-649.
15. Mangun, G. R., & Hillyard, S. A. (1988). Spatial gradients of visual attention: Behavioral and electrophysiological evidence. *Electroencephalography & Clinical Neurophysiology,*

*70,*417-428.

16. Müller, N. G., Mollenhauer, M., Rösler, A., & Kleinschmidt, A. (2005). The attentional field has a Mexican hat distribution. *Vision Research, 45*, 1129-1137.

17. Pan, K., & Eriksen, C. W. (1993). Attentional distribution in the visual field during same-different judgments as assessed by response competition. *Perception & Psychophysics, 53,* 134-144.

18. Posner, M. I. (1978). Orienting. *Chronometric explorations ofmind* (*pp.* 185-215).

19. Hillsdale, NJ: Erlbaum. Posner, M. I., Nissen, M. J., & Ogden, W. C. (1978). Attended and unattended processing modes: The role of set for spatial location. In H. J. Pick & I. J. Saltzman (Eds.), *Modes of perception (pp.* 137-157). Hillsdale, NJ: Erlbaum.

20. Shaw, M. L. (1984). Division of attention among spatial locations: A fundamental difference between detection of letters and detection of luminance increments. In H. Bouma & D. G. Bonwhuis *(Eds.), Attention and performance X (pp.* 109-120). Hove, UK: Erlbaum.

21. Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97-136.

22. Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review, 95,* 15-48.

23. Tsotsos, J. K. (1993). An inhibitory beam for attentional detection. In L. Harris and M. Jenkin. (Eds.), *Spatial vision in human and robots* (*pp.* 313-331). Cambridge: Cambridge University Press.

24. Tsotsos, J. K. (1997). Limited capacity of any realizable perceptual system is a sufficient reason for attentive behavior. *Consciousness and Cognition: An International Journal, 6,*429-436.

25. Yeshurun, Y. (2019). The spatial distribution of attention. *Current Opinion in Psychology, 29,* 76-81.