The influence of fixation points on contrast detection and discrimination of patches of grating: Masking and facilitation

Robert J. Summers, Tim S. Meese

School of Life and Health Sciences, Aston University, Birmingham B47 ET, UK

ARTICLE INFO

Article history:
Received 21 August 2008
Received in revised form 18 March 2009

Keywords:
Human vision
Psychophysics
Masking
Fixation point
Contrast sensitivity
Methods
Psychometric function
Slope

ABSTRACT

The use of fixation points (FPs) in visual psychophysics is common practice, though the costs and benefits of different fixation regimens have not been compared. Here we investigate the influence of several different types of FP configurations on the contrast detection of patches of sine-wave gratings. We find that for small targets (<1°), the addition of a superimposed central FP can increase thresholds by a factor of ~1.3 (~2.5 dB) in comparison with no FP, and a factor of ~1.5 (~3.6 dB) in comparison with FPs that surround the target. These results are consistent with (i) a suppressive influence on the central region of the target from a central FP, and (ii) facilitatory influences from surrounding FPs. Our analysis of the slope of the psychometric function suggests that the facilitatory influence is not due to reduction of uncertainty. Plausible candidate causes for the facilitation are: (i) sensory interactions, (ii) aids to ocular accommodation and convergence, (iii) a reduction in eye-movements and (iv) more accurate placement of the observer’s window of attention. Masking by a central FP is not found for the suprathreshold task of contrast discrimination, suggesting that the masking effects of pedestal and FP do not combine linearly. This means that estimates of the level of masking produced by a contrast pedestal can depend on the details of the fixation point.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

Fixation points, marks or contours (hereafter, FPs) are small visual indicators that are displayed either throughout, or extinguished just before, the presentation of a target. In contrast detection (and other types of psychophysical experiment) they are used because they are thought to help (i) achieve ocular accommodation (e.g. Owens & Leibowitz, 1975), (ii) achieve convergence (e.g. Marefat, Wu, & Yang, 1997), (iii) reduce eye-movements (e.g. Legge & Campbell, 1981; see also Sheedy, 1981), and (iv) reduce spatial uncertainty (e.g. Legge & Campbell, 1981; Petrov, Verghese, & McKee, 2006). As each of these factors is likely to improve sensitivity, there is a general belief that it is good psychophysical practice to use FPs because this will improve the likelihood of measuring the observer’s true sensitivity. However, although fixation itself has been studied intensively (see Coubard & Kapoula, 2005 for a brief review), surprisingly little research has been done to investigate whether FPs are effective or whether they have unwanted side-effects.

Of the studies that we know that have considered the roles of FPs in helping accommodation (Owens & Leibowitz, 1975) or reducing eye movements (Legge & Campbell, 1981), evidence is either weak or absent for their effectiveness, though circular FPs that surround the target (a ring) have been shown to improve mean fixation accuracy (Steinman, 1965). On the other hand, there are grounds for supposing a beneficial role for FPs by comparison with masking studies. For pedestal- or surround-masking experiments, it is claimed that the pedestal (Pelli, 1985) or annular mask (Petrov et al., 2006) reduces uncertainty and thereby improves performance. This is either by lifting the target above the level of the distracting noisy mechanisms (in the pedestal case) or by providing a cue to direct (spatio-temporal) attention in the annular or cross-oriented cases. Indeed, pedestals (Legge & Foley, 1980; Nachmias & Sansbury, 1974), annular masks (Meese, Summers, Holmes, & Wallis, 2007; Petrov et al., 2006; Yu, Klein, & Levi, 2002) and superimposed cross-oriented masks (Meese & Holmes, 2007; Meese, Summers, et al., 2007) have all been found to facilitate detection of the target (see also Meese, Holmes, & Challinor, 2007). However, it remains unclear how this facilitation should be apportioned between reduction of uncertainty (Pelli, 1985), sensory interactions (Chen & Tyler, 2001; Meese, Summers, et al., 2007) and direct excitation of the target mechanism by the mask (Legge & Foley, 1980; Stromeyer & Klein, 1974). Nevertheless, it seems plausible that FPs might cause effects that are similar to at least some of these types of facilitatory mask (Meese, Summers, et al., 2007; Petrov et al., 2006). In general then, there are reasons to suppose that FPs will help the observer detect the target. However, a recent study highlighted
the possibility of adverse effects of FPs (Meese & Hess, 2007). For small patches of target grating (~0.4°), contrast detection thresholds were about 1.76 dB (a factor of 1.2) lower when using four FPs arranged in a square around the target (‘quad’ FPs – see ahead to Fig. 1B) than when using a single point placed in the centre of the display (‘central’ FP – see ahead to Fig. 1A). However, it was not clear whether the differences arose from masking by the central FP or extra facilitation from the quad of FPs. As suppressive interactions between masks and targets are well established (Foley, 1994; Meese & Holmes, 2002, 2007; Ross & Speed, 1991) the possibility of suppressive influences from FPs is a distinct possibility.

There were two main aims to the present study. First, to conduct a detailed investigation of the effects of FPs on contrast detection thresholds. We did this for several configurations of FP and for several sizes and spatial frequencies of grating-type targets. Second, to try and establish whether the differences found by Meese and Hess (2007) were due to masking from the central FP or facilitation from the quad of FPs. We achieved this second goal by introducing a new form of FP configuration: a quad of FPs with an additional central FP. Comparisons between this and the other configurations were intended to reveal the influence of the two different components to the configuration. We conclude that both processes occur: central FPs can have a marked suppressive effect (>3 dB of masking) when the target is small, and surround FPs can improve detection (~1.5 dB) beyond that found without FPs.

These results were first presented in abstract form by Summers and Meese (2007).

2. Methods

2.1. Equipment

Stimuli were displayed on an Eizo M9000 CRT with a frame rate of 120 Hz using a CRS VSG 2/5 stimulus generator operating in pseudo 15-bit mode. The mean luminance of the central region (512 × 512 pixels; 5.4° × 5.4°) of the display was 40 cd/m². The surrounding region of the display was dark (<1 cd/m²). Gamma correction was performed to ensure linearity over the full range of target contrasts. Observers sat in a dark room at a viewing distance of 220 cm with their head in a chin and headrest. The casing of the display monitor was clearly visible to the observers. The experiment was controlled by a PC.

2.2. Stimuli

Except where stated, stimuli were 3 cycles of a horizontal sinu-soidal luminance grating modulated by a circular raised cosine envelope with a central plateau of one cycle and a blurred boundary width of one cycle (i.e. a full-width half-height of 2 cycles). Stimulus duration was 100 ms.

In Experiment 1, four stimuli were used with spatial frequencies of 1, 2, 4 and 8 c/deg, subtending 3°, 1.5°, 0.75° and 0.375°, respectively. Most of the subsequent experiments were carried out with the 4 c/deg grating patch, though Experiment 3 used the 1 c/deg patch. In Experiment 4 the full diameter of the 4 c/deg patch was extended to 12 cycles, matching the size of the 1 c/deg grating in Experiment 1. The spatial envelope was also the same as that used for the 1 c/deg patch (i.e. the central plateau was 4 cycles in diameter and the full-width at half-height was 8 cycles). Stimuli were always presented in the centre of the display and were in sine-phase (as shown in Fig. 1) and were viewed binocularly.

Contrast is expressed as Michelson contrast \( C \) in % \( \left( C = 100\left(\frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}} + L_{\text{min}}}\right)\right) \) and in dB re 1% \( (20 \cdot \log_{10} C) \).

2.3. Fixation points (FPs)

In Experiment 1 four different arrangements of FPs were used: no FP, a central FP (Fig. 1A), a quad of FPs (Fig. 1B) and a quad of FPs plus a central FP (Fig. 1C). The size of each FP was 2.6° square (4 × 4 pixels square) and was of the lowest luminance available from the monitor, appearing black. The centre of each point in the quad FPs lay on the corners of a square that surrounded the target. The side of the square was equal to the full width of the stimulus plus two pixels (1.3°).

In further experiments, other arrangements of FPs were used and are described in Section 3.

2.4. Procedure

In most experiments, the contrast level of the target was selected by a three-down, one-up staircase procedure (Wetherill & Levitt, 1965) and the threshold for a single FP was tested using a pair of randomly interleaved staircases (Cornsweet, 1962). The test contrast always began well above detection threshold and in an initial stage of data collection a large step-size was used (12 dB). After the first reversal the step-size was reduced to 3 dB and data collection continued for a further 12 reversals of each staircase. These last 12 reversals constituted the test-stage for each staircase. In Experiment 5 we used a method of constant stimuli (MCS) with 3 dB spacing between each of six target contrast levels. A single experimental session involved 20 trials randomly interleaved from each of the six target contrasts (i.e. 120 trials for each FP condition). In this experiment targets were presented on a pedestal contrast of either 0% or 20%.

We used a two-interval forced-choice (2IFC) procedure, where one interval contained the target and the other interval was blank. The onset of each 100 ms test interval was indicated by an auditory tone and the duration between the two intervals was 400 ms. Observers were required to select the interval containing the target using one of two buttons to indicate their response. Correctness of response was provided by auditory feedback, and the computer se-

Fig. 1. Examples of the fixation points (FPs) used in the experiments with a 4 c/deg patch of target grating. The target has a full-width at half height of 2 cycles (0.5°). (A) Central FP. (B) quad FP. (C) quad + central FP. In each panel, the FPs are shown in true scale against the size of the target patch.
lected the order of the intervals randomly. Different analysis methods were used for the staircase and MCS experiments. For each run with staircases, data from the test-stages (above) were collapsed across the two staircases (i.e. data from 24 reversals in total) and thresholds (75% correct) and standard errors were estimated by probit analysis. Individual estimates for each psychometric function were based on around 100 trials. Probit analysis also delivers an estimate of the slope of the psychometric function expressed as the sigma ($\sigma$) parameter (in dB) of the fitted cumulative log-normal distribution. This was converted to the more familiar Weibull $\beta$ parameter using the approximation $\beta = 10.3/\sigma$ (Summers & Meese, 2007). For the MCS experiment, the data were collapsed across sessions and fitted by a Weibull function using a maximum likelihood method (Wichmann & Hill, 2001a) with the lapse-error. The standard error calculation used for probit analysis was used only for the rejection criterion (see below) and not for graphical purposes. The errors bars in the figures show ±1SE of the mean across either different sessions for individual observers, or across different observers, as appropriate (see figure captions).

Experiments were blocked by the FP conditions and other stimulus conditions (e.g. spatial frequency and size) as appropriate. (In no experiment were trials from different experimental conditions interleaved.) Each experimental session comprised all the relevant conditions (blocks) selected in a random order. For each experiment, observers completed at least four sessions. Thus, mean thresholds were based on around 400 trials or more for each observer.

Before data collection began (and consistent with much of our earlier work), the following rejection and replacement criterion was set to lessen the impact of unreliable estimates of threshold. If the standard error of a threshold estimate (determined by probit analysis) within a block was greater than 3 dB (estimated by probit analysis), the data for that condition were discarded and the block was rerun. Only five thresholds were rejected by this criterion.

2.5. Observers

Three highly practiced psychophysical observers performed the experiments. These were the authors (RJS and TSM) and a postgraduate student (SAW). All observers wore their normal optical correction. RJS was the only observer to perform all of the experiments.

3. Results

3.1. Experiment 1: contrast sensitivity functions

In Experiment 1 we measured contrast sensitivity functions in the absence of a FP (open circles), with a central FP (solid circles), with a square quad of FPs (open squares) and with a combination of the quad and central FP (solid squares). Experimental results are shown in Fig. 2 averaged across three observers and the results of two-factor ANOVAs for each observer’s contrast sensitivity are shown in Table 1. The ANOVAs confirm that there are significant effects of spatial frequency, fixation point and interaction between these two factors for each observer. From Fig. 2A it is clear that for 1 and 2 c/deg there is little or no effect of the FP condition on sensitivity. In other words, at these spatial frequencies, the FPs conferred neither an advantage nor disadvantage. However, at 4 and 8 c/deg, FP effects were quite marked. Thresholds were higher when a central FP (solid circles) was used than when a quad FP (open squares) was used. At 4 c/deg the average difference between these two conditions was about 3.7 dB (a factor of 1.5) and at 8 c/deg it was about 4.5 dB (a factor of 1.7).

With regard to the specific (second) aim of our study, concerning influences from the centre and surround, there are two important comparisons here. The first is between the quads (square symbols), with and without a central FP (solid and open squares, respectively). This provides direct evidence that the central FP masks the target at 4 and 8 c/deg. The second is between no FPs and the quads. This provides direct evidence that detection is facilitated by FPs that surround the target. This small advantage (~1.2 dB) at 4 and 8 c/deg is consistent with that found by Meese and Hess (2007), and could be due to a reduction in uncertainty provided by the quad FPs. If this were so, then we should expect to see a corresponding reduction in the slope of the psychometric function (Pelli, 1985; Tyler & Chen, 2000). However, this was not found. The psychometric functions had similarly steep slopes ($\beta ~ 3$) for all four FP conditions and spatial frequencies (Fig. 2B). This suggests that the advantage conferred by the quad FPs was not due to a reduction in uncertainty (we consider this in greater detail in Section 4). For completeness, we also show the slopes of the psychometric functions for each of our subsequent experiments.

3.2. Experiment 2: does the central FP hide too much of the target?

One obvious problem with the central FP is that it obscures some of the target from view, and this could be the cause of the loss of contrast sensitivity. To address this we constructed a new FP condition made from a normal dark quad of FPs, plus a central FP of mean (background) luminance. This stimulus presents the observer with the same target area as in the earlier quad plus central FP condition, where all five points were dark. A comparison of the sensitivities for these two conditions, and the conventional quad condition is shown for RJS in Fig. 3A (all three conditions were run in this experiment). The effect of the central dark FP (quad + central) was the same as before, but when the central FP had mean luminance (quad + grey) there was no effect, providing clear evidence that the loss of sensitivity in the dark FP condition was not due to a loss of target area (or energy). Instead, this result

![Fig. 2. Results for Experiment 1. (A) Average thresholds for three observers (RJS, SAW and TSM) for four spatial frequencies (inverted contrast sensitivity functions) and four different types of FP. (B) Average psychometric slopes for the same observers and conditions as in (A). Error bars are ±1 standard error of the mean across observers where larger than symbol size.](image-url)
is consistent with the idea that the masking from the dark central FP arises from a suppressive influence driven by its own luminance contrast.

3.3. Experiment 3: are the effects due to the relative size of the FPs?

In Experiment 1 we varied the size and spatial frequency of the targets, but not the FPs. Therefore, the apparent absence of FP effects at low spatial frequencies could be due to the relatively small FP sizes in those conditions. To investigate this we measured detection thresholds for a 1 c/deg grating using FPs that were 16 × 16 pixel (10.4°) square for three observers. This represents a linear scaling of the size of the FPs used in the 4 c/deg condition from Experiment 1. It is not a serious candidate for an FP configuration in conventional psychophysical experiments (it is unreasonably large), but tests whether the FP effects are scale invariant with the size and spatial frequencies of the FPs and targets. The experiment was done for the three FP types shown in Fig. 3 plus a no FP condition. Results for the 4 c/deg condition from Experiment 1, using conventional sized FPs, are replotted for comparison (the experiments were performed within a few days of each other).

The use of large FPs at 1 c/deg (Fig. 4A, open circles) produced more masking than that seen in Experiment 1 (Fig. 2A), to the extent that the loss of sensitivity caused by the central FP (compared to no FP) was the same at both spatial frequencies (left half of Fig. 4A). However, the effects at 1 c/deg did not superimpose those at 4 c/deg (Fig. 4A, open circles) in each of the FP conditions, indicating a general lack of scale invariance. Most notably, a benefit from the quad FPs was not found at 1 c/deg. Furthermore, the addition of a central FP to the quads produced more masking at 4 c/deg than at 1 c/deg (right half of Fig. 4A). Thus, while the size of the central FP relative to the target bar-width appears to be important for suppression, this is not the critical factor for the facilitatory influence from the surround.

3.4. Experiment 4: do the FP effects depend on size or spatial frequency?

The results from Experiment 1 (Fig. 2A) suggest a dependency of FP effects on spatial frequency. However, since the size of the stimulus was also scaled with spatial frequency it is not clear which of these (spatial frequency or size) is the critical factor. To investigate whether the FP effects depend on target size or target spatial frequency, we performed an experiment using two 4 c/deg gratings of different sizes. The ‘small’ target was the same as that used in Experiments 1–3, and had a total diameter of 3 cycles. A new, ‘large’ target was scaled to have the same size as the earlier 1 c/deg grating, giving it a total diameter of 12 cycles. The experiment was performed for the two FP conditions shown in Fig. 5, and results are averaged across three observers.

Adding a central FP to the quad condition had no effect for the large target (large circles) but produced about 3 dB of masking for the small target (small circles), as in the previous experiments. Results are also replotted from Experiment 1 for the same three observers, reiterating that there is no effect for the large 1 c/deg target (grey squares). This pattern of results indicates that the central FP effect (with quads) depends critically on target size. Thus, it is plausible that the spatial frequency effects in Fig. 2A owe entirely to the reduction (scaling) of patch size in that experiment. This suggests that we might expect to find central FP effects at 1 c/deg with the 4 × 4 pixel FP if much smaller patches of grating were used. But reducing the target diameter of a 1 c/deg patch to match that in the conventional 4 c/deg condition would produce a target of less than one full cycle (0.5 cycles full-width at half-height). We were reluctant to pursue this because of the spectral contamination that would be produced by the severe spatial windowing of the target. In any case, stimulus patches with less than one cycle are rarely used in experiments, so the issue is of little practical concern.

3.5. Experiment 5: contrast detection and contrast discrimination

The previous experiments show that a central FP can mask the detection of small central patch of grating. Here we investigated...
whether this masking also occurs for the suprathreshold task of contrast discrimination. We used a method of constant stimuli with a pedestal contrast of either 0% (contrast detection) or 20% (contrast discrimination) for the stimulus configurations shown in Fig. 1B and C. The results are shown in Fig. 6 for two observers (RJS and TSM). We used a bootstrapping technique (Wichmann & Hill, 2001b) to reconfirm the masking effect at detection threshold (Fig. 6A and C) but show that there is no such effect well above detection threshold (Fig. 6B and D) (see figure caption for details). Note also that the slope of the psychometric function is much shallower for the contrast discrimination task (see figure caption for details), as was to be expected (Foley & Legge, 1981; Meese, Georgeson, & Baker, 2006).

3.6. Other experiments (Experiments 6+)

We investigated several other minor issues using the small 4 c/deg patch of target grating (Fig. 1) as follows. We confirmed that masking by the central FP (in the presence of quad FPs) was not affected by randomising the phase of the target (0°, 90°, 180°, 270°) or by reducing the size of the FPs by a factor of 2 (to 1.3°). This was the smallest size FP (2 × 2 pixels) that we could use in our laboratory while permitting central placement in our 512 pixel wide display region and without the aid of mirrors. We also found that this masking was reduced only very slightly (~0.5 dB) when the central ‘black’ FP (Fig. 1A) was replaced with a bright central FP (with a luminance of 80 cd/m²). Finally, we also tried a circular FP that was a 1 pixel wide dark grey ring with a contrast of ~15% (Petrov et al., 2006). The ring was centred on the target and had a diameter of 0.8° (3.2 target cycles). Compared to no FP, this produced the same benefits (facilitation of ~1.5 dB) as did the quad FP. Contrary to Petrov et al. (2006) we found no evidence that the ring FP reduced the slope of the psychometric function.

4. Discussion

We have provided the first detailed investigation of the effects of FPs on the detection of sine-wave patches of grating. We studied several different configurations of FP, several target and FP sizes, several target spatial frequencies, and found two types of effects: those where the FPs interfere with detection and those where they benefit detection. For the 4 c/deg target and 4 × 4 pixel FPs, the average sizes of the effects across all of our experiments were: 2.54 dB of masking for central FP vs. no FP; 3.56 dB of masking for central + quad FP vs. quad FP; and 1.66 dB of facilitation for quad FP vs. no FP.

4.1. Central fixation points are masks

We found that when an FP is superimposed centrally on a target patch of grating it can elevate detection thresholds, either relative to no FP (confirming Meese & Hess, 2007) or when it is embedded in a quad of FPs (relative to the quad baseline). This masking increases with a reduction in patch size (Experiment 4) and to some extent with an increase in FP size (Experiment 3, but see Experiments 6+), and can be found across a wide range of spatial frequencies (Experiments 1 and 3). We have not ruled out the possibility of an interaction between target size and spatial frequency. However, the results of Experiment 4 suggest that what appears as a spatial frequency effect in Experiment 1 can be attributed (in whole or in part) to a target-size effect. We found no situation where the presence of the widely used central FP (whether embedded in a quad or not) benefited the observer (improved contrast sensitivity) compared to no FP.

We attribute the threshold elevation produced by the central FP (with and without quads) to a broadband suppressive effect from the high-contrast FP (Experiment 2) whose influence increases with FP size (Experiment 3). This suppression presumably arises from either the cortical ‘gain pool’ considered by Albrecht and Geisler (1991) and Heeger (1992), and/or the subcortical ‘suppressive field’ identified by Shapley and Victor (1978) and Bonin, Mante, and Carandini (2005). Note that the failure to find a masking effect from a central FP in contrast discrimination is consistent with this conclusion, with the caveat that the masking effects from the pedestal and FP do not combine linearly (Foley, 1994).

4.2. Surrounding fixation points: uncertainty reduction or other factors?

Contrast detection thresholds with surrounding FPs (quads and ring) were around 1.5 dB lower than without a FP. This varied a little across FP conditions and observers, but is slightly less than the benefit of ~2.5 dB found by Petrov et al. (2006) for a ring FP or surrounding oriented lines. This could be due to differences between observers across studies (see the variation between observers in Petrov et al., 2006) or slight differences in the stimulus and FP configurations between studies. Petrov et al. attributed the improvement in their study to a reduction in uncertainty, citing steeper psychometric slopes and higher thresholds in the no FP condition as evidence for this (cf. Pelli, 1985). Uncertain observers attend to more mechanisms than are excited by the target and those extra (noisy) mechanisms act in a similar way to a hard threshold, causing a loss of overall sensitivity and steeper psychometric slopes (Georgeson, Yates, & Schofield, 2008; Pelli, 1985; Tyler & Chen,
From Pelli's (1985) Table 1, the level of uncertainty (M) for a Weibull $\beta = 3$ (fairly typical of the no FP condition here) is around 100. From the same table it can be shown that facilitation of ~1.5 dB requires a reduction in uncertainty from M = 100 to M ~ 27. This predicts a reduction of Weibull $\beta$ to ~2.4. Although this effect is quite small, we found no hint of it for our ring or quad FPs (and neither did Meese & Hess, 2007 for their quad FPs).

Overall, the slopes of the psychometric functions in the present study were fairly similar for all the FP configurations at contrast detection threshold ($\beta$ ~ 3 or 4; Figs. 2B–6), suggesting that reduction of uncertainty was not a major factor. One reason for this might be that the stimuli were always displayed in the centre of a large bright display region that was 5.4° square, against a dark background (see Methods). This arrangement might have been sufficient to avoid spatial uncertainty at least. Nevertheless, surrounding FPs typically improved performance by comparison with no FP (e.g. Fig. 2), so what might be the origins of this benefit? As mentioned in the Introduction, other potential influences of FPs include aiding accommodation and convergence, and reducing eye-movements. We know of little evidence to suggest that FPs are effective in these roles (Legge & Campbell, 1981; Owens & Leibowitz, 1975) but if they are, we expect that this would reduce variability (non-stationarity) of the psychometric function. In other words, we should expect these factors to make the psychometric function slightly steeper in the presence of FPs than in their absence. Presumably, this effect would also be greater at higher spatial frequencies, where small eye-movements and failures of accommodation and convergence would have the greatest consequences. In fact, our results here (and in Meese & Hess, 2007) do hint at support for this hypothesis, as can be seen from the psychometric slopes for the 4 c/deg patches (no FP vs. quads) in Figs. 2B and 4B. Results from Experiment 6+ were also consistent with this (not shown). Nevertheless, why we (and Meese & Hess, 2007) tend to find the opposite result to Petrov et al. (2006) remains unclear.

There is one form of uncertainty model that is consistent with these data though. It could be that without the FPs, observers systematically misplaced their spatial window of attention (e.g. slightly above where it should be), thus compromising their sensitivity. In this case, the FPs would help to bring the attention window back into place, thereby increasing sensitivity but not changing the slope of the psychometric function.

Finally, we cannot rule out the possibility that the surrounding FPs improved performance owing to facilitatory sensory interactions (Chen & Tyler, 2001; Meese et al., 2007; Yu et al., 2002b). However, as there is no ground truth regarding the ‘true’ sensitivity to our targets this is a difficult hypothesis to test directly. A possibly more fruitful avenue might be to make careful recordings of gaze direction, eye-movements and accommodation (e.g. Horwood & Ridell, 2008) to determine the level to which each of these factors are in fact involved. If they cannot account fully for the effects (~1.4 dB for quad FP vs. no FP), then facilitatory interaction is the only remaining possibility.

### 4.3. Implication for other studies

As a central FP causes more masking for small targets than large targets (Experiments 1 and 4), this has implications for any study that has used a central FP and varied stimulus size (either with our without co-variation of spatial frequency). For example, area summation studies (that have included small targets of ~0.5° or less) can be expected to deliver greater estimates of summation if a central FP is used than if it is not (Meese & Hess, 2007). However, although FP effects have not been thoroughly documented until now, it seems that previous experimenters have been mindful of this pitfall. The FP arrangements in the following area summation studies were as follows. Rovamo, Luntinen, and Nasanen (1993) and Meese and Summers (2007) used no FP; Manahilov, Simpson, and McCulloch (2001), Robson and Graham (1981), Mayer and Tyler (1986) and Meese and Hess (2007) all used remote FPs (at least for the conditions where the target was viewed peripherally); Summers and Meese (2007a, 2007b) used quads; Foley, Varadharajan, Koh, and Farias (2007) used surrounding cross-hairs; the modelfested consortium used surrounding ‘Ls; and Meese, Hess, and Williams (2005) used a central FP, but with 1 c/deg targets, where masking effects are not evident (Fig. 2A). In some respects this caution is not surprising—it stands to reason that if the target is very small, then it will be obscured by a centrally placed FP (though see Experiment 2). Nevertheless, we are struck that marked masking effects (2.5–3.6 dB, depending upon the choice of baseline) can be measured for FPs that occupy as little real estate in the display region as that shown in Fig. 1A and C.

The results here also have implications for masking studies. For example, if a central FP is used, then a fair judgement of the experimental masker can be made only if its influence combines linearly with that produced by the FP. However, Experiment 5 shows that this does not occur; the central FP causes masking only at detection threshold. Thus, the level of masking produced by the pedestal in Experiment 5 appears to be 2.64 dB less when a central FP is used (see Fig. 6 caption for details). It would seem that in this situation the quad arrangement of FPs provides the cleaner method of investigation. Indeed, this was the approach used by Meese and Holmes (2007) and Meese and Baker (2009) in their studies of spatiotemporal cross-orientation masking. However, as we have not ruled out the possibility that quad FPs involve sensory facilitation, the possibility remains that this arrangement might also interfere with data interpretation.

### 5. Conclusions and recommendations

Different configurations of grating stimulus and FPs can lead to threshold elevation, threshold facilitation and no effect. An experimenter’s choice of FP will depend very much upon the requirements of the experiment, though the aim is usually to provide conditions in which sensitivity can be measured for the target, uncontaminated by extraneous influences. In this case, we suggest that experimenters avoid using a central FP (Fig. 1A) with patches of target grating that have a full-width at half height of less than 1°. A reasonable alternative is a quad of FPs (Fig. 1B), though surrounding ‘Ls (e.g. modelfest; Polat & Tyler, 1999) surrounding rings (Petrov et al., 2006) and cross-hairs (Foley et al., 2007) might also be considered. We have suggested that the small benefits of these over no FP might be caused by an improvement in accommodation and convergence and stability of eye-movements. However, we cannot rule out the possibility that the benefit arises from sensory interactions from the surround, such as that which is thought to happen for annular gratings. If this were so, then the benefits might be viewed as contamination. But in any case, design criteria for the lowly fixation point should not be derived as an idle afterthought.

### Acknowledgments

This work was supported in part by a grant from the Engineering and Physical Sciences Research Council (GR/S74515/01). We also thank an anonymous reviewer for suggesting the point about the template model and uncertainty in Section 4.2.

### References


