Journal of Experimental Psychology:
Human Perception and Performance
2005, Vol. 31, No. 3, 592–607

0096-1523/05/$12.00 DOI: 10.1037/0096-1523.31.3.592

Look Here but Ignore What You See: Effects of Distractors at Fixation

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Distractor interference effects were compared between distractors in the periphery and those placed at fixation. In 6 experiments, the authors show that fixation distractors produce larger interference effects than peripheral distractors. However, the fixation distractor effects are modulated by perceptual load to the same extent as are peripheral distractor effects (Experiments 1 and 2). Experiment 3 showed that fixation distractors are harder to filter out than peripheral distractors. The larger distractor effects at fixation are not due to the cortical magnification of foveal stimuli (Experiments 4 and 5), nor can they be attributed to cuing by the fixation point (Experiment 2), the lower predictability or greater location certainty of fixation distractors (Experiment 5), or their being in a central position (Experiment 6). The authors suggest that preferential access to attention renders fixation distractors harder to ignore than peripheral distractors.

Keywords: distractor, fovea, perceptual load, attention, response competition

A fundamental issue in the study of selective attention concerns the extent to which irrelevant distractors can be ignored. Although there have been many studies to address this issue, in the majority of them, the to-be-ignored distractors have been presented in the periphery. Indeed, the distractors presented in the response competition paradigm, the dominant paradigm in this field, are often termed flankers because they are presented in the periphery, flanking the target on both sides (B. A. Eriksen & Eriksen, 1974).

In the response competition paradigm, participants are asked to make speeded choice responses to a target among distractors. Although participants are told to ignore the distractors, the distractors are associated with responses that are either compatible or incompatible with the target response. The extent to which the distractors are processed is then assessed by the degree to which the response-incompatible distractor interferes with (slows) performance relative to the response-compatible distractor. A significant difference in RTs between compatible and incompatible distractor trials indicates that participants perceived the identity of the distractor. This method established that irrelevant distractors in the periphery can produce robust interference effects as long as the perceptual load of the relevant task is low (for a review, see Lavie & Tsal, 1994). In contrast, interference from peripheral distractors is typically reduced when the relevant task involves a high perceptual load that exhausts attentional capacity. Thus, larger set sizes and increased similarity between targets and nontargets in visual search, as well as complex discrimination of a conjunction of features (vs. simple presence detection), all increase the perceptual load of the relevant task and have all reduced distractor interference (e.g., Lavie, 1995; Lavie & Cox, 1997; for a recent review, see Lavie, 2005). However, as mentioned, these findings rely almost entirely on evidence from peripheral distractors.

In the present experiments, we extended the research on distractor processing to distractors presented at fixation. The superior visual processing of foveal information suggests that it may be harder to ignore distractor stimuli when presented directly at fixation than when presented in the periphery. To test this, we compared interference effects on reaction times (RTs) from peripheral distractors with interference effects on RTs from distractors presented at fixation. Moreover, we asked whether interference from distractors presented at fixation would be subject to the same resource limitations as interference from peripheral distractors and would thus also be modulated by the level of perceptual load in the relevant task. Because previous perceptual load studies have presented distractors in the periphery, it is unknown whether perceptual load has any effect on the processing of distractors at fixation. Given that the visual system is highly specialized to process information at fixation, and that under normal circumstances attention and the direction of gaze are highly correlated (see our review below), it is possible that fixation distractors will always be processed regardless of the level of perceptual load on the relevant task.

Vision at Fixation Versus in the Periphery

There are a number of reasons to suspect that placing distractors at fixation might result in greater interference than would placing them in the periphery. There is abundant evidence that the fovea is both physiologically and functionally special. It is well known that visual acuity, resolution, and contrast sensitivity are higher in central vision than in the periphery. These functional inequalities between the fovea and the periphery are paralleled and indeed explained by a similar physiological inequality. Cone density declines by a factor of three from the fovea to 10° eccentricity, as does visual acuity (Fiorentini & Berardi, 1991). These inequalities are propagated further along the visual system, with relatively

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This research was supported by a Medical Research Council (United Kingdom) Career Award and Biotechnology and Biological Sciences Research Council (United Kingdom) Grant 31/S09509 to Nilli Lavie.

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larger regions of lateral geniculate nucleus and visual cortex being devoted to foveal vision than to peripheral vision (Connolly & Van Essen, 1984; Daniel & Whitteridge, 1961; Hubel & Wiesel, 1974). In other words, the visual system is designed to preferentially process foveal stimuli. The question is, does this preferential processing lead to a poorer ability to ignore distractor stimuli at fixation?

Attentional Factors

The degree to which stimuli at fixation are distracting is also related to the degree to which attention can be divorced from fixation. If attention is to some degree tied to the fovea, then any information presented there may be harder to ignore. Although many spatial cuing studies have demonstrated that spatial shifts of attention away from fixation can be induced without making eye movements (Posner, 1980; Posner, Nissen, & Ogden, 1978), the eye movement literature suggests that foveal vision and attention are still linked. One way to describe an eye movement is as a shift of the fovea. In fact, the purpose of an eye movement is usually to bring the fovea in line with items that require further processing. Not only do eye movements and spatial shifts of attention in the absence of eye movements activate similar regions of the frontoparietal cortex (see Corbetta et al., 1998), but also a wealth of behavioral experiments suggests that eye movements and attention are functionally related. Early research showed that participants tend to move their eyes in the same direction as their attention (Bryden, 1961; Crovitz & Daves, 1962) even in the absence of any visual stimulation (i.e., when attention is auditorily cued to the right or left ear; Gopher, 1973).

More recent studies have also shown the reverse to be true: Saccades tend to involve shifts in attention (Chelazzi et al., 1995; Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995; Shepherd, Findlay, & Hockey, 1986). Shepherd et al. (1986), for example, found that participants were faster to detect a probe in an invalid position (20% probability) that was in the direction of a saccade than they were to detect a probe at an 80% valid position but in the opposite direction to the saccade. However, the probe remained on the screen during the eye movement, so their results could be explained entirely in terms of the retinal eccentricity of the probe. More recently, this problem was rectified by removing the probe before the eye movement was executed (Chelazzi et al., 1995; Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). Participants were still faster at detecting a target at the saccadic location than at other locations (Chelazzi et al., 1995) and were more accurate at identifying targets at the saccadic location than elsewhere (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995).

In summary, although attention may be moved independently of the fovea, as shown by spatial cuing studies, it appears that when participants are free to make eye movements, these eye movements tend to follow the direction of attentional shifts, and conversely, shifts of the fovea typically involve shifts of attention. It remains possible, however, that this linkage between fixation and attention may only apply to eye movements and may not extend to situations in which the eye is stationary. In the present study, we asked whether irrelevant distractors at fixation could be ignored in a situation in which short exposure durations discouraged eye movements.

Irrelevant Information at Fixation

There have been three previous studies that examined distractor processing at fixation. Goolkasian (1981) used a separated Stroop paradigm in which the distracting dimension (e.g., a word) remained at fixation while the target dimension (e.g., a color patch) was presented either at the fovea (directly under the distractor) or at various peripheral retinal locations (7°, 15°, or 25° eccentricity). She found that foveal distractors influenced RTs at all target locations except for the most distant (25° eccentricity). Moreover, as with peripheral distractors (Kahneman & Henik, 1981), she found that interference decreased as the distance between fixation distractor and target increased. However, a peripheral distractor condition was not included in this experiment, so it was not possible to directly compare the effects of fixation distractors and peripheral distractors. Thus, the question of whether fixation distractors are more distracting than peripheral distractors was left open.

A direct comparison of the processing of irrelevant information at fixation versus in the periphery was conducted in two more recent lines of study. It is interesting that although most of the evidence we previously reviewed suggests that stimuli at fixation may be harder to ignore than peripheral stimuli, both of these lines of study suggest, at first glance, that it is easier to ignore information at fixation than in the periphery. Mack and Rock (1998) compared the rate of "inattentional blindness" between irrelevant foveal stimuli and parafoveal stimuli. In the case of irrelevant foveal stimuli, they presented a small (less than 1° of visual angle) task-irrelevant object briefly and unexpectedly at fixation while participants were engaged in a demanding parafoveal task (comparing the lengths of the arms of a crosshair, presented in one of four positions in the parafovea). Immediately after the object was presented, participants were asked whether they saw anything additional in the display. Across a number of experiments, 50% to 90% of participants reported being unaware of the presence of any object at fixation (i.e., they appeared to be inattentionally blind to that object). Surprisingly, this rate was even higher than reports of inattentional blindness (approximately 25% of the participants) for unexpected objects presented in the parafovea (at 2° eccentricity) during performance of a crosshair task at fixation.

However, this finding may be a result of differences in the task demands for targets presented at fixation (in the case of the unexpected object in the parafovea) and targets presented in one of four positions in the parafovea (in the case of the unexpected object at fixation). The parafoveal task, for example, involves greater location uncertainty than the same task at fixation.[1] In addition, focusing attention away from fixation on a parafoveal target may be more difficult than focusing attention on a fixated

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[1] Mack and Rock (1998) found similar results (i.e., greater inattentional blindness for unexpected objects at fixation than in the parafovea) in one study in which the parafoveal target location was cued with a central arrow that was presented for 1 s before the target. Such long cue durations, however, allow for eye movements, thus precluding a clear interpretation of the results from this study.

target.[2] It is thus possible that the parafoveal task imposed greater demands on attention than the fixation task and thus reduced the availability of attention for processing irrelevant information (e.g., Lavie, 1995, 2001) at fixation, more than the fixation task did for irrelevant information at the parafovea.

A similar account can explain another set of results that appear, at first sight, to show that it is easier to ignore distractors at fixation than in the periphery. Using a flanker task, Goolkasian (1999) assessed the effects of spatial separation between target and distractors on processing foveal versus peripheral distractors. She found that the effect of target-to-distractor distance was greater from foveal distractors than from peripheral distractors, such that, at greater target-to-distractor separations, distractor compatibility effects were larger for the peripheral distractors than the foveal distractors. However, as in Mack and Rock's (1998) study, the task demands were not equivalent between the fixation and peripheral distractor conditions. Whenever distractors were peripheral, the target task was foveal, and whenever the distractor was foveal, the target task was peripheral. Moreover, peripheral targets could appear in one of two peripheral locations, whereas foveal targets were only ever presented at the fovea. Thus, again, the reduced foveal distractor effects in the peripheral target condition (vs. peripheral distractor effects in the foveal target condition) may be the result of greater demands on attention by the peripheral versus foveal target tasks in these conditions.

The Present Experiments

In the present experiments, we compared response compatibility effects for peripheral versus fixation distractors presented while participants searched for a target letter in a parafoveal letter-circle (see Figure 1). The fixation distractor was presented in the center of the letter-circle, and the peripheral distractor was presented at the same distance from the circle but outside it. The target array was always in the same position regardless of the position of the distractor (cf. Goolkasian, 1999). In this way, the demands of the relevant tasks were kept constant across peripheral and fixation distractor conditions. Under all distractor conditions, participants searched for the letters *X* or *N* among five other letters (Experiments 1–2) or among place holders (Experiments 1–5). The distractor letter was also an *X* or an *N*, and distractor processing was assessed by comparing target RTs between compatible and incompatible distractor conditions. We hypothesized that if fixation distractors are harder to ignore than peripheral distractors, then they should produce larger interference effects.

To somewhat anticipate our findings—fixation distractors did indeed produce larger distractor interference in all our experiments. In Experiments 1 and 2, we examined whether interference effects from fixation distractors would be modulated by load to the same extent as interference effects from peripheral distractors. In Experiment 2, we also examined whether cuing by the initial fixation dot might be responsible for the increased distractor effects at fixation. Experiments 1 and 2 also revealed an effect of general slowing in the presence of any to-be-ignored item at fixation versus in the periphery, and in Experiment 3 we examined this effect further. In Experiments 4 and 5, we examined whether the cortical magnification of distractor stimuli at fixation could account for the increased interference from fixation distractors. The possibility that the predictability (i.e., probability of occurrence) and location certainty of the fixation distractors versus those of the peripheral distractors contributed to the differences in distractor effects was assessed in Experiment 5. Finally, in Experiment 6, we examined whether the display arrangement contributed to the different fixation and peripheral distractor effects. Specifically, we examined whether the larger distractor effects at fixation than in the periphery were due to the fact that the fixation distractors were positioned in the center of the relevant letter-circle, whereas the peripheral distractors were outside of it.

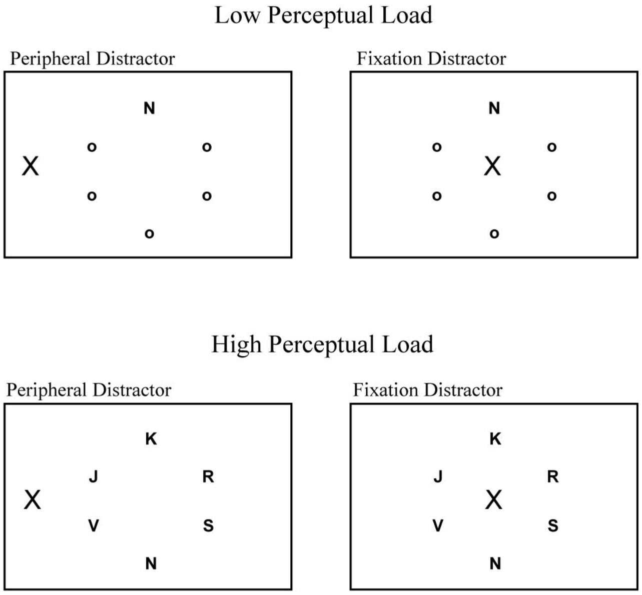

Figure 1. Example stimuli used in Experiments 1 and 2. In all four examples, the distractor is incompatible with the target. Displays in Experiments 3–5 were similar to the low perceptual load displays except that in Experiment 3, the incompatible distractor was replaced with a neutral distractor (*S*), and in Experiments 4 and 5 the distractors were sized according to their cortical magnification.

Experiment 1

In Experiment 1, we compared compatibility effects of peripheral and fixation distractors as a function of the level of perceptual load in the relevant search task. Figure 1 presents an example of the stimulus displays in this experiment. Participants searched for either an *X* or an *N* target letter among five other letters in the high perceptual load condition, or among five place holders (small circles) in the low perceptual load condition. We were interested in whether distractor effects differed when the distractor letter (an *X* or *N*) appeared at fixation (in the center of the circle) versus in the left or right periphery. We also asked whether the perceptual load of a relevant task has the same effect on processing distractors at fixation as it does in the periphery. Previous studies demonstrated that high perceptual load in a relevant task reduces processing of irrelevant distractors (see Lavie, 2001, 2005, for reviews). However, this finding has always applied to peripheral distractors. If

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[2] Mack and Rock (1998) made a similar argument to explain their results, only they posited an additional inhibition of information at fixation.

stimuli at fixation are given such high priority that they are always processed, regardless of the demands in a relevant task, then the perceptual load of the relevant task should have no, or comparatively little, effect on fixation distractor effects relative to peripheral distractor effects. Alternatively, like the processing of peripheral distractors, the processing of fixation distractors may also depend on the availability of spare capacity from the relevant task and may thus be similarly modulated by perceptual load.

Method

Participants

Twelve participants were recruited from University College London and were paid for their participation. They were all between 18 and 35 years of age, had normal or corrected-to-normal vision, and were naive to the experimental hypotheses.

Apparatus and Stimuli

The experiments were created and run on an IBM-compatible PC attached to a Sony Trinitron monitor using MEL software (Psychology Software Tools, Inc., Pittsburgh, PA; Schneider, 1988). Participants viewed the displays through a custom-built viewing box that kept their distance from the screen at 60 cm. Participants responded by pressing one of two buttons on the keyboard.

All stimuli were presented in a light gray color on a black background. Displays consisted of a target letter (*X* or *N*) that appeared randomly but with equal probability in one of six positions arranged in a circle with a radius of 2°. The other five positions were either occupied by small circles (low perceptual load, see top of Figure 1), or by five nontarget letters (*S*, *K*, *V*, *J*, and *R*; high perceptual load, see bottom of Figure 1). The five nontarget letters could appear in any of the six positions randomly and with equal probability. At a viewing distance of 60 cm, the target and nontarget letters subtended 0.36° of visual angle horizontally and 0.54° vertically. In addition to the task-relevant stimuli, an irrelevant distractor letter was located in one of three positions: at fixation or with the center of the distractor letter positioned 3.5° to the left or the right of fixation. The distractor was slightly larger (0.43° × 0.67°) than the target and nontarget letters in order to ensure visibility in the periphery and to provide an additional cue to differentiate target and distractor. The distance between both the fixation and peripheral distractors and the nearest letter was 2° from center to center. The distractor was equally likely to be compatible (e.g., an *X* when the target was an *X*) or incompatible (e.g., an *X* when the target was an *N*). A set of 72 different displays was made to include a fully counterbalanced presentation of distractor position (3), distractor letter (2), target position (6), and target letter (2).

Procedure

Each trial began with a fixation dot presented in the center of the screen for 1,000 ms. The circular letter display and distractor were then presented for 100 ms. Participants were asked to respond as quickly as possible by pressing the *0* key on the numeric keypad for an *X* target, and the *2* key for an *N* target. They were also instructed to ignore the distractor letter and told that it might have a detrimental effect on performance. A new trial was initiated following a participant's response, or after 2 s if she or he failed to respond. Feedback was given in the form of a computer beep for incorrect responses or failures to respond within 2 s.

Participants alternated between blocks with high perceptual load and blocks with low perceptual load. Half of the participants began with a low-load block, and half began with a high-load block. The distractor appeared in one of the three distractor positions (fixation, left periphery, and right periphery) with equal probability (i.e., 33.3% of the trials) within a block. Participants received two example blocks (one high and one low load) of 12 trials, two practice blocks of 72 trials, and eight experimental blocks of 72 trials. Example and practice blocks were excluded from the analysis.

Results and Discussion

Mean RTs and error rates were computed for each participant as a function of perceptual load (high vs. low), compatibility (compatible vs. incompatible), and distractor position (fixation vs. periphery) and entered into a three-way within-subjects analysis of variance (ANOVA). Table 1 presents the average of these mean RTs and error rates across participants. Incorrect trials were excluded from the RT analysis. The average error rate was 16% and ranged from 24% to 9% across participants.

RTs

RT analysis revealed a main effect of load, $F(1, 11) = 224.58$, $p < .01$. As expected, participants were slower in the high load than low load conditions. There was also a main effect of compatibility, $F(1, 11) = 24.19$, $p < .01$, and an interaction of load and compatibility, $F(1, 11) = 5.77$, $p < .05$, showing that response

Table 1
Mean Reaction Times (RTs, in Milliseconds) and Error Rates Across Participants (n = 12) as a Function of Distractor Compatibility, Distractor Position, and Load in Experiment 1

	Distractor compatibility					
	Incompatible (I)		Compatible (C)		I − C	
Distractor position	RT	% error	RT	% error	RT	% error
Periphery						
Low load	608 (46)	12 (2)	556 (38)	7 (2)	52* (20)	5 (1)
High load	713 (45)	22 (2)	713 (41)	17 (2)	0 (15)	5 (2)
Fixation						
Low load	671 (47)	17 (3)	568 (38)	10 (2)	103* (22)	7 (4)
High load	784 (44)	30 (2)	734 (40)	22 (3)	50* (15)	8 (3)

Note. Standard errors of the mean appear in parentheses.
* RT effects significant at $p < .01$.

compatibility effects were significantly reduced by higher load (see Table 1). These results are consistent with previous findings (e.g., Lavie, 1995; Lavie & Cox, 1997) that higher perceptual load leads to reduced distractor compatibility effects, and support the idea that processing of irrelevant distractors depends on the extent to which a relevant task leaves spare capacity that "spills over" to the processing of those distractors.[3]

The novel results of this experiment concern the effects of distractor position. The ANOVA revealed an interaction of distractor position and compatibility, $F(1, 11) = 10.62, p < .01$. This interaction was most relevant for our current interest: Compatibility effects were larger for fixation distractors (76 ms) than peripheral distractors (26 ms), as we anticipated. Because target-to-distractor distance varied in the peripheral distractor condition (owing to the variations in target position; see Figure 1), we conducted another comparison in which we excluded those trials in which the peripheral distractor was further from the target than was the fixation distractor. However, we point out that it has been shown previously that target-to-distractor distance has little effect on response compatibility effects when the target varies in location from trial to trial (Goolkasian & Bojko, 2001), as it does in our experiment. Consistent with this finding, the additional analysis replicated our effect of a significantly larger response compatibility effect for fixation distractors (76 ms) than peripheral distractors (25 ms), $F(1, 11) = 5.33$ $p < .05$. The issue of target-to-distractor distance is further addressed in Experiment 6, where fixation and peripheral target-to-distractor distance were equated.

There was also a main effect of distractor position, $F(1, 11) = 77.10$ $p < .01$, such that target responses were slower in the presence of fixation distractors than in the presence of peripheral distractors. As can be seen in Table 1, this slowing was found both for incompatible distractors, $F(1, 11) = 63.74$, $p < .01$ for the simple main effect, and for compatible distractors, although this difference was not significant in the latter case, $F(1, 11) = 2.94$, $p = .11$. Distractor position also did not interact with load ($F < 1$).

There was no three-way interaction among distractor position, load, and compatibility ($F < 1$). As can be seen in Table 1, response compatibility effects for fixation and peripheral distractors were modulated equally by perceptual load. Perceptual load reduced the response compatibility effect from 52 ms to 0 ms in the case of peripheral distractors and from 103 ms to 50 ms in the case of fixation distractors. Thus, distractor effects at fixation seemed to depend on availability of attention (as varied by the level of perceptual load in the relevant task) to the same extent as did the peripheral distractors.

The finding that the increase in interference effects from fixation distractors to peripheral distractors was constant at each level of perceptual load points to an overall processing advantage for information at fixation. Although processing distractor information at fixation depends on the availability of attention (and is thus reduced by conditions of high perceptual load that impose greater demand on attention), for the same level of attention, distractors at fixation have a greater effect on behavior than do peripheral distractors. We return to a discussion of the nature of this advantage in the General Discussion after we replicate the advantage for distractors at fixation (vs. in the periphery) while ruling out several alternative accounts.

Error Rates

Error rates, submitted to the same three-way within-subjects ANOVA as the RT data, revealed main effects of load, $F(1, 11) = 51.54$, $p < .01$, compatibility, $F(1, 11) = 14.01$, $p < .01$, and distractor position, $F(1, 11) = 15.63$, $p < .01$. As can be seen in Table 1, error rates were in the same direction as the RTs: Participants made more errors in high-load (23%) than in low-load (11%) conditions, more errors in incompatible (20%) than in compatible (14%) distractor conditions, and more errors when the distractor was at fixation (20%) than in the periphery (15%). There were no significant interactions in the error data ($p > .50$ in all other comparisons).

Experiment 2

Because a fixation dot in the center of the display preceded each display, it is possible that in Experiment 1 the larger fixation distractor effects were due to spatial cuing of the fixation distractors by the fixation dot (see Paquet & Lortie, 1990). In Experiment 2, the fixation dot was replaced by a fixation ring that cued the circle of target positions rather than the center of the display. The question we asked in this experiment was whether distractor effects remain greater at fixation than in the periphery when cuing of the fixation distractor is eliminated.

Method

Participants

Twelve new participants were recruited from University College London and were paid for their participation. One participant performed at chance in one condition and was replaced by another participant. They were all between 18 and 35 years of age, had normal or corrected-to-normal vision, and were naive to the experimental hypotheses.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure were the same as those in Experiment 1 except that a fixation ring (4° diameter) positioned in the center of the display was used instead of a fixation dot. The center of the fixation distractor was positioned to coincide with the center of the ring, and the centers of the task-relevant letters or circles were positioned to coincide with the ring itself. Participants were told that they needed to fixate in the center of the ring in order to be able to resolve all six target positions.

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[3] Another factor that may have contributed to the distractor effects in the condition with low perceptual load in this experiment is the fact that both the target and the distractor appear somewhat as singletons in this condition—the distractor because it is spatially separated from the circular letter array, and the target because it is the only letter in the circle. However, only the distractor might appear as a singleton in the condition with high perceptual load. The effects of perceptual load, however, do not depend on this characteristic. For example, Lavie and Cox (1997) showed that distractor effects are found at all levels of relevant set size smaller than 6 despite the target's no longer being a singleton in relevant set sizes greater than 1. Furthermore, Lavie (1995) showed effects of perceptual load on distractor processing by manipulating task requirements rather than the physical characteristics of the displays.

Results and Discussion

As in Experiment 1, incorrect trials were excluded from the RT analysis. The average error rate was 9% and ranged from 15% to 5% across participants. Table 2 presents the average RTs and error rates across the participants for all the experimental conditions. As can be seen from the table, the results for Experiment 2 were very similar to those of Experiment 1.

RTs

As in Experiment 1, a three-way within-subjects ANOVA of the RTs revealed main effects of load, $F(1, 11) = 57.64$, $p < .01$, and compatibility, $F(1, 11) = 24.19$, $p < .01$, as well as an interaction of load and compatibility, $F(1, 11) = 5.92$, $p < .05$, showing that distractor compatibility effects were again reduced by perceptual load, in accordance with Lavie's previous studies (e.g., Lavie, 1995; Lavie & Cox, 1997). Once again, there was an interaction between distractor position and compatibility $F(1, 11) = 28.88$, $p < .01$; response compatibility effects were larger for fixation distractors (69 ms) than peripheral distractors (11 ms). This effect cannot be attributed to the peripheral distractors' being more distant from some of the targets, as response compatibility effects were still significantly larger for fixation distractors (69 ms) than for peripheral distractors (6 ms) with the same target-to-distractor distance as the fixation distractors, $F(1, 11) = 27.60$, $p < .01$.

It is interesting that there was again a main effect of distractor position, $F(1, 11) = 23.55$, $p < .01$, which did not interact with load ($p > .20$); target responses were again slower in the presence of fixation distractors than in the presence of peripheral distractors. Simple effects revealed that this difference was significant for both incompatible trials, $F(1, 11) = 29.19$, $p < .01$, and compatible trials, $F(1, 11) = 8.67$, $p < .05$. The fact that this slowing occurred even when the distractor was compatible with the current response suggests that, in addition to the larger compatibility effect, there is a general RT cost associated with the presence of any stimulus at fixation (vs. in the periphery) regardless of identity. Such an effect may reflect a filtering cost similar to that reported by Kahneman, Treisman, and Burkell (1983). They found that participants were slower to read a word when it was presented with nonword distractors that were neither similar to the target nor response relevant (e.g., a dot patch). Because this interference effect appeared to be due to the simple presence of any other stimulus in the display, Kahneman et al. suggested that it reflects an initial process of filtering out any event in an irrelevant position in order to focus on a relevant event. If the general lengthening of RTs in our experiment reflects greater filtering costs, then our results would suggest that it takes longer to filter out information at fixation than it does in the periphery. However, there is an alternative explanation. The increase in RTs for the compatible fixation distractors may simply be due to participants responding more cautiously in the presence of all fixation distractors (including the compatible ones) because they know that the distractors could be incompatible, and incompatible distractors at fixation are more interfering than those at the periphery. This possibility was addressed in Experiment 3.

The three-way interaction of load, compatibility, and distractor position was not significant ($F < 1$). As before, fixation distractors were affected by perceptual load to the same extent as were peripheral distractors. High perceptual load reduced the response compatibility effect produced by peripheral distractors from 24 ms to −3 ms, and in the presence of fixation distractors, high perceptual load reduced the response compatibility effect from 82 ms to 55 ms.

Note that the response compatibility effects for both distractor positions were smaller for the low-load condition in this experiment than for the low-load condition in Experiment 1. This result may be attributed to better focusing on the relevant letter-circle now that it was cued by a ring and may have been confined to the low-load condition because attention was already maximally focused on the target in the high-load condition (Lavie, 1995, 2005). Consistent with this possibility is the fact that participants were faster ($M = 612$ ms) and more accurate (mean errors = 0.9%) in the current experiment than in Experiment 1 (mean RT = 668 ms and mean errors = 1.7%). Regardless of the cause of these differences, the overall pattern of results in Experiment 2 was the same as in Experiment 1. In both experiments, fixation distractors produced larger interference effects than peripheral distractors, but distractor effects at fixation and in the periphery were similarly affected by load. Clearly, the greater interference of distractors at fixation is not due to cuing by the fixation dot.

Table 2
Mean Reaction Times (RTs, in Milliseconds) and Error Rates Across Participants (n = 12) as a Function of Distractor Compatibility, Distractor Position, and Load in Experiment 2

	Distractor compatibility					
	Incompatible (I)		Compatible (C)		I − C	
Distractor position	RT	% error	RT	% error	RT	% error
Periphery						
Low load	524 (35)	6 (1)	500 (39)	4 (1)	24* (7)	2 (1)
High load	658 (28)	11 (2)	661 (30)	11 (2)	−3 (6)	0 (1)
Fixation						
Low load	597 (39)	11 (2)	515 (33)	6 (1)	82* (19)	5 (1)
High load	748 (33)	26 (2)	693 (31)	24 (2)	55* (12)	2 (2)

Note. Standard errors of the mean appear in parentheses.
* RT effects significant at $p < .01$.

Table 3
Mean Reaction Times (RTs, in Milliseconds) and Error Rates Across Participants (n = 8) as a Function of Distractor Compatibility and Distractor Position in Experiment 3

	Distractor compatibility					
	Neutral (N)		Compatible (C)		N − C	
Distractor position	RT	% error	RT	% error	RT	% error
Periphery	438 (19)	7 (1)	422 (19)	6 (1)	16 (9)	1 (1)
Fixation	478 (26)	12 (2)	421 (24)	5 (1)	57* (11)	8 (2)

Note. Standard errors of the mean appear in parentheses.
* RT effects significant at $p < .01$.

Error Rates

A three-way within-subjects ANOVA of the error data revealed significant main effects of load, $F(1, 11) = 15.79$, $p < .01$, compatibility, $F(1, 11) = 13.72$, $p < .01$, and distractor position, $F(1, 11) = 22.41$, $p < .01$. These effects were in the same direction as the effects in the RTs. Participants made more errors in high-load (13%) than in low-load (7%) conditions, more errors in incompatible (11%) than in compatible (9%) distractor conditions, and more errors (12%) in the presence of fixation distractors than in the presence of peripheral distractors (8%). There were no significant interactions in the error data ($p > .10$ for all).

Experiment 3

In Experiments 1 and 2, not only did fixation distractors produce larger compatibility effects than peripheral distractors, but there was an overall increase in RTs in the presence of any fixation distractors (including those that were response compatible). Because it is difficult to separate overall RT increases from the facilitatory and inhibitory components induced by compatible and incompatible distractors, these distractors are not ideal for assessing a general increase in RT.[4] In order to better assess whether there was indeed a general increase in RTs at fixation versus in the periphery, in Experiment 3 we included a neutral distractor (*S*) that had no relationship with the target response (*X* or *N*). Any increase in RTs for neutral distractors at fixation (vs. in the periphery) must be independent of the facilitation or interference associated with response compatibility.

Because perceptual load was shown to have the same effects on distractors in both positions in Experiments 1 and 2, only the low-load condition was used in this experiment. Also, in order to establish whether the lengthening of target RTs in the presence of response-neutral stimuli at fixation reflects a general filtering cost that occurs even if those stimuli can never be response-incompatible, we omitted the incompatible trials in this experiment, leaving only neutral and compatible trials. If the main effects of distractor position we found earlier were due to greater caution with stimuli at fixation induced by the presence of incompatible stimuli on some trials, then removing those trials should eliminate the effect, and we should see no RT cost for fixation versus peripheral neutral trials. However, if the distractor position effect reflects filtering costs associated with any to-be-ignored stimulus at fixation, then we should see a significant increase in RTs in the presence of neutral distractors at fixation versus in the periphery.

Method

Participants

Eight new participants were recruited from University College London and were paid for their participation. They were all between 18 and 35 years of age, had normal or corrected-to-normal vision, and were naive to the experimental hypotheses.

Stimuli and Procedure

The stimuli and procedure were the same as those in Experiment 1 except that only a low-load condition was used and a neutral distractor (*S*), which was not associated with the target response, was used instead of incompatible distractors. The experiment consisted of five experimental blocks of 72 trials preceded by a practice block of 72 trials and an example block of 12 trials.

Results and Discussion

Incorrect trials were excluded from the RT analysis. The average error rate was 7% and ranged from 2% to 10% across participants. Mean RTs were computed for each participant as a function of compatibility (compatible vs. neutral) and distractor position (fixation vs. in the periphery) and were entered into a two-way within-subjects ANOVA. Table 3 presents the average RTs and error rates across the participants.

RTs

There were again main effects of compatibility, $F(1, 7) = 17.65$, $p < .01$, and an interaction of compatibility and distractor position, $F(1, 7) = 21.54$, $p < .05$, showing that the fixation distractor produced greater compatibility effects than the peripheral distractor, as in all the previous experiments. Moreover, the interaction was also found when the analysis was limited to those trials in which the distance between the target and the distractor was the same for both fixation and peripheral distractors, $F(1, 7) = 12.93$, $p < .01$. For the purposes of this experiment, the main effect of distractor position, $F(1, 7) = 9.94$, $p < .05$, is the most relevant.

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[4] For example, in Experiment 1 there may be an underlying increase in RT for all fixation distractors, but the greater facilitation induced by the compatible distractor at fixation may have been such that it obscured this effect, thus resulting in an insignificant RT difference between compatible distractors at fixation and in the periphery.

Despite the removal of incompatible trials, RTs were longer in the presence of distractors at fixation than in the presence of distractors in the periphery. This finding is clearly a result of filtering costs that cannot be attributed to response compatibility costs.

As can be seen in Table 3, in this experiment, RTs were not longer in the presence of compatible distractors at fixation than in the presence of compatible distractors at the periphery. This finding is likely due to the greater facilitation at fixation than in the periphery (as indicated by the significant interaction of distractor compatibility and position), offsetting the effect of a general slowing of performance in the presence of stimuli at fixation and thus brings RTs in line with the compatible trials in the periphery.

This experiment thus clearly demonstrates that response-neutral stimuli are harder to filter out at fixation than in the periphery. Although these findings show that greater filtering costs associated with fixation cannot be a consequence of the compatibility effects, it remains possible that the greater compatibility effects found at fixation may be a consequence of the greater filtering costs. In particular, because items at fixation take longer to filter out (i.e., greater filtering costs) than comparable items in the periphery, any response-compatible or response-incompatible stimulus at fixation will have more time to affect response decisions. For example, longer latencies may allow items at fixation to be processed to the level of identification to a greater degree than items in the periphery.

Of course, it is also possible that the two effects—greater filtering cost and greater compatibility effects at fixation—are independent. Items at fixation may be harder to filter out, and on top of this, they may have stronger weights in response decisions than may peripheral distractors. Indeed, Experiment 6 provides evidence in support of the independence of these two components. We return to this issue in the General Discussion.

Error Rates

An ANOVA on error rates revealed main effects of compatibility, $F(1, 7) = 15.28$, $p < .01$, and an interaction between compatibility and distractor position, $F(1, 7) = 9.25$, $p < .05$. Consistent with the RT data, participants made more errors during neutral (10%) than during compatible (5%) distractor conditions. Moreover, the difference between neutral and compatible trials was larger for fixation distractors (8%) than for peripheral distractors (1%).

Experiment 4

In this experiment, we examined whether the greater interference effects from distractors at fixation than from distractors in the periphery could be explained by the cortical magnification of fixation stimuli. In Experiments 1–3, we used distractors of the same size at fixation and in the periphery to ensure that the size similarity between the target and the distractor was the same for fixation and peripheral distractors. Similarity between targets and distractors (e.g., in terms of their color and size) has previously been shown to be a strong determinant of distractor interference effects in the flanker task. Specifically, distractor interference tends to decline with reduced similarity between target and distractor (e.g., B. A. Eriksen & Eriksen, 1974; C. W. Eriksen & Schultz, 1979; Humphreys, 1981). Thus, in order to equate similarity to the target, the fixation and peripheral distractors in Experiments 1−3 were identical in size. However, this meant that the peripheral and fixation distractors were not equal in terms of retinal acuity. Although the peripheral distractor was clearly visible at the size in which it was presented (and indeed produced significant compatibility effects, indicating that it was identified), the cortical representation of the peripheral distractor would have been smaller than that of the fixation distractor because foveal regions of the visual field have a larger representation in cortex than in peripheral regions (termed *cortical magnification*; see Daniel & Whitteridge, 1961). In Experiment 4, we thus attempted to equate fixation and peripheral distractors in terms of their cortical representation by scaling the distractor sizes in accordance with the cortical magnification equations of Rovamo and Virsu (1979) and Virsu and Rovamo (1979). Specifically, distractor size was scaled according to the average of the following two equations:

$$M(\text{nasal visual field}) = 1 + 0.33\,E + 0.00007\,E^3$$

$$M(\text{temporal visual field}) = 1 + 0.29\,E + 0.000012\,E^3$$

where E refers to the eccentricity in degrees of visual angle and M is the magnification factor.

In addition to the scaling factor, distractor sizes were chosen such that the ratio between the fixation distractor and the target was the same as the ratio between the target and the peripheral distractor. This was done in an attempt to equate the relative size similarities between the fixation distractor and target and between the peripheral distractor and target (see C. W. Eriksen & Schultz, 1979). Specifically, the fixation distractors were now 2/3 the size of targets, whereas the peripheral distractors were now 3/2 the size of targets.

Method

Participants

Fifteen new participants were recruited from University College London and were paid for their participation. They were all between 18 and 35 years of age, had normal or corrected-to-normal vision, and were naive to the experimental hypotheses.

Stimuli and Procedure

Peripheral distractors were centered at an eccentricity of 3.5°, which according to the above cortical magnification equations required them to be approximately twice ($M = 2.08$) as large as the fixation distractor in order for both distractors to activate the same amount of primary visual cortex. With the additional requirement that the size ratio between the fixation distractors and the target be approximately equal to the ratio between the target and the peripheral distractors, the following sizes were chosen: Fixation distractors subtended 0.28° × 0.38°, peripheral distractors subtended 0.57° × 0.86°, and targets subtended 0.38° × 0.57°. These sizes produced a ratio of 2/3 between the target and fixation distractors and 3/2 between the target and peripheral distractors and a cortical magnification that slightly favored the peripheral distractor. The peripheral distractors were 2.3 times larger than the fixation distractors vertically, rather than reflecting the required cortical magnification factor of 2.08. Horizontally, the peripheral distractors were the required 2.0 times larger than the fixation distractors. The ratio of width to height of the letters was unchanged from Experiments 1−3. Finally, the distance between the edge of each distractor and the nearest potential target was 1.7°. All other aspects of the stimuli and procedure were the same as in the low-load conditions of Experiment 1. As only the low-load condition was run, the experiment consisted of four experimental blocks of 72 trials preceded by a practice block of 72 trials and an example block of 12 trials.

Results and Discussion

Incorrect trials were excluded from the RT analysis. The average error rate was 8% and ranged from 15% to 1% across participants. Mean RTs were computed for each participant as a function of compatibility (compatible vs. incompatible) and distractor position (fixation vs. periphery) and entered into a two-way within-subjects ANOVA. Table 4 presents the average RTs and error rates across the participants.

RTs

There were again main effects of compatibility, $F(1, 14) = 54.12$, $p < .01$, and distractor position, $F(1, 11) = 45.96$, $p < .01$, as well as an interaction between compatibility and distractor position, $F(1, 14) = 29.64$, $p < .01$. As can be seen in Table 4, response compatibility effects were again larger for fixation distractors (101 ms) than peripheral distractors (28 ms). As in Experiments 1 and 2, this effect cannot be attributed to the distance between the target and the distractor. The response compatibility effect was still significantly larger for fixation distractors (101 ms) than for peripheral distractors with the same target-to-distractor distance as the fixation distractors (23 ms), $F(1, 11) = 20.68$, $p < .01$. Thus, it is clear that the larger cortical representation of fixation distractors than of peripheral distractors in Experiments 1–3 cannot explain the larger fixation distractor effects. Even with cortical representations equated, fixation distractors still produced a much larger response compatibility effect than did peripheral distractors.

In fact, the larger peripheral distractors in Experiment 4 produced smaller distractor effects (28 ms) than did the peripheral distractors in Experiment 1 (52 ms in the corresponding low-load condition). As mentioned earlier, distractors were more similar in size to the target in Experiment 1 than they were to the target in Experiment 4. Thus, the smaller distractor effect for the larger peripheral distractor suggests that similarity between target and distractors is more critical than absolute size in determining peripheral distractor effects. Fixation distractor effects, by contrast, were unaffected by the reduced size similarity between the fixation distractor and the target. Distractor effects were 101 ms in Experiment 4 and 103 ms in the corresponding low-load condition of Experiment 1 even though the fixation distractors in Experiment 4 were smaller than the target and had the same target-to-distractor size ratio as the peripheral distractors that showed the reduced interference in this experiment.

As in Experiments 1–3, there was a main effect of distractor position, with RTs being 62 ms longer in the presence of fixation distractors than in the presence of peripheral distractors. This effect was found for incompatible, $F(1, 14) = 52.37$, $p < .01$, as well as compatible distractors, $F(1, 14) = 8.98$, $p < .05$. Given the results of Experiment 3, we interpret this effect as a general filtering cost associated with the presence of any to-be-ignored stimulus at fixation versus in the periphery. As this effect persisted despite cortical magnification of the peripheral stimuli, the greater filtering cost at fixation cannot simply be due to the greater acuity of fixation stimuli. Indeed, this is what one might expect from a general filtering cost account of the general slowing in performance in the presence of any stimuli at fixation (vs. at the periphery), as the account does not depend on the identity of the stimulus.

Overall, then, Experiment 4 shows that the greater cortical representation of stimuli at fixation than at the periphery cannot explain the larger response competition effects as well as the general slowing effects of fixation distractors. Scaling according to the cortical magnification factor has been shown to minimize visibility differences across eccentricities in a number of visual tasks (for reviews, see Goolkasian, 1994, and Virsu, Nasanen, & Osmoviita, 1987). In Experiment 4, however, cortical scaling did not produce any reduction in the difference between fixation and peripheral distractors effects. In fact, this difference was elevated compared to that in Experiments 1 and 2. Clearly, our effect cannot be attributed to simple differences in cortical size between fixation and peripheral stimuli.

Error Rates

An ANOVA on error rates revealed main effects of compatibility, $F(1, 11) = 8.17$, $p < .05$, and distractor position, $F(1, 11) = 20.85$, $p < .01$. As in the previous experiments, participants made more errors during incompatible (11%) than compatible (6%) distractor conditions and more errors when the distractor was at fixation (11%) than in the periphery (6%). There was no interaction between compatibility and distractor position ($p > .10$).

Table 4
Mean Reaction Times (RTs, in Milliseconds) and Error Rates Across Participants (n = 15) as a Function of Distractor Compatibility and Distractor Position in Experiment 4

	Distractor compatibility					
	Incompatible (I)		Compatible (C)		I − C	
Distractor position	RT	% error	RT	% error	RT	% error
Periphery	535 (30)	8	507 (31)	5	28* (7)	3
Fixation	633 (27)	15	532 (31)	8	101* (14)	7

Note. Standard errors of the mean appear in parentheses.
* RT effects significant at $p < .01$.

Experiment 5

Experiments 2 and 4 ruled out cuing by the fixation dot and cortical magnification as accounts for the greater interference from distractors at fixation than from distractors in the periphery. It remains possible, however, that the greater interference from fixation distractors in these experiments was due to a difference in the predictability of a distractor at fixation than of a distractor in either of the two (left and right) peripheral positions. In Experiments 1–4, although each of the three distractor positions (right periphery, left periphery, and fixation) was equally likely to have a distractor, the probability of a distractor in the periphery (66.7%) was twice the probability of a distractor at fixation (33.3%). Perhaps, then, peripheral distractors were more effectively ignored than fixation distractors because a distractor was more probable in the periphery than at fixation.

In Experiment 5, the distractor appeared with equal probability at fixation and in the periphery. Furthermore, in the previous experiments, the location of the fixation distractor was always fixed, whereas the location of the peripheral distractor varied from trial to trial. In the current experiment, only one peripheral location was used. This had the advantage of equating not only the predictabilities of fixation and peripheral distractors but also their location certainties.

Finally, although the lack of any cortical magnification effect in Experiment 4 fits with a higher level attentional account for the fixation advantage, it may appear somewhat surprising given the clear effects that cortical magnification has on low-level vision. In Experiment 5, we thus sought to further confirm that the fixation advantage in attention does not depend on cortical magnification. We therefore magnified the stimuli at the periphery once again, using the same cortical magnification formula and target-to-distractors ratios as in Experiment 4 but doubling the size of all stimuli for the sake of generality.

Method

Participants

Twelve new participants were recruited from University College London and were paid for their participation. They were all between 18 and 35 years of age, had normal or corrected-to-normal vision, and were naive to the experimental hypotheses.

Stimuli and Procedure

The stimuli and procedure were the same as those in Experiment 4 except that only one peripheral distractor position was used for each participant. For half the participants, the peripheral distractor always appeared on the right, and for the other half, the peripheral distractor always appeared on the left. With only one peripheral distractor position, the predictabilities of the fixation and peripheral distractors were also equated. On half the trials, the distractor appeared in the periphery, and on the other half, it appeared at fixation. Because the target letters were equally likely to appear in any of the six positions on the circle, participants still had to maintain central fixation to perform the task well. The cortical magnification factor and letter positions were the same as those used in Experiment 4 except that the sizes of all the letters were doubled. Fixation distractors subtended 0.52° × 0.78°, peripheral distractors subtended 1.12° × 1.68°, and targets subtended 0.73° × 1.12°.

Results and Discussion

Incorrect trials were excluded from the RT analysis. The average error rate was 13% and ranged from 5% to 30% across participants. Mean RTs were computed for each participant as a function of compatibility (compatible vs. incompatible), distractor position (fixation vs. periphery), and side of peripheral distractor (right vs. left; a between-subjects factor) and were entered into a mixed factor ANOVA. Table 5 presents the average RTs and error rates across the participants.

RTs

As in the previous experiments, there was a main effect of compatibility, $F(1, 10) = 27.59$, $p < .01$, and of distractor position, $F(1, 10) = 13.93$, $p < .01$, as well as an interaction between compatibility and distractor position, $F(1, 10) = 10.00$, $p < .05$. As argued earlier and substantiated by the results of Experiment 3, the main effect of distractor position can be interpreted as greater filtering costs at fixation than in the periphery. As can be seen in Table 5, response compatibility effects were again larger for fixation distractors (168 ms) than peripheral distractors (74 ms). Once again, this effect cannot be attributed to the distance between the target and distractor because the response compatibility effect was still significantly larger for fixation distractors than for peripheral distractors with the same target-to-distractor distance as the fixation distractors, $F(1, 11) = 10.53$, $p < .01$. There was no main effect of or interaction with the side of the peripheral distractor ($p > .20$ in all cases). These results suggest that the increased interference at fixation found in the previous experiments cannot be attributed to differences in the probability of occurrence and the location certainty of the fixation and peripheral distractors. The present results also confirm that cortical magnification cannot

Table 5
Mean Reaction Times (RTs, in Milliseconds) and Error Rates Across Participants (n = 12) as a Function of Distractor Compatibility and Distractor Position in Experiment 5

	Distractor compatibility					
	Incompatible (I)		Compatible (C)		I − C	
Distractor position	RT	% error	RT	% error	RT	% error
Periphery	506 (18)	15 (3)	432 (20)	10 (3)	74* (12)	5 (1)
Fixation	611 (30)	18 (3)	443 (20)	9 (2)	168* (36)	9 (2)

Note. Standard errors of the mean appear in parentheses.
* RT effects significant at $p < .01$.

account for the greater effects of distractors at fixation compared with those in the periphery. Once again, fixation distractors produced greater response competition effects as well as greater slowing of overall responses despite the scaling of the stimuli in the periphery. The larger overall level of response competition effects may be due to the greater distractor sizes used in this experiment.

Error Rates

An ANOVA on error rates revealed a main effect of compatibility, $F(1, 11) = 50.98$, $p < .01$, and an interaction between compatibility and distractor position, $F(1, 11) = 7.21$, $p < .05$. As in the previous experiments, participants made more errors during incompatible (16%) than compatible (9%) distractor conditions. Moreover, the difference between incompatible and compatible trials was larger for fixation distractors (10%) than peripheral distractors (5%).

Experiment 6

In the experiments presented thus far, the fixation distractors were always presented in the center of the circle of task-relevant letters, whereas the peripheral distractors were always presented outside of the circular letter array. In the present experiment, we asked whether this difference was responsible for the greater interference from distractors at fixation than from distractors in the periphery. The previous display arrangement may have resulted in the perception of the fixation distractor as being a part of the same perceptual group as the circle of task-relevant letters, whereas the peripheral distractor may have been perceived as a separate object (see Treisman, Kahneman, & Burkell's, 1983, demonstration of perceptual grouping effects for similar display arrangements of objects within a frame or outside a frame). Distractor compatibility effects in the flanker paradigm are known to be affected by whether the target and distractor are perceived as parts of the same perceptual group (see Baylis & Driver, 1992; Driver & Baylis, 1989; Kramer & Jacobson, 1991). The greater distractor interference from fixation distractors than from peripheral distractors may thus be attributed to effects of perceptual grouping rather than retinal position.

In addition, space-based models of attention might argue that the within-circle position of the fixation distractors may have been more difficult to ignore. According to such models, in order to ignore the peripheral distractor, participants must focus the attentional "spotlight" (or zoom lens; see C. W. Eriksen & St. James, 1986) on a contiguous region of space within the circle, simply contracting it to exclude the distractors outside of the spotlight or zoom. However, in order to ignore the fixation distractor, participants would be unable to distribute spatial attention across contiguous regions of space. Instead, they would essentially have to produce a ringlike zone of attention. Although there is some evidence that such a distribution of attention is possible (Egly & Homa, 1984; Juola, Bouwhuis, Cooper, & Warner, 1991; Müller & Hübner, 2002), there are also several reports of failures to distribute attention in a ringlike shape (Eimer, 1999, 2000; C. W. Eriksen & Yeh, 1985; Heinze et al., 1994; Posner, Snyder, & Davidson, 1980). These findings suggest at the very least that distributing attention in a ringlike shape may be more difficult than distributing attention across a contiguous region of space.

In Experiment 6, we thus manipulated whether the fixation distractor or the peripheral distractor appeared inside or outside the circular letter array by leaving the fixation and peripheral distractors where they were in the previous experiments but moving the letter-circle from trial to trial. On a random half of the trials, the letter-circle was centered in the display, as it was in the previous experiments, and on the other half of the trials, the letter-circle was centered around either the right or left peripheral distractor position (see Figure 2). If fixation distractors were more distracting because of their position in the center of the letter-circle, then moving the circular letter array into the periphery, leaving the fixation distractor outside the relevant letter array and the peripheral distractor inside the letter-circle, should reverse the results. That is, we might expect greater distractor effects from the peripheral distractors than from the fixation distractors.

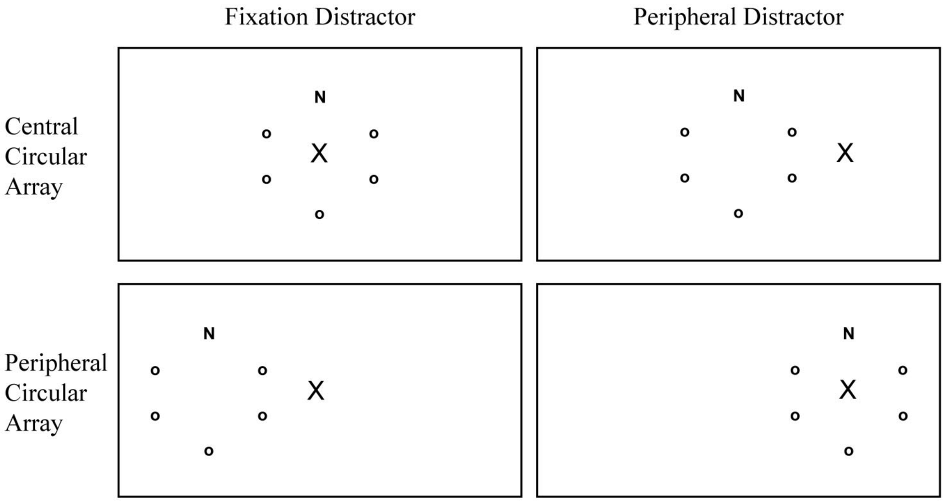

Figure 2. Example of display configurations used in Experiment 6. In all four examples, the rectangle represents the computer screen, with fixation at the center of each rectangle.

Cortical magnification was not used in this experiment because varying the sizes of stimuli could have interacted with the manipulation of perceptual grouping and because the scaling of stimulus sizes in both Experiments 4 and 5 had no effect on the results, clearly indicating that cortical magnification of the fovea is not responsible for the greater interference at fixation.

Method

Participants

Twelve new participants were recruited from University College London and were paid for their participation. They were all between 18 and 35 years of age, had normal or corrected-to-normal vision, and were naive to the experimental hypotheses.

Stimuli and Procedure

Stimuli were the same as those in Experiment 1 except that the circular letter array could either surround fixation (as in Experiments 1–5) on half of the trials or surround one of the peripheral distractor positions (3.5° to the left or right of fixation) with equal probability. The distractor also appeared at fixation on half of the trials and in one of the peripheral positions with equal probability on the other half of the trials. The factors of distractor position and circular letter array position were orthogonally combined to produce four trial types (shown in Figure 2): fixation distractor inside the central circular letter array, fixation distractor outside the peripheral circular letter array, peripheral distractor inside the peripheral circular letter array, and peripheral distractor outside the central circular letter array. There were no trials in which a peripheral distractor was outside of a peripheral letter array; if a trial contained both a peripheral distractor and a peripheral letter array, then the peripheral letter array was always centered on the peripheral distractor. A full counterbalancing of target, compatibility, target position, distractor position, and array position was achieved across two consecutive blocks of 96 trials each.

Once again, only the low-load condition was used. The experiment began with an example block of 24 trials and two practice blocks of 96 trials, followed by six experimental blocks. All other aspects of the stimuli and procedure were the same as in Experiment 1.

Results and Discussion

Incorrect trials were excluded from the RT analysis. The average error rate was 6% and ranged from 11% to 1% across participants. Mean RTs were computed for each participant as a function of compatibility (compatible vs. incompatible), distractor position (fixation vs. periphery), and letter-circle position (central vs. periphery), and entered into a three-way within-subjects ANOVA. Table 6 presents the average RTs and error rates across the participants.

RTs

RT analysis revealed main effects of compatibility, $F(1, 11) = 67.75$, $p < .01$, and distractor position, $F(1, 11) = 6.73$, $p < .05$. As in the previous experiments, participants were slower in the presence of incompatible distractors than in the presence of compatible distractors and slower in the presence of fixation distractors than in the presence of peripheral distractors. Moreover, compatibility and distractor position interacted, $F(1, 11) = 10.84$, $p < .01$, again revealing larger response compatibility effects for fixation distractors than peripheral distractors (see Table 6). This effect cannot be attributed to the distance between the target and distractor because in the current design, both peripheral and fixation distractors were equally likely to be near or far from the targets (see Figure 2).

It is important to note that the larger response compatibility effect for fixation distractors than for peripheral distractors was unaffected by the position of the letter-circle (insignificant three-way interaction, $F < 1$). Notably, even when the fixation distractor was outside the letter-circle (i.e., the letter-circle was in the periphery), it still produced a larger response competition effect than that produced by a peripheral distractor inside the letter-circle; that is, the interaction of distractor position and compatibility for the peripheral letter-circle conditions was significant, $F(1, 11) = 5.56$, $p < .05$.

The peripheral letter-circle also had longer overall RTs (538 ms) than the central letter-circle (483 ms; i.e., there was a main effect of letter-circle position), $F(1, 11) = 45.87$, $p < .01$, and suffered from a larger compatibility effect (131 ms) than the central letter-circle (95 ms; i.e., there was a significant interaction of letter-circle position and compatibility), $F(1, 11) = 11.94$, $p < .01$. These results are likely to be due to the fact that the target in the peripheral (vs. central) letter-circles suffered from reduced retinal

Table 6

Mean Reaction Times (RTs, in Milliseconds) and Error Rates Across Participants ($n = 12$) as a Function of Distractor Compatibility, Distractor Position, and Letter-Circle Position in Experiment 6

	Distractor compatibility					
	Incompatible (I)		Compatible (C)		I − C	
Distractor position	RT	% error	RT	% error	RT	% error
Central array						
Fixation (inside)	527 (28)	6 (1)	425 (27)	3 (1)	102* (12)	3 (1)
Periphery (outside)	534 (42)	7 (2)	446 (32)	3 (1)	88* (22)	4 (1)
Peripheral array						
Fixation (outside)	636 (38)	12 (3)	484 (32)	5 (1)	152* (19)	7 (1)
Periphery (inside)	571 (31)	6 (1)	460 (27)	4 (1)	111* (11)	2 (2)

Note. Standard errors of the mean appear in parentheses.
* RT effects significant at $p < .01$.

acuity as well as increased location uncertainty (the peripheral letter-circle could occur on either the right or the left). The reduced visibility of the targets would have resulted in slower identification RTs and may have rendered them more prone to distractor interference, as recently established by Lavie and de Fockert (2003). Moreover, the relative location uncertainty of the target array may have made focusing on either one of the peripheral letter-circles more difficult, thus allowing for more distractor intrusions. Goolkasian and Bojko (2001) found significant compatibility effects from distractors as far away as 40° when target position varied across that same distance from trial to trial. However, compatibility effects were eliminated at even half that distance when the target was presented at fixed location throughout a block. Although target location varied in all of our experiments, the variation was greatest in the current experiment, as it included peripheral circle positions in addition to the central circle. Thus we would expect participants to adopt a broader focus of attention, resulting in greater distractor effects overall.

Letter-circle position interacted with distractor position, $F(1, 11) = 8.69$, $p < .05$. Specifically, the peripheral letter-circle condition produced the typical filtering cost found in previous experiments, with a slowing of target responses in the presence of any fixation distractor (including compatible ones) relative to the peripheral distractors, $F(1, 11) = 13.46$, $p < .01$. However, the central letter-circle conditions produced an opposite (although nonsignificant, $p > .20$) trend for slower responses in the presence of any peripheral distractor than any fixation distractor. In other words, for each letter-circle, participants were slower whenever distractors appeared outside it rather than inside it. This pattern of results is consistent with those of Treisman et al. (1983). They found that RTs were longer when the display contained two perceptual groups (as when the distractor was positioned outside the letter-circle) than when the display items were integrated into one perceptual group (as when the distractor was inside the letter-circle). They argued that the increased RTs in the two-group condition reflect a competition between the two objects for attention. This competition does not exist when the two items are integrated into a single object. It is important to note, however, that although filtering costs were affected by whether the distractors fell inside or outside the circle, response competition effects were still greater for distractors at fixation than for distractors in the periphery even when fixation distractors did not produce general lengthening of RTs, as was the case for the central letter-circle. This result suggests that the effect of distractor identity on responses is independent of its filtering cost.

Error Rates

The ANOVA of errors revealed main effects of compatibility, $F(1, 11) = 13.13$, $p < .01$, distractor position, $F(1, 11) = 5.79$, $p < .05$, and letter-circle position, $F(1, 11) = 7.06$, $p < .05$. These effects were in the same direction as the effects for the RT data. Participants made more errors during incompatible (7%) than compatible (4%) conditions, more errors when the distractor was at fixation (6%) than in the periphery (5%), and more errors when the letter-circle was in the periphery (6%) than in the center (5%). As in the RT data, there was also a significant interaction of compatibility and distractor position, $F(1, 11) = 11.59$, $p < .01$, showing greater compatibility effects for fixation distractors than for peripheral distractors. As can be seen in Table 5, this interaction was driven by the peripheral letter-circle conditions, whereas the central letter-circle condition had a small trend in the opposite direction, although the three-way interaction of compatibility, distractor position, and array position did not reach statistical significance, $F(1, 11) = 3.54$, $p = .07$. This trend is similar to the RT results, which also showed a trend for greater compatibility effects from fixation distractors (vs. peripheral distractors) in the peripheral letter-circle than in the central letter-circle.

Although there was no interaction of compatibility and letter-circle position in the error data ($p > .10$), there was a numerical trend for greater compatibility effects in peripheral circles than in central circles, similar to the effect in the RT data. Finally, as in the RT data, there was an interaction between distractor position and letter-circle position, but the interaction was not quite significant, $F(1, 11) = 4.21$, $p = .06$.

General Discussion

The experiments presented here clearly demonstrate that fixation distractors are harder to ignore than peripheral distractors. In all six experiments, fixation distractors produced significantly greater response compatibility effects than peripheral distractors. Such a result is in accordance with research (outlined in the introduction) showing that stimuli at fixation receive better visual representation (e.g., activate more cells in visual cortex and are perceived with higher acuity) than more peripheral stimuli. However, Experiments 4 and 5 also showed that the larger distractor effects at fixation cannot be explained by the larger cortical area devoted to foveal vision than peripheral vision. Fixation distractors continued to produce greater interference even when the physical size of the fixation and peripheral distractors was scaled according to the cortical magnification factor in these experiments. In fact, the difference in interference effects between fixation and peripheral distractors was even larger when distractors were presented in sizes of equivalent cortical representation, presumably because of a greater effect of distractor/target similarity on the interference from peripheral distractors than on that from fixation distractors. Such a result argues against simple visibility explanations of the greater distractor effects at fixation than in the periphery in this study. Greater interference from fixation distractors is not simply a function of the number of cells devoted to foveal vision. Instead, an appeal to higher level processes such as attention must be made.

Our experiments also ruled out a number of alternative accounts for the greater interference effect at fixation than in the periphery: (a) Cuing of the fixation distractors by the fixation dot was ruled out in Experiment 2, as fixation distractors continued to produce significantly larger distractor effects than did peripheral distractors when the fixation dot was replaced by a ring that cued the positions of the relevant letter-circle. (b) A lower probability of distractor occurrence at fixation (33%) than in the periphery (66%), and therefore reduced habituation, or better setup of attentional filters, was ruled out in Experiment 5. Fixation distractors produced greater interference than peripheral distractors even when the distractors were equally likely to occur at fixation (50%) and in the periphery (50%). Moreover, in this experiment, only one peripheral distractor position was used, which thus equated location certainty across fixation and peripheral distractors. (c) The central position of the fixation distractor inside the task-relevant letter-circle versus the positioning of the peripheral distractor outside the task-relevant letter-circle was also ruled out as an alternative account in Experiment 6. Fixation distractors continued to produce larger interference than peripheral distractors when the display arrangement was reversed so that fixation distractors were presented outside the task-relevant letter-circle and the peripheral distractors were presented in the center of the letter-circle.

Filtering Cost

Our experiments also showed an overall slowing of target responses in the presence of any distractor (i.e., including distractors that are response compatible) at fixation versus in the periphery. As mentioned earlier, because this interference was also found for response-compatible and neutral distractors, and was unaffected by the extent to which the relevant task imposed a load on attention, it seems most likely to be due to earlier processes than those responsible for the response compatibility effect. Specifically, we argue that the interference is due to what Kahneman et al. (1983) term *filtering cost*. They found a cost, relative to when the target was presented alone, for responding to a target in the presence of another object, regardless of the identity or relevance of that object. Our conclusions were substantiated in Experiment 3 by the overall slowing of target responses in the presence of neutral distractors at fixation versus in the periphery, despite the absence of response-incompatible distractors in this experiment. As such, this effect could not be due to a strategy of greater caution toward fixation distractors on the basis of their greater interference when they are response incompatible. The results thus showed that it takes longer to filter out information at fixation than it does in the periphery.

Why Are Fixation Distractors Harder to Ignore?

The question then arises, why are fixation distractors more distracting? The experiments involving perceptual load and the neutral distractor are the most illuminating on this account. Experiments 1 and 2 clarified that distractor processing at fixation depends on the availability of attention to the same extent as does distractor processing in the periphery. Distractor interference effects from both fixation and peripheral distractors were similarly modulated by the level of load imposed on attention by the relevant letter task. Moreover, the increase in interference from distractors at fixation relative to those in the periphery remained constant at each level of perceptual load. However, although processing information at fixation depends on attention to the same extent as does processing information in the periphery (and is thus reduced by conditions of high perceptual load that impose a greater demand on attention), when both distractor positions receive similar attentional resources, fixation distractors produce greater response competition effects. This is best explained as resulting from a greater weight for stimuli at fixation in response selection. Although the finding that fixation stimuli are also associated with a greater filtering cost raised the possibility that the greater response competition effects from distractors at fixation (vs. in the periphery) are due to the longer latency to filter them out, thus allowing their identities to be processed more fully, Experiment 6 demonstrated that the two components can be dissociated. Even though under conditions that emphasize grouping there is no longer a greater filtering cost at fixation than in the periphery (in fact, the trend is for a reverse effect), the advantage of fixation distractors in response competition effects remains, suggesting that filtering costs and compatibility effects are independent.

Related Research

The present results are in contrast to results from two previous studies in which irrelevant stimuli at fixation appeared to have been more successfully ignored than irrelevant stimuli at more peripheral positions. Mack and Rock (1998) reported greater inattentional blindness for an unexpected stimulus in the fovea than for an unexpected stimulus in the parafovea, and Goolkasian (1999) reported that as spatial separation between targets and distractors increased, distractor compatibility effects became larger for the peripheral distractors than for the foveal distractors. Although these studies involved different paradigms (i.e., with Mack & Rock assessing explicit reports of awareness and Goolkasian assessing indirect response compatibility effects on target RTs), the experimental designs in both of these studies covaried target position, as well as target position uncertainty, with the position of the irrelevant stimulus. That is, targets were either presented in one of four positions in the parafovea (Mack & Rock, 1998) or in one of two positions in the periphery (Goolkasian, 1999) when the irrelevant stimulus was foveal, whereas the target was always presented in one position, at the fovea, when the irrelevant stimulus was in the parafovea or the periphery. Thus, the parafoveal and peripheral target conditions involved greater demands on attention than did the foveal targets. Therefore, the reduced interference from, and awareness of, irrelevant stimuli at fixation compared with irrelevant stimuli in the periphery (in the foveal target conditions) may be due to the reduced availability of attention for the processing of irrelevant stimuli when the target task imposes a greater demand on attention (e.g., Lavie, 1995, 2001). Indeed, we have shown that distractor processing at fixation depends on the availability of attention (as manipulated by varying the relevant task demands in our experiments) to the same extent as does distractor processing in the periphery.

The complications of unequal task demands were avoided in our paradigm by requesting participants to perform an identical task on parafoveal targets in all of the distractor position conditions. An interesting question for further investigation is whether with equal task demands, as in the present task, stimuli at fixation will start showing an advantage in awareness and produce less inattentional blindness, instead of more, when compared with stimuli in the periphery (Cartwright-Finch & Lavie, 2005).

Summary

Taken together, our results demonstrate that fixation distractors both are more difficult to filter out and have greater weight in response selection than do peripheral distractors. These advantages are robust. Not only did scaling by cortical magnification fail to reduce the advantage for distractors at fixation relative to distractors in the periphery, but the apparent prioritizing of information at fixation remained unaffected by various other manipulations such as the level of perceptual load in a relevant task, position cuing, probability of occurrence, location certainty, and position relative to the task-relevant letter-circle.

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Received January 9, 2003
Revision received July 29, 2004
Accepted November 29, 2004 ■

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