Chen, Z. (2008). Distractor eccentricity and its effects on selective attention.

Experimental Psychology, *55*(2), 82-92.

Distractor Eccentricity and its Effect on Selective Attention

Zhe Chen

University of Canterbury, Christchurch, New Zealand

Zhe Chen
Department of Psychology
University of Canterbury
Private Bag 4800
Christchurch
New Zealand
e-mail: zhe.chen@canterbury.ac.nz
phone: 3-3642987 ext. 7179
fax: 3-3642181

Abstract

Previous research has shown conflicting results regarding the effect of distractor eccentricity on selective attention. The present study examines the relationship between a distractor's retinal location and participants' response latencies to a target while holding constant the distribution of attention. In three experiments, the participants searched for a target among several distractors. The retinal location of the critical distractor was manipulated so that it was at either a central or a peripheral location. The results show that all else being equal, an incompatible distractor causes more interference at a peripheral location than at a central location. This *distractor eccentricity effect* suggests that the visual system can overcome the default bias in the distribution of attention that favors a central stimulus.

Keywords: visual attention, distractor eccentricity effect

One way to understand visual selective attention is to understand the conditions under which task irrelevant items interfere with the processing of a task relevant object. Extensive research has been conducted to determine the factors that modulate the degree of distractor interference on target selection. In a typical experiment (e.g., B. A. Eriksen & C. W. Eriksen, 1974), observers are shown a target together with one or more distractors. The distrators can be compatible, incompatible, or neutral in relation to the target response. Relative to the neutral trials, participants are usually faster on compatible trials and slower on incompatible trials. This response compatibility effect has been found in a variety of paradigms (e.g., Chen & Cave, 2006; Eriksen & St. James, 1986; Kramer & Jacobson, 1991).

Several factors have been shown to influence the magnitude of the response compatibility effect. These include the spatial separation and perceptual grouping between the target and distractors (B. A. Eriksen & C. W. Eriksen, 1974; Kramer & Jacobson, 1991), the subjective organization of the stimulus configuration (Chen & Cave, 2006), the extent of attentional focus induced by a task (Chen, 2000, 2003; C. W. Eriksen & St. James, 1986; LaBerge, Brown, Carter, Bash, & Hartley, 1991), and the perceptual and working memory loads involved in the processing of a target (Lavie, 2005; but see Chen & Chan, in press).

Recent research suggests that the extent of distractor processing may also be influenced by distractor eccentricity. Several studies have reported less interference when a distractor is at fixation than when it is at the periphery (Goolkasian, 1981; 1999; Jonides, 1981; Juola, Koshino, & Warner, 1995; Mack & Rock, 1998). Jonides (1981) reported that whereas his participants were unable to disregard a peripheral cue when

they were explicitly told to do so, they could successfully ignore a central one in accordance with the instruction. This result suggests that a central stimulus is more sensitive to attentional modulation than a peripheral stimulus. Similar results were observed by Juola et al. (1995), whose participants also found it easier to disregard central cues than peripheral ones.

Mack and Rock (1998) further demonstrated that a central stimulus is less likely to be detected than a parafoveal one when the stimulus is not expected to appear in a target display. They coined the term *inattentional blindness*, referring to the phenomenon that participants often failed to report an unexpected superthreshold stimulus when their attention was engaged in another task. Interestingly, when the unexpected stimulus appeared at fixation and the target was situated at a peripheral location, inattentional blindness was stronger than when the locations of the two stimuli were switched.

Using a response compatibility paradigm, Goolkasian (1999) reported less interference from an incompatible foveal distractor than from a peripheral one. In several experiments, she manipulated the eccentricities of the target and of the distractor, and found that an incompatible foveal distractor had a narrower scope of interference when it was paired with a peripheral target than when the same distractor was placed at a peripheral location and paired with a foveal target. Moreover, when the target and distractor were at the same eccentricity in opposite hemifields, the magnitude of distractor interference was smaller when both stimuli were closer to the fovea than when they were farther away from the fovea. Based on these results, Goolkasian concluded that the visual system was more effective in controlling foveal than peripheral events. Related results were reported by Bouma (1973), who demonstrated that at the same eccentricity

the recognition of initial or final letters for both words and letter strings was better for outward letters (i.e., initial letters in the left visual field (VF) or final letters in the right VF) than for inward letters (i.e., final letters in the left VF or initial letters in the right VF). Taken together, these studies support the notion that a central distractor causes less interference than a peripheral distractor. In the rest of this article, I will use the term *the distractor eccentricity effect* to refer to this phenomenon.

However, despite the empirical support for the distractor eccentricity effect described above, recent experiments by Beck and Lavie (2005) suggest that the effect of distractor eccentricity on selective attention is more complex than was previously understood. Beck and Lavie noted that in prior studies (e.g., Goolskasian, 1999; Mack & Rock, 1998) the target was typically associated with greater location uncertainty and at a greater eccentricity when the distractor was at fixation than when it was in the periphery. This means that task demand was likely to be greater in the former situation than in the latter one. Because an increase in task demand can lead to a decrease in distractor processing, the distractor eccentricity effect could be caused by a difference in distractor eccentricity, a difference in task demand, or both.

To test their hypothesis, Beck and Lavie (2005) conducted several experiments in which they manipulated distractor eccentricity and task difficulty while controlling target eccentricity and the number of target locations. For example, in one experiment, the participants searched for a target letter among a circular array of homogenous (the easy condition) or heterogeneous (the hard condition) neutral letters in addition to a critical distractor which could be compatible or incompatible with the target response. The critical distractor was either inside the letter array at fixation (the fixation condition) or

outside it at one of two parafoveal locations (the periphery condition). The results confirmed the researchers' hypothesis. The response compatibility effect was larger when the task was easy than when it was hard, and more important, it was larger when the distractor was at fixation than when it was in the periphery. Beck and Lavie attributed this anti-distractor eccentricity effect to the preferential access of attention by the fovea, which in turn led to the incompatible distractor at the fovea causing more interference than the one in the periphery.

Beck and Lavie's (2005) findings are intuitively appealing, and they are consistent with the role of the fovea in target processing. It has long been known that the fovea is responsible for the perception of color and fine details (Boynton, 1979; Roedieck, 1973). Relative to the periphery, it has higher visual acuity, spatial resolution, and contrast sensitivity (Connolly & Van Essen, 1984; Fiorentini & Berardi, 1991). Recent research has also shown that searching for a target in a typical visual search display is more efficient when the target is near the fovea than when it is in the periphery (Wolfe, O'Neill, & Bennett, 1998). Furthermore, this target eccentricity effect[1] (Carrasco, Evert, Chang, & Katz, 1995) has been attributed to a bias in attention allocation which prefers central stimuli over peripheral ones (Wolfe et al., 1998).

Beck and Lavie's (2005) results raised an interesting question regarding the visual system. If the foveal bias observed in their experiments reflected an inherent feature of the visual system, their findings would suggest a very rigid visual system, one that enhanced the processing of a foveal distractor even though doing so was harmful. On the other hand, if their results were caused by specific task demand, it should be possible to overrule the anti-distractor eccentricity effect under appropriate experimental conditions.

A careful examination of the Beck and Lavie (2005) study indicated that task demand was likely to be the primary cause for their results. In their study, the critical distractor was equally likely to be compatible or incompatible. In other words, the participants could respond on the basis of the distractor and still be correct on half of the trials. This in turn might induce the participants to pay attention to the distractor in addition to the target array. If the default setting of the visual system concerning attention distribution was to favor the fovea, a foveal distractor would get more attentional resources than a peripheral one, resulting in the observed anti-distractor eccentricity effect.

If the above reasoning is correct, replacing the compatible distractor with a neutral one should discourage participants from attending to the critical distractor, which in turn may abolish the anti-distractor eccentricity effect. There is some evidence in visual search that the target eccentricity effect can be modulated by the distribution of attention. Wolfe et al. (1998, Experiment 5) reported that visual search was more efficient for a central than a peripheral target when the target and distractors were at different eccentricities, but not when they were at the same eccentricity. According to the researchers, the target eccentricity effect arose in the different eccentricity condition because an increase in target eccentricity was accompanied by an increase in the number of distractors closer to the fixation, and this in turn decreased the likelihood of attention visiting a target first at a larger eccentricity than one at a smaller eccentricity. In contrast, the target eccentricity effect was eliminated in the same eccentricity condition because it was equally likely for attention to visit the target first regardless of whether the target was

at a small or a large eccentricity. These results suggest that the distribution of attention plays a key role in the manifestation of the target eccentricity effect.

Linnell and Humphrey (2004) also showed that the target eccentricity effect could be overruled when participants had advance knowledge of the target location. Specifically, the researchers presented all stimuli on three concentric rings, and the target ring was either cued or uncued. The target eccentricity effect was found only when the target ring was not cued. In other words, central distractors impaired target response more than peripheral distractors only when the target location was unknown. When it was known in advance, target eccentricity had no effect on performance. These results indicate that the bias in attention distribution favoring central over peripheral stimuli can be controlled.

In the experiments reported here, the role of distractor eccentricity on selective attention was assessed in several ways. Experiment 1 tested whether the effect of distractor eccentricity on target selection is a function of participants' response strategy by manipulating the type of distractors within a block. Experiments 2 and 3 further examined the role of distractor eccentricity in selective attention while holding constant the participants' distribution of attention. Taken together, these experiments show that all else being equal, an incompatible distractor causes less interference when it is at fixation than when it is in the periphery.

Experiment 1

Experiment 1 examined whether the effect of distractor eccentricity on target selection was modulated by participants' response strategies, which in turn were

influenced by the type of distractors in a block. Each participant performed two blocks of trials, and the task was to search for a target among several distractors. Whereas a compatible distractor appeared on half of the trials in one block, it was replaced by a neutral distractor in the other block. Of particular interest was whether the anti-distractor eccentricity effect would be found in the former situation but not in the latter one.

Method

Participants. Twenty-four students from the University of Canterbury volunteered for the study. Each was paid NZ$10. All participants reported having normal or corrected-to-normal vision.

Apparatus and Stimuli. The stimuli were white against a black background. They were shown on a Power Macintosh 6100/66 computer with a 14-inch RGB monitor. An experimental program, MacProbe (Hunt, 1996), was used to display and to record responses. Participants were individually tested in a dimly lit room. They viewed the stimuli from a distance of approximately 60 cm.

Each trial consisted of a fixation, a blank screen, and a target display (see Figure 1). The fixation was a white cross at the center of the screen. It subtended 0.48^0 of visual angle on each side. The target display was made of six equally spaced capital letters along an imaginary circle with its center at fixation and a radius of 2^0 of visual angles. The target, which was equally likely to be an N or an X among five neutral letter O’s, could occur at any of the six positions randomly and with equal probability. In addition to the letter array, there was also a critical distractor, an N, X, or G depending on the specific experimental condition. On half of the trials, the distractor was at fixation (the

fixation condition). On the other half of the trials, it was equally likely to be on the left or right side of the screen at 4^0 eccentricity (the periphery condition). The letters were all written in Monaco font and their sizes were scaled in accordance with the cortical magnification factor (Rovamo & Virsu, 1979; Virsu & Rovamo, 1979). Specifically, whereas the letters in the target array were size 20, the critical distractor was size 14 at fixation and size 29 in the periphery.

Insert Figure 1 About Here

Design and Procedure. The experiment was a 2 x 2 x 2 within-subjects design. The principal manipulations were distractor location (fixation vs. periphery), target-distractor compatibility (incompatible vs. non-incompatible), and the type of non-incompatible distractor in a block (neutral vs. compatible). Whereas the first two variables were manipulated within a block, the last one was varied across blocks. The order of the blocks was counterbalanced across the participants.

Each trial started with a 1,005 ms presentation of the fixation. After a 495 ms delay, the target display was shown for 120 ms. The task was to decide whether the target was an N or an X. The participants pressed the "." key if the target was an N, and the "/" key if it was an X. The entire experiment consisted of two blocks of 288 trials, with 36 practice trials before each block. Both speed and accuracy were emphasized.

Results and Discussion

Table 1 shows the results. Two participants' data were excluded, one because of high error rates that exceeded 30%, and the other due to slow response latencies with the mean being three standard deviations above the average reaction time of the other participants. A 2 x 2 x 2 repeated measures analysis of variance (ANOVA) was conducted on the participants' median reaction time data. The results showed significant main effects of response compatibility [$F(1, 21) = 90.78$, $MSE = 1216$, $p < .001$] and distractor location [$F(1, 21) = 30.77$, $MSE = 675$, $p < .001$]. The participants were slower on the incompatible trials (591 ms) than on the non-incompatible trials (541 ms), and in the fixation condition (577 ms) than in the periphery condition (555 ms). There was also a significant location by compatibility interaction [$F(1, 21) = 4.80$, $MSE = 545$, $p < .05$], suggesting a larger response compatibility effect in the fixation condition (58 ms) than in the periphery condition (43 ms). More important, there was a significant three-way interaction among distractor location, response compatibility, and distractor type [$F(1, 21) = 5.56$, $MSE = 197$, $p < .05$].

Insert Table 1 About Here

Two additional ANOVAs, one for each block, were conducted to clarify the interaction. For the compatible block, all effects were significant [$F(1, 21) = 36.64$, $MSE = 405$, $p < .001$, for distractor location; $F(1, 21) = 33.24$, $MSE = 1750$, $p < .001$, for response compatibility; and $F(1, 21) = 11.56$, $MSE = 307$, $p < .01$, for location by compatibility interaction]. For the neutral block, whereas significant effects were found for distractor location [$F(1, 21) = 12.85$, $MSE = 521$, $p < .01$] and response compatibility

[$F(1, 21) = 131.85$, $MSE = 397$, $p < .0001$], their interaction was not reliable [$F(1, 21) = 0.38$, $MSE = 435$, *ns*]. These results confirmed the existence of the anti-distractor eccentricity effect in the compatible block, but not in the neutral block.

A similar ANOVA was conducted on the accuracy data, indicating higher accuracy on the non-incompatible (3.3% error) than on the incompatible (6.8% error) trials [$F(1, 21) = 36.35$, $MSE = 15$, $p < .001$], and in the periphery (4.5% error) than in the fixation (5.6% error) condition [$F(1, 21) = 8.66$, $MSE = 7.03$, $p < .01$]. No other effects reached significance. There was no evidence of a speed-accuracy tradeoff, either.

As expected, the participants showed a strong response compatibility effect. This finding was nothing new, and had been reported in many previous studies (e.g., B. A. Eriksen & C. W. Eriksen, 1974; Kramer & Jacobson, 1991). In addition, there was a distractor location effect. Reaction time was longer in the fixation than in the periphery condition. Beck and Lavie (2005) reported a similar finding, and interpreted it in terms of a filtering cost (Kahneman, Treisman, & Burkell, 1983). Past research has shown that filtering cost is larger when distractors are located between the targets than when they are outside the targets (Chen, 2000). The fact that the critical distractor was inside the target array in the fixation condition and outside it in the periphery condition in Experiment 1 could make the distractor harder to filter out in the former than in the latter condition, resulting in the distractor location effect.

The most important finding in Experiment 1 was the observation of the anti-distractor eccentricity effect in the compatible block but not in the neutral block. This pattern of data was consistent with the notion that the anti-distractor eccentricity effect was a by-product of participants' response strategies. In the compatible block, the

compatible distractor indicated the same response as the target on half of the trials. This would induce the participants to pay attention to the distractor and/or to its location. Assuming that the fovea was favored in the distribution of attention unless doing so was undesirable, more attention would be allocated to the fovea than to another location, resulting in a larger response compatibility effect in the fixation condition than in the peripheral condition.

Contrary to the situation in the compatible block, the participants in the neutral block were unlikely to pay attention to either the distractor or to its location, because doing so could only impair performance. When attention was away from the fovea, a foveal distractor could no longer get more processing than a peripheral one. Consequently, the response compatibility effect was comparable in the foveal and in the peripheral conditions.

If the participants' response strategies were modulated by the type of distractors in a block, is it possible that they might also be influenced by the participants' prior experiences with the stimulus displays? To examine this possibility, I conducted two more three-way ANOVAs on the participants' reaction time data for the compatible and the neutral blocks separately. In both analyses, the order of the blocks was treated as a between-subjects variable while distractor location and target-distractor compatibility were treated as within-subjects variables.

Tables 2A and 2B show the data. For the neutral block, the only significant effects were the main effects of distractor location [$F(1, 20) = 12.73$, $MSE = 480$, $p < .01$] and response compatibility [$F(1, 20) = 124.57$, $MSE = 417$, $p < .0001$]. There was no order effect or interactions that involved order, even though there was a numerical increase in

the difference of the magnitude of the response comparability effects from the foveal to peripheral conditions in the direction of the anti-eccentricity effect in the second block (55 ms and 43 ms for the foveal and peripheral conditions, respectively) relative to the first block (49 ms for both the foveal and the peripheral conditions). These results suggest that the participants' response strategies were primarily influenced by the nature of the stimulus, with perhaps minor modulation from prior experience with the stimulus displays.

Insert Tables 2A and Table 2B About Here

The compatible block showed a different pattern of data. In addition to the main effects of distractor location [$F(1, 20) = 34.70$, $MSE = 416$, $p < .0001$], response compatibility [$F(1, 20) = 34.60$, $MSE = 1577$ $p < .0001$], and their interaction [$F(1, 20) = 12.26$, $MSE = 255$, $p < .01$], there was also a three-way interaction among block order, distractor location, and response compatibility [$F(1, 20) = 5.21$, $MSE = 255$, $p < .05$]. Further analyses indicated that whereas a significant anti-distractor eccentricity effect (85 ms vs. 46 ms for the fixation and the periphery conditions, respectively) was found when the compatible block was the first block [$F(1, 11) = 12.34$, $MSE = 381$, $p < .01$], such an effect was not observed (39 ms for the fixation condition and 31 ms for the periphery condition) when it was the second block [$F(1, 9) = 1.71$, $MSE = 102$, *ns*]. These results suggest that participants' response strategies were a joint function of the nature of the stimulus and their prior experiences with the stimulus displays. Those participants who completed the neutral block before the compatible block appeared to have used the same

response strategies in the second block as they did in the first block despite the change of the distractor from a neutral to a compatible stimulus on half of the trials. Perhaps once the participants had learnt to ignore the distractor, they continued using the same strategy. After all, paying attention to the distractor comes with a price. Analysis on the accuracy data indicated no speed-accuracy tradeoff.

Taken together, the results of Experiment 1 suggest that the anti-distractor eccentricity effect was a by-product of participants' response strategies. However, no firm conclusion regarding the effect of distractor eccentricity on selective attention could be drawn yet, because the allocation of attention was not strictly controlled. The fact that the target display was centered at fixation makes it likely that attention was concentrated at the area around the fovea even in the neutral block. This in turn could result in uneven distribution of attention that favored the foveal distractor.

Experiment 2

Experiment 2 investigated the effect of distractor eccentricity on selective attention while controlling the distribution of attention. Of particular interest was whether the magnitude of the response compatibility effect would be different between the fixation and the periphery conditions.

Method

Several changes were made to the stimuli of Experiment 1 (see Figure 2). First, for attention to be distributed evenly in the fovea and periphery conditions, the center of the target array was moved from fixation to 4^0 eccentricity, equally likely to be on the left

or right of fixation. In addition, a 120 ms precue was added before the onset of the target. The cue was made of a pair of vertically aligned white bars with a separation of 6.3^0. It was located at 4^0 eccentricity, and always occurred on the same side of the screen as the target. Second, on half of the trials, the critical distractor was presented at fixation. On the rest of the trials, it was at 8^0 eccentricity in the left or right side of the screen with equal probability. Third, as before, the stimuli were scaled. The sizes of the letters in the target arrays were 20, 27, and 34 from closest to the fovea to farthest away from the fovea, and the sizes of the critical distractor were 14 at fixation and 40 at 8^0. Finally, only the neutral condition of Experiment 1 was included in Experiment 2, and the participants were explicitly instructed to keep their eyes fixated at the center of the screen throughout the duration of a trial.

The experiment was a 2 x 2 within-subjects design, with the principal manipulations being distractor location (fixation vs. periphery) and target response compatibility (neutral vs. incompatible). All the other aspects of the experiment were identical to those of Experiment 1. Fifteen new participants volunteered for the experiment. Each performed four blocks of 96 trials.

Insert Figure 2 About Here

Results and Discussion

Table 3 shows the data. A repeated measures ANOVA on participants' median reaction times indicated faster reaction time when the distractor was neutral (560 ms)

than when it was incompatible (603 ms) [$F(1, 14) = 32.91$, $MSE = 844$, $p < .001$]. More important, there was a distractor eccentricity effect [$F(1, 14) = 6.06$, $MSE = 310$, $p < .05$], suggesting a larger response compatibility effect when the distractor was in the periphery (54 ms) than when it was at fixation (32 ms). The distractor location effect was not significant [$F(1, 14) = 3.21$, $MSE = 428$, *ns*].

Insert Table 3 About Here

A similar ANOVA was conducted on the accuracy data, showing fewer errors when the distractor was neutral (4.7% error) than when it was incompatible (10%) [$F(1, 14) = 14.37$, $MSE = 29$, $p < .01$]. No other effects reached significance.

The critical finding of Experiment 2 was the observation of the distractor eccentricity effect. This suggests that the visual system was flexible, and that it took into account the specific task demand in the deployment of attention. When attention to the fovea was undesirable, the visual system could prevent the fovea from having preferential access to attention, thereby avoiding excessive processing of the distractor there. In fact, the distractor was processed to a greater degree when it was in the periphery than when it was at the fovea, and these results are consistent with several findings in prior research (e.g., Goolkasian, 1981; 1999; Mack & Rock, 1997).

It is worth noting that the distractor location effect disappeared in Experiment 2. If anything, there was a trend toward longer reaction time in the periphery than the fovea condition. This result is important, because it provided empirical support for the proposal that the distractor location effect found in Experiment 1 was caused primarily by the

location of the distractor relative to the target array, which in turn led to differential levels of filtering cost in the fixation and in the periphery conditions. When distractor location was moved in Experiment 2 so that it was outside the target array in both conditions, the location effect disappeared.

Experiment 2 demonstrated the distractor eccentricity effect. Unfortunately, it also contained a confound. Given the relatively long duration between the onset of the cue and the offset of the target (240 ms), it is possible that the participants might orient overtly towards the cue. This in turn would bias the peripheral distractor in its favor, giving rise to the observed distractor eccentricity effect. Experiment 3 was designed to address this issue.

Experiment 3

Experiment 3 examined whether the distractor eccentricity effect found in Experiment 2 would be replicated when overt orientation was minimized. This was achieved by reducing the interval between the onset of the cue to the offset of the target from 240 ms in Experiment 2 to 180 ms in Experiment 3. Because it typically takes about 200 ms to make an overt eye movement (Alpern, 1972; Mayfrank, Kimming, & Fischer, 1987), it was hoped that the new cue-target interval would minimize overt orienting. If the distractor eccentricity effect in Experiment 2 was not caused primarily by overt eye movements, the participants in Experiment 3 should still show a larger response compatibility effect in the peripheral condition than in the central condition. Otherwise, the magnitude of the response compatibility effect should be comparable between the two conditions.

In addition to the shorter cue-target duration, Experiment 3 differed from Experiment 2 in one other important way. The locations of the central and peripheral distractors were moved from 0^0 and 8^0 eccentricities to 1^0 and 9^0 eccentricities. This change in location was to equate the number of distractor locations between the central and peripheral conditions. Recall that in Experiment 2, whereas the critical distractor was associated with only one location in the central condition, it was associated with two locations in the peripheral location. Although it was unclear how this difference in location uncertainty might influence the observed distractor eccentricity effect, it would be desirable to eliminate any systematic differences between the critical experimental conditions.

Method

Participants. Fourteen undergraduate students from Princeton University took part in the experiment in exchange for course credit.

Apparatus and Stimuli. The stimuli were shown on a PC with a 22-inch monitor, and E-Prime was used to generate stimuli and to collect responses.

To test the generality of the distractor eccentricity effect, I used a different paradigm in Experiment 3. The task was to search for a target letter H or X among neutral letter Os and a critical distractor that could be incompatible or neutral to the target response. Each trial consisted of three stimulus displays: the fixation, the cue, and the target (see Figure 3). Unlike Experiment 2, The fixation was made of a small dot extended 0.2^0 of visual angle at the center of the screen, and two pairs of vertical bars with the individual bar subtended 1.6^0, and a gap of 7.6^0 between the nearest ends of the

bars. Each pair of bars was centered at 5^0 eccentricity, with the left pair on the left side of the screen and the right pair on the right side of the screen. The cue comprised a pair of bars identical to the one in the fixation display. It was made by removing the fixation dot as well as the left or the right pair of bars. The target display consisted of a 3-letter target array and a single critical distractor. The letters in the target array were the same size (size: 17) and in the same horizontal row. They were equally likely to be above or below the horizontal meridian. The central letter was directly under the cue, and was 5.3^0 away from the fixation. It had a separation of 1.9^0 from its left or right counterpart. Two of the three letters were O's, with the third one a target letter H or X. The target was equally likely to occur at any position in the target array. The critical distractor was always presented on the horizontal meridian at 1^0 or 9^0 eccentricity on the left or right of fixation with equal probability. As before, it was incompatible (H or X) on half of the trials, and neutral (L) on the rest of the trials. All the letter stimuli were written in Arial Narrow font. The critical distractor was scaled relative to the central letter of the target array. It was size 9 and bold at 1^0 eccentricity, and size 24 and plain at 9^0 eccentricity.[2]

Insert Figure 3 About Here

Design and Procedure. The design of the experiment was the same as that of Experiment 2, with distractor location (central vs. peripheral) and target-distractor compatibility (incompatible vs. neutral) as the principal manipulations.

Each trial started with the presentation of the fixation display for 1,000 ms, followed by an inter-stimulus-interval (ISI) of 480 ms. Then, the cue display was shown

for 40 ms. After another ISI of 40 ms, the target display was presented for 100 ms. The participants pressed the "." key if the target was an H, and the "/" if it was an X. As in Experiment 2, both speed and accuracy were emphasized.

Results and Discussion

The data are illustrated in Table 4. Repeated measures ANOVAs on participants' median reaction times and mean error rates showed that the participants were faster and more accurate on the neutral (427 ms with 3.6% error) than on the incompatible trials (457 ms with 5.7%) [$F(1, 13) = 45.41$, $MSE = 265.07$, $p < .0001$ and $F(1, 13) = 5.56$, $MSE = 11.39$, $p < .05$ for reaction time and accuracy, respectively]. They were also faster when the critical distractor was at a central (438 ms) rather than a peripheral location (446 ms) [$F(1, 13) = 4.83$, $MSE = 218.19$, $p < .05$]. Furthermore, there was a significant compatibility by distractor location interaction [$F(1, 13) = 10.95$, $MSE = 125$, $p < .01$]. The response compatibility effect was larger when the critical distractor was at a peripheral location (40 ms) than when it was at a central location (19 ms). No other effects reached significance.

Insert Table 4 About Here

The finding that the participants in Experiment 3 showed the distractor eccentricity effect provided converging evidence to the results of Experiment 2. It suggests that the differential magnitude of the response compatibility effect observed in

Experiment 2 was unlikely to be caused by overt orientation in favor of the peripheral distractor. It is also worth noting that the pattern of data regarding the distractor location effect in Experiment 3 was similar to that in Experiment 2. Although the distractor location effect was significant in Experiment 3 but not in Experiment 2, in both experiments the participants showed comparable response latencies on the neutral trials regardless of distractor eccentricity. In contrast, their reaction times were substantially longer on the incompatible trials when the distractor was at a peripheral rather than at a central location. These results are consistent with the notion that when the allocation of attention is controlled, a central distractor does not cause more interference than a peripheral distractor.

General Discussion

Prior studies have established that distractor eccentricity plays an important role in target selection. Relative to a peripheral stimulus, a central stimulus is easier to ignore (Jonides, 1981; Juola et al., 1995), has a smaller scope of interference (Goolkasian, 1999), and is less likely to be detected when its occurrence is not expected (Mack & Rock, 1998). Furthermore, when compatible and incompatible distractors are equally likely to appear with the target display, a foveal distractor impairs target selection more than a peripheral distractor (Beck & Lavie, 2005). The present research extends these findings by showing that the effect of distractor eccentricity on selective attention is a by-product of participants' response strategies instead of an inherent feature of the visual system. All else being equal, an incompatible distractor causes more interference when it is in the periphery than when it is at the fovea.

Stimulus eccentricity and the speed of visual information processing

As was mentioned earlier, the target eccentricity effect can be explained very well in terms of an attention allocation account (Linnell & Humphrey, 2004; Wolfe et al., 1998). However, the attention account does not have the same degree of explanatory power for the distractor eccentricity effect reported in this paper. The fact that a larger response compatibility effect was found in the peripheral than in the central condition of Experiments 2 and 3 even though the distribution of attention was controlled indicates that the allocation of attention can not fully account for the distractor eccentricity effect.

What is the primary cause for the distrator eccentricity effect then? One possibility is the differential processing speed between a peripheral stimulus and a central one. Carrasco and her associates (Carrasco, Giordano, & McElree, 2006; Carrasco, McElree, Denisova, & Giordano, 2003) recently reported a positive relationship between an object's eccentricity and the speed of its information processing. Using a response signal speed-accuracy tradeoff procedure (Reed, 1973; Wickelgren, 1977) which provided conjoint measures of discriminability and information accrual, Carrasco and her associates (Carrasco et al., 2003; 2006) found more efficient responses to a target at a peripheral location than one at a parafoveal location. For example, in one experiment in Carrasco et al. (2003), the participants saw stimulus displays that consisted of a target either presented alone or with distractors. All of the stimuli were located at 4^0 or 9^0 eccentricity, and the task was orientation discrimination. The results show that target responses were faster when the target was at 9^0 than at 4^0 eccentricity regardless of whether the target was presented alone or with distractors. Subsequent experiments

indicated that comparable results could be obtained even when the location of the target was precued (Carrasco et al., 2006).

Converging evidence for faster processing speed for a peripheral stimulus than a central stimulus can also be found in physiological studies which show that the periphery has higher temporal resolution than the fovea (Hartmann, Lachenmayr, & Brettel, 1979) and that in macaque the conduction speed for magnocellular (M) cells are faster than that for parvocellular (P) cells (Schmolesky, Wang, & Hanes et al., 1998). Because the ratio of P:M cells decreases with eccentricity, the different conduction speeds for the two types of cells are consistent with the notion that the processing speed of a stimulus increases with eccentricity.

In terms of the distractor eccentricity effect, notice that in both Experiments 2 and 3 the participants showed substantial response compatibility effects in both the fixation and periphery conditions. This suggests that the critical distractor was processed even though it was clearly designated and should be easily distinguishable from the target array. On the neutral trials, the difference in the stimuli’s processing speed between the fixation and the periphery conditions might not affect target response because the distractor was not related to the target. On the incompatible trials, however, this difference might cause more interference to the target response in the periphery condition than in the fixation condition because the distractor indicated a different response from the target. This in turn could result in longer response latencies in the peripheral condition than in the foveal condition, giving rise to the distractor eccentricity effect.

Distractor inhibition at central versus peripheral locations

Alternatively, the distractor eccentricity effect can be caused by more efficient inhibition at a central location than at a peripheral location. Although no explicit tests were performed in the present experiments to determine whether active inhibition was applied to the distractor and/or to its locations, given that target facilitation and distractor inhibition are two important components of selective attention (Chelazzi, Miller, Duncan, & Desimone, 1993; Keele & Neill, 1978; Moran & Desimone, 1985), it seems impossible that the selection of the target was not accompanied by the inhibition of the distractor. If that was the case, it is possible that suppression was more effective at a central than at a peripheral location. This hypothesis is consistent with the results of Jonides (1981), whose participants could successfully ignore a central cue but not a peripheral cue, and of Mack and Rock (1998), who reported stronger inattentional blindness when the unexpected stimulus appeared at fixation than at a parafoveal location. Based on their results, Mack and Rock suggested that active inhibition can be applied to fixation distractors, especially when targets are known to occur at a different location.

Assuming that inhibition was indeed evoked, it was more likely to be applied to distractor locations rather than to some specific features of the distractors. Recall that in all the experiments, the critical distractor on one trial could become the target on a different trial. This means that inhibition on the basis of form was virtually impossible. In contrast, inhibition on the basis of location was relatively easy because the target never occurred at the same location as the distractor. Although the distractor locations were not inside a contiguous region of space, there is evidence that inhibition can be applied to noncontiguous regions of space (Cepeda, Cave, Bichot, & Kim, 1998).

Conclusion

Taken together, the results of the present experiments suggest that all else being equal, an incompatible distractor causes less interference at the fovea than in the periphery. This distractor eccentricity effect suggests that the visual system can overcome the default bias in the distribution of attention that favors a central stimulus, and that the fovea may play an important role in distractor inhibition in addition to target facilitation.

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Acknowledgments

I thank Klaus Rothermund and two anonymous reviewers for comments on an early version of the manuscript, and Steve Yantis and Anne Treisman for helpful discussion of this research. Correspondence concerning this article should be addressed to Zhe Chen, Department of Psychology, University of Canterbury, Private Bag 4800, Christchurch, New Zealand. E-mail: zhe.chen@canterbury.ac.nz.

Table 1

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 1.

	Compatible Block				Neutral Block			
	Compatible		Incompatible		Neutral		Incompatible	
Distractor location	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
	Reaction times (ms)							
Fixation	556	13.3	620	17.8	539	11.3	591	12.3
Periphery	543	13.5	582	13.8	524	9.9	571	10.6
	Error rates (% incorrect)							
Fixation	3.7	0.81	7.5	1.15	4.3	0.85	7.0	0.90
Periphery	2.4	0.40	6.0	0.88	2.7	0.37	6.7	0.93

Table 2A

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for the Neutral Block of Experiment 1.

	Neutral Block First				Neutral Block Second			
	Neutral		Incompatible		Neutral		Incompatible	
Distractor location	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
				Reaction times (ms)				
Fixation	547	18.9	596	20.3	532	13.9	587	15.8
Periphery	538	17.2	587	16.1	513	10.9	556	13.3
				Error rates (% incorrect)				
Fixation	4.2	1.24	6.9	1.08	4.4	1.21	7.1	1.44
Periphery	2.5	0.63	6.5	1.11	2.9	0.47	7.0	1.47

Table 2B

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for the Compatible Block of Experiment 1.

	Compatible Block First				Compatible Block Second			
	Compatible		Incompatible		Compatible		Incompatible	
Distractor location	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
				Reaction times (ms)				
Fixation	570	16.4	656	22.6	539	21.4	578	22.5
Periphery	561	17.3	607	18.4	520	20.0	551	16.9
				Error rates (% incorrect)				
Fixation	3.7	1.00	7.8	1.66	3.8	1.38	7.1	1.62
Periphery	2.8	0.65	5.7	1.26	2.0	0.39	6.3	1.28

Table 3

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 2.

	Neutral		Incompatible	
Distractor location	*M*	*SE*	*M*	*SE*
	Reaction times (ms)			
Fixation	560	23.5	592	28.3
Periphery	559	21.4	613	29.3
	Error rates (% incorrect)			
Fixation	4.8	1.05	10.0	2.25
Periphery	4.6	1.17	10.0	1.98

Table 4

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 3.

	Neutral		Incompatible	
Distractor location	*M*	*SE*	*M*	*SE*
	Reaction times (ms)			
Central	428	10.7	447	9.6
Peripheral	426	10.7	466	11.1
	Error rates (% incorrect)			
Central	3.7	0.77	4.7	1.07
Peripheral	3.4	0.65	6.6	1.40

Note:

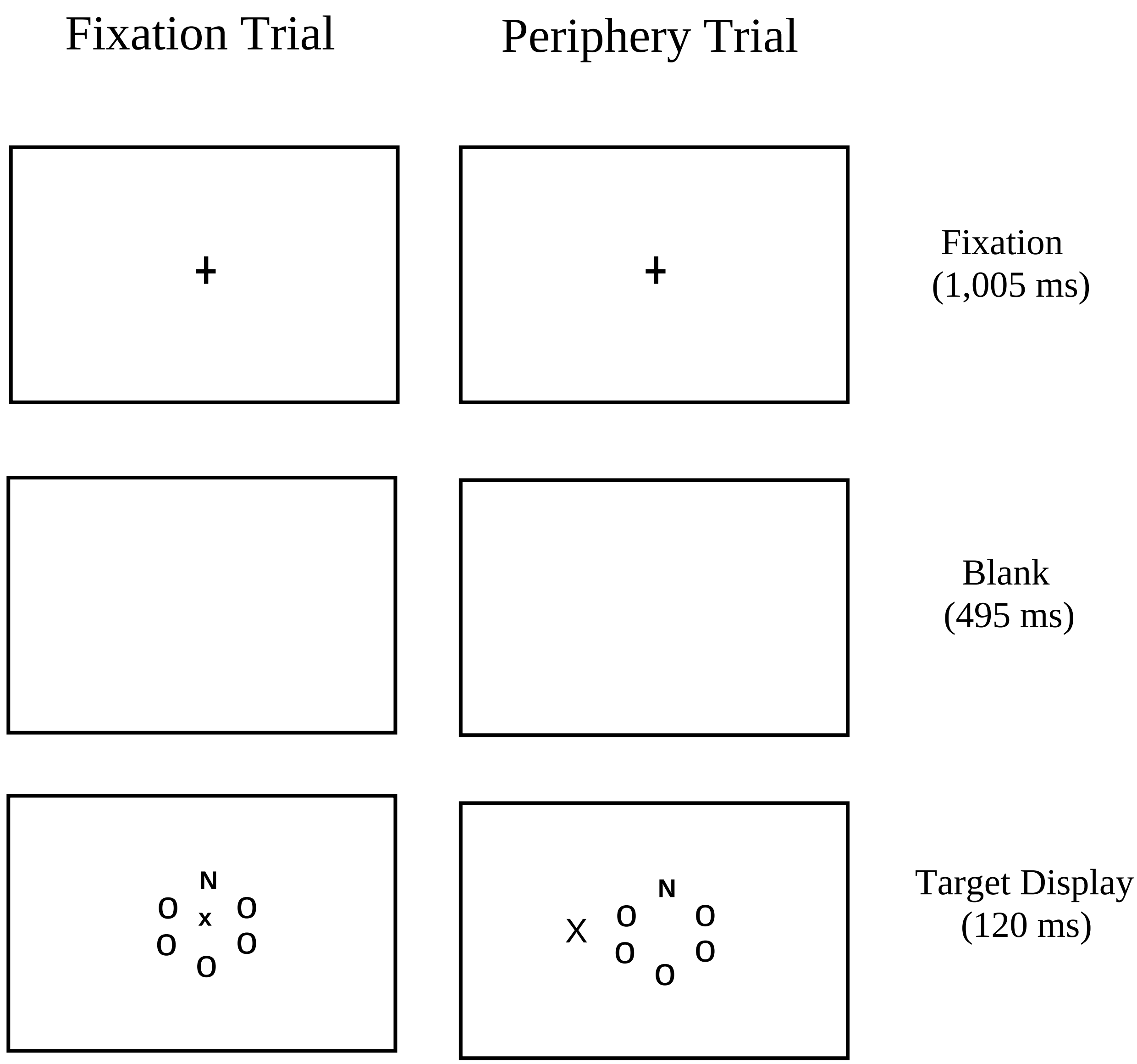
1. Carrasco et al. (1995) referred to the effect as the “eccentricity effect” instead of the “target eccentricity effect”. The word “target” was added here to differentiate the effect from the “distractor eccentricity effect”.
2. A pilot study in which an independent group of participants performed a letter discrimination task of a single target that appeared at 1^0 or 9^0 eccentricity confirmed that these specific values (i.e., size 9 and bold at 1^0 eccentricity versus size 24 and plain at 9^0 eccentricity) produced comparable performance in both reaction time and accuracy.

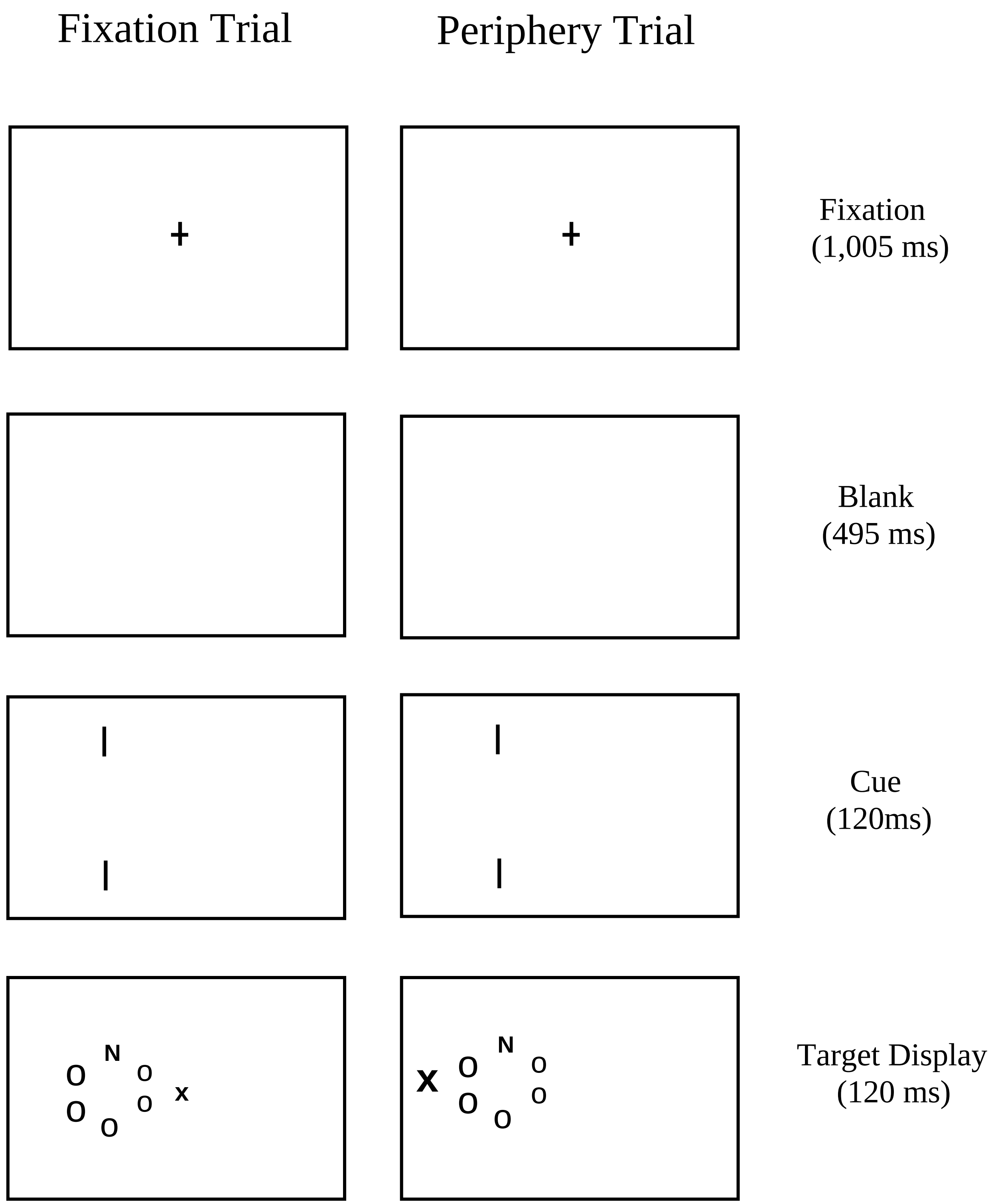
Figure Caption

Figure 1. Examples of stimulus displays from Experiment 1. The task was to search for a target letter N or X among five neutral distractor Os. The critical distractor, which could be N, X, or G depending on the specific experimental condition, was situated either at fixation or in the left or right side of the screen at 4^0 eccentricity.

Figure 2. Examples of stimulus displays from Experiment 2. The critical distractor was equally likely to be at fixation or at 8^0 eccentricity left or right of fixation.

Figure 3. Examples of stimulus displays from Experiment 3. The critical distractor was equally likely to be at 1^0 or 9^0 eccentricity left or right of fixation.


Fixation Trial
Periphery Trial
+
+
Fixation
(1,005 ms)
Blank
(495 ms)
N
O x O
O O
O
X O N O
O O
O
Target Display
(120 ms)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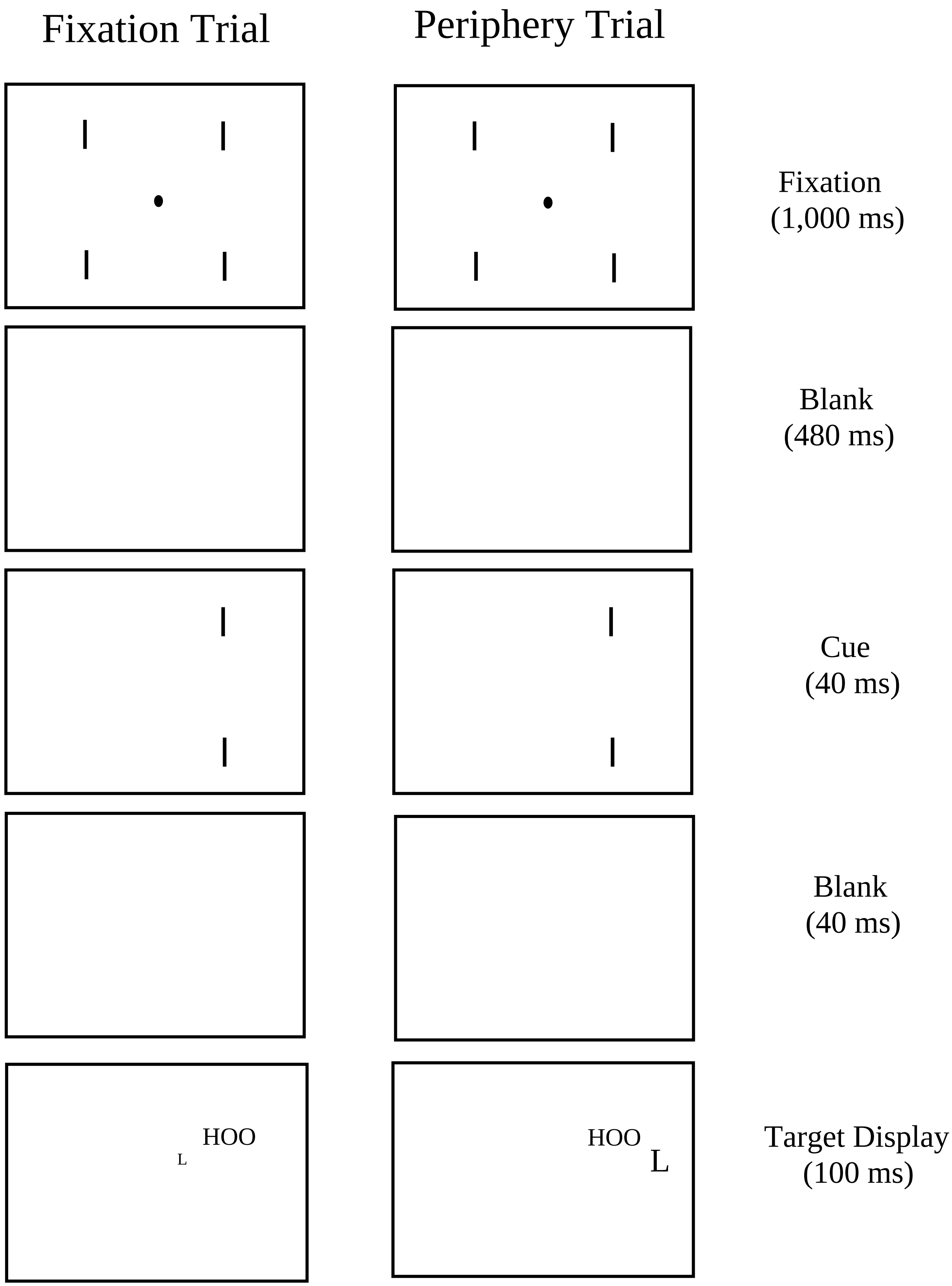
Periphery Trial
Fixation
(1,005 ms)
Blank
(495 ms)
Cue
(120ms)
Target Display
(120 ms)


Fixation Trial
Periphery Trial
Fixation
(1,000 ms)
Blank
(480 ms)
Cue
(40 ms)
Blank
(40 ms)
HOO
L
HOO
L
Target Display
(100 ms)