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Psychometric curves of lateral facilitation

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Abstract—Visibility of an oriented stimulus may be enhanced by nearby stimuli that are co-aligned with the target. However, the underlying mechanism governing this facilitation is controversial. Here we measured the dependence of percent correct detection on the target's contrast (psychometric curve) with and without flankers, where flankers were either collinear with or orthogonal to the target. We find that the effect of collinear flankers can be described as a translation of the psychometric function along the linear contrast axis. This behavior is consistent, within experimental error, with two types of models: (1) non-linear transduction of target contrast with collinear flankers having additive effects on contrast, and (2) uncertainty reduction (Pelli, 1985) by collinear flankers. We discuss properties of collinear facilitation that can help deciding between these two models.

Keywords: Lateral interactions; uncertainty; psychometric function.

1. INTRODUCTION

Sensitivity for detecting a Gabor target is enhanced when it is presented between two flanking high-contrast Gabor patches that are co-aligned with the target (Polat and Sagi, 1993, 1994; Solomon *et al.*, 1999; Solomon and Morgan, 2000; Williams and Hess, 1998; Woods *et al.*, 2002). It was suggested that this collinear facilitation is mediated by lateral interactions between target- and flanker-responsive filters at low-level visual areas, since it is local and orientation-specific (Polat and Sagi, 1993, 1994). Models of this phenomenon attributed the facilitation to an increase in sensitivity of the responding filters. This could be obtained by direct input from the flankers to the target responding filters (Solomon *et al.*, 1999, though this model falls short in predicting long range facilitation), or by lateral interactions that affect the gain of the filter's transducer-function either directly via multiplicative processes (Adini *et al.*, 1997; Chen and Tyler, 2001) or by shifting its operating point to a point of higher sensitivity (Usher *et al.*, 1999; Zenger and Sagi, 1996). We use here the term 'non-linear sensory facilitation' to describe this group of models as they

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all incorporate some nonlinearity at the sensory stage, either in the form of non-linear contrast transduction or (/and) in the form of nonlinear effects of flankers on the target response. An alternative approach posits that the collinear flankers facilitate detection by reducing uncertainties about the target such as orientation and localization (Levi *et al.*, 2002; Petrov *et al.*, 2006). Such a model attributes facilitation to a selection process which in the presence of flankers can better read the sensory data by ignoring non-relevant input channels. Selection can be based on information external to the stimulus or information present in the stimulus. The outcome is an increased signal-to-noise ratio and thus improved detection (d').

Here we examine predictions derived from some specific implementations of these general models. The predicted performances of the different models depend on the transducer function, the type of target-flankers interactions and on the detection mechanism assumed, and thus span a wide range of behaviors. We consider here four simple models that were selected to demonstrate some typical behaviors that are discussed in the literature.

1. The flankers' effect is modeled as an additive effect on target contrast, without uncertainty.
2. The flankers' effect is modeled as a multiplicative effect on contrast without uncertainty.
3. The flankers' effect is to reduce uncertainty; decision is based on the maximal response among N channels, of which only one is relevant for the task (Pelli, 1985).
4. The flankers' effect is to reduce uncertainty; decision is based on the added activity across N channels, of which only one is relevant for the task.

These models have different predictions for the effect of flankers on the shape of the psychometric function (the function that relates percent correct detection to contrast, $P = \Psi(C)$).

1. Model 1 predicts a translation of the psychometric function toward lower values of contrast in the presence of flankers when plotted against linear contrast ($\Psi_f(C) = \Psi(C + K_f)$). Thus we do not expect a change in shape of the psychometric curve when using a linear scale but do expect a change when plotted on a logarithmic scale. The predicted leftward translation is expected to widen the psychometric curve on a logarithmic scale.
2. Model 2 predicts a contraction of the psychometric curve when using a linear C scale ($\Psi_f(C) = \Psi(C * K_f)$), meaning a shift toward lower C values (reduced threshold) and a narrower width. When using a logarithmic contrast scale, this model predicts a translation of the psychometric curve without a change in width.
3. Model 3, which assumes uncertainty reduction, was shown, using some additional assumptions, to predict a correlation between threshold and log–log slope, so that facilitation is accompanied by a reduction in the slope of the psychometric function when plotted as $\log(d')$ against log(contrast) (Pelli, 1985; Tyler and

Chen, 2000). For psychometric functions relating percent correct to contrast, the Weibull approximation to the function shows an increase in the steepness parameter (β) with increasing uncertainty and thus with decreasing sensitivity (Pelli, 1985; Tyler and Chen, 2000).

4. According to model 4, the mean response to the target does not depend on the uncertainty level, as the non-relevant channels have zero mean response, but the noise increases with the number of non-relevant channels. Thus, $d'(C) = \mathrm{f}(C)/(K * \sigma)$ where d' is defined here as signal-to-noise ratio, $\mathrm{f}(C)$ is the transducer function, and K is a constant that depends on the number of irrelevant channels and their noise correlations. At low contrasts, $\mathrm{f}(C)$ is often assumed to be a power function of contrast, so that $d'(C) = C^p/(K * \sigma) = (C/K^{1/p})^p/\sigma$. It is clear that under the present assumptions, uncertainty reduction is equivalent to a multiplicative operation on contrast as in the case of model #2.

The predictions of these four models show that the uncertainty assumption cannot be tested by simply looking at the effect of flankers on the psychometric functions. The correlation between log–log slope and sensitivity, typically attributed to the uncertainty model (Levi *et al.*, 2002; Petrov *et al.*, 2006) can also be obtained without the uncertainty assumption with a non-linear sensory model (model #1, as will be shown in detail below). The above analysis does show, however, a way to distinguish between additive and multiplicative interactions.

Previous studies on lateral facilitation of contrast detection used a staircase method, thus obtaining only threshold estimation. An exception is the study of Levi *et al.* (2002), where psychometric curves were obtained (see also Petrov *et al.*, 2006). These authors suggested that the mechanism of uncertainty reduction underlies collinear facilitation though, as pointed out above, such evidence can not be used to decide for or against the uncertainty based model of facilitation. Here we examined the psychometric curves obtained from a contrast detection task of a centrally fixated Gabor target, to investigate the effect of flankers on both the steepness and threshold parameters of the psychometric curves. In this way we hoped to gain a better understanding of the mechanism underlying collinear facilitation. We added an orthogonal condition, in which the orthogonal flankers possess the same spatial and spatial-frequency information as the collinear flankers, in order to specifically assess the orientation effect of the collinear flankers. In this way we are able to separate any spatial effects from the orientation uncertainty reduction effects that the flankers might have if uncertainty exists. Previous experimental evidence excluded orthogonal interactions with high-contrast flankers; Polat and Sagi (1993) showed that detection thresholds in the presence of orthogonal flankers are the same as without flankers, and psychophysical evidence for cross-orientation surrounding facilitation was obtained only with low-contrast flankers (Yu *et al.*, 2002). Hence, any difference between the psychometric curves under the collinear and orthogonal conditions would be attributed to the orientation domain. We tested three spatial configurations: (1) a target without flankers ('no-flank'), (2) a target flanked by two high-contrast collinear flankers at a distance of either 3λ or

4λ, and (3) orthogonal flankers at either 3λ or 4λ. The question of interest was the change in slope *vs.* threshold according to the tested condition, as obtained from the psychometric curves.

2. METHODS

2.1. Stimulus and procedure

To minimize extrinsic uncertainty, stimulus parameters were blocked in all experiments reported here. Observers performed a contrast detection task for an 8-cpd Gabor target ($\sigma = \lambda$) placed at 0° eccentricity. The target was flanked top and bottom by two high-contrast (60%) Gabor patches. There were five conditions; the patches were either turned off ('no-flank'), or they were collinear or orthogonal, either 3λ or 4λ distant from the target. In each block of trials only one condition was tested with the target and flankers having fixed contrast and orientation. The target's orientation was always vertical, and the orthogonal flanker's orientation was horizontal. The phase of all Gabor stimuli was 0°. Four peripheral white crosses (2.4° eccentricity, $0.58° \times 0.58°$, $0.7'$ thick) were displayed simultaneously with the target and flankers. The presentation sequence and duration were as follows: The observer initiated each trial by pressing the mouse scroll button. A small black fixation cross appeared for 100 ms. Next, a 400-ms blank screen appeared followed by the first stimulus interval lasting 90 ms. Then there was a 1-second inter-stimulus interval, followed by a second 90-ms stimulus interval. The observer determined the interval in which the target appeared by pressing the mouse buttons. Observers ran two sessions on each experimental day, each session lasting approximately 30 min with a break of 30 min between sessions. In each session, three out of the five conditions were randomly presented in separate blocks of trials. For each condition, several target contrasts were presented in descending order over blocks. There were 455 trials per contrast on the average.

2.2. Data analysis

Psychometric curves were generated and fitted by a Weibull function (P_W):

$$P_W(C) = 1 - 0.5\exp(-(C/T)^{\beta}), \tag{1}$$

where T is the contrast threshold at a performance level of 81.6% correct, C represents contrast (0-1), and β corresponds to the steepness.

The fitting was done in Matlab using a non-linear least-squares method.

We repeated the Weibull fit, incorporating a finger error parameter, P_{FE}, defined as the percentage of trials where the observer does not follow the Weibull function but rather have equal probability to produce the two responses:

$$P(C) = 0.5P_{FE} + (1 - P_{FE})P_W(C). \tag{2}$$

Table 1.
Weibull function parameters including finger errors

Condition	Observer	Thr	β
nf	DG	8.9	4.6
	YG	12.1	3.3
	RZ	5.6	4.4
	mean	8.9	4.1
col3	DG	6.0	3.2
	YG	6.5	1.6
	RZ	4.7	2.5
	mean	5.8	2.4
col4	DG	6.5	3.3
	YG	8.1	1.7
	RZ	4.7	2.5
	mean	6.4	2.5
orth3	DG	7.5	5.4
	YG	9.7	2.6
	RZ	5.2	3.4
	mean	7.5	3.8
orth4	DG	7.6	6.2
	YG	10.5	2.7
	RZ	5.7	3.7
	mean	7.9	4.2

For each observer the finger error rate was determined separately by averaging the error rates (0-1; returned by the Matlab function) of the different conditions (not including cases in which the observers did not reach their maximum performance level at the highest contrast tested). P_{FE} was 0.077, 0.09 and 0.02 for observers RZ, DG and YG, respectively. The threshold and steepness parameters obtained from the Weibull fits including the finger error parameter appear in Table 1. Basically, incorporating the finger error parameter did not have a major effect on the Weibull parameters as compared to those obtained without finger errors (Fig. 1a–c). The goodness of the fits was measured by normalizing the error of the fits to the variance of the data. Most of the normalized errors did not exceed 3%, except for condition col3 of observer DG, which was 9% without finger error and 6% with the finger error parameter.

2.3. Observers

Three trained observers with normal or corrected-to-normal vision participated in these experiments.

2.4. Apparatus

Stimuli were displayed as a gray-level modulation on a 22″ Mitsubishi Diamond Pro 2060u color monitor using an ATI Radeon Graphic card. The video format was

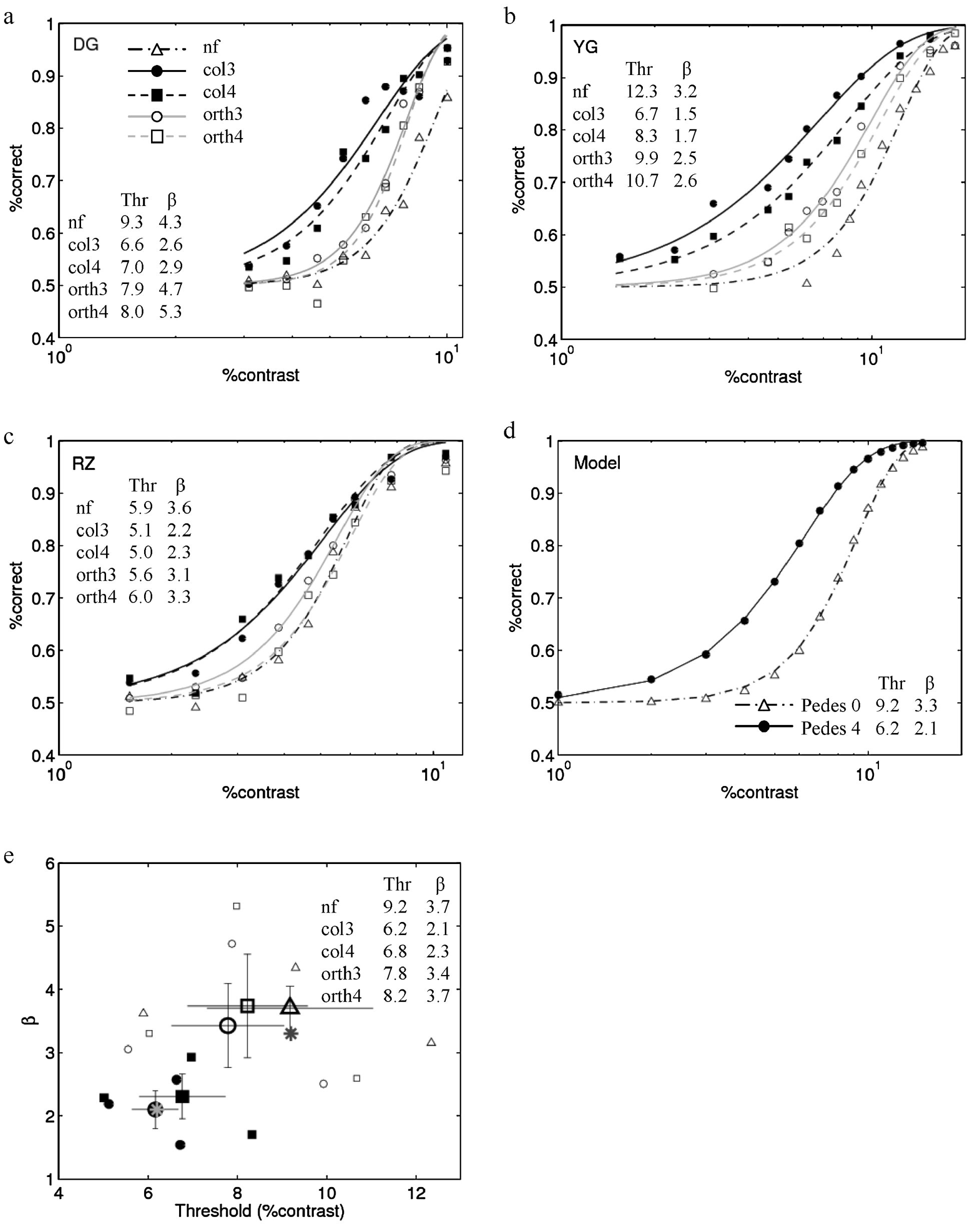

Figure 1. (a–c) Experimental data and its Weibull fits (lines) for detection of a foveal Gabor target flanked by high-contrast Gabor flankers. Five conditions are plotted: no-flank (nf, triangles, dot-dashed line), collinear flankers at 3λ from target (col3, filled circles, black solid line), collinear at 4λ (col4, filled squares, black dashed line), orthogonal flankers at 3λ (orth3, empty circles, gray solid line), and orthogonal at 4λ (orth4, empty squares, gray dashed line). The Weibull parameters, β (steepness) and threshold are shown for each observer individually. (d) Data points predicted from Legge and Foley's non-linear transducer model (1980), and the corresponding Weibull fits for pedestal $= 0$ (pedes 0; equivalent to no-flank) and pedestal $= 4$ (pedes 4; equivalent to collinear flankers) conditions.

85 Hz non-interlaced. An 8-bit RGB mode was used and Gamma correction was applied to produce displayed luminance with linear behavior. The mean display luminance was 30 cd/m^2, in an otherwise dark environment. Screen resolution was 1600×1200 pixels and the sitting distance was 125 cm.

3. RESULTS

We generated psychometric curves for contrast detection of a centrally presented Gabor target in three spatial configurations: (1) an isolated target, (2) a target surrounded by remote collinear flankers, and (3) a target surrounded by remote orthogonal flankers (Fig. 1a–c). We fitted the data with a Weibull function and obtained the threshold and the curve's steepness parameters for each condition (Fig. 1a–c). We found that collinear thresholds were significantly lower than orthogonal ones (paired t-test: $p < 0.01$) in accordance with previous studies (Polat and Sagi, 1993, 1994; Solomon and Morgan, 2000; Solomon *et al.*, 1999; Williams and Hess, 1998; Woods *et al.*, 2002). In addition, the steepness of the collinear curves was significantly lower than that under the orthogonal condition (paired t-test: $p < 0.01$). The steepness under the no-flank and orthogonal conditions were similar. Interestingly, orthogonal thresholds were slightly better than no-flank for two out of the three observers (but on the average it was not statistically significant), unlike the original report that showed they are the same (Polat and Sagi, 1993), although in that study $\sigma = 2\lambda$, resulting in a narrower orientation bandwidth of the stimulus. Usually performance with a flanker distance of 3λ was better than with 4λ, especially under the collinear condition; however, the threshold differences between 3λ and 4λ did not reach statistical significance, in either the collinear or the orthogonal conditions.

In order to distinguish between additive and multiplicative interactions, each psychometric curve was both shifted on a linear contrast axis (Fig. 2), and scaled by a scaling factor (Fig. 3), to overlap the curve corresponding to the no-flank condition. The shifting values and scaling factors were calculated by minimizing the mean square difference between two Weibull functions: one that is fitted to the no-flank condition and one that is fitted to the shifted condition (col3, col4, orth3, orth4), and are indicated for each condition in the graphs. The fitting errors (2-norm residual) for each condition appear in Table 2. When shifted on a linear scale by an additive value, the psychometric curves overlap considerably (Fig. 2), as predicted from Model #1. A scaling of the contrast according to Model #2 results in a poorer fit of the collinear curves, as they do not overlap with those of the no-flank condition (Fig. 3). This is also evident from the fitting errors of the scaled collinear curves,

Figure 1. (Continued). (e) Pairs of steepness (β) and threshold obtained from the Weibull fits in a–c (small symbols) and their averages for each condition (large symbols) with $\pm$ 1 standard errors. Asterisks, transducer model predictions from (d) for no-flank (dark gray) and interacting flankers (light gray), respectively (see text).

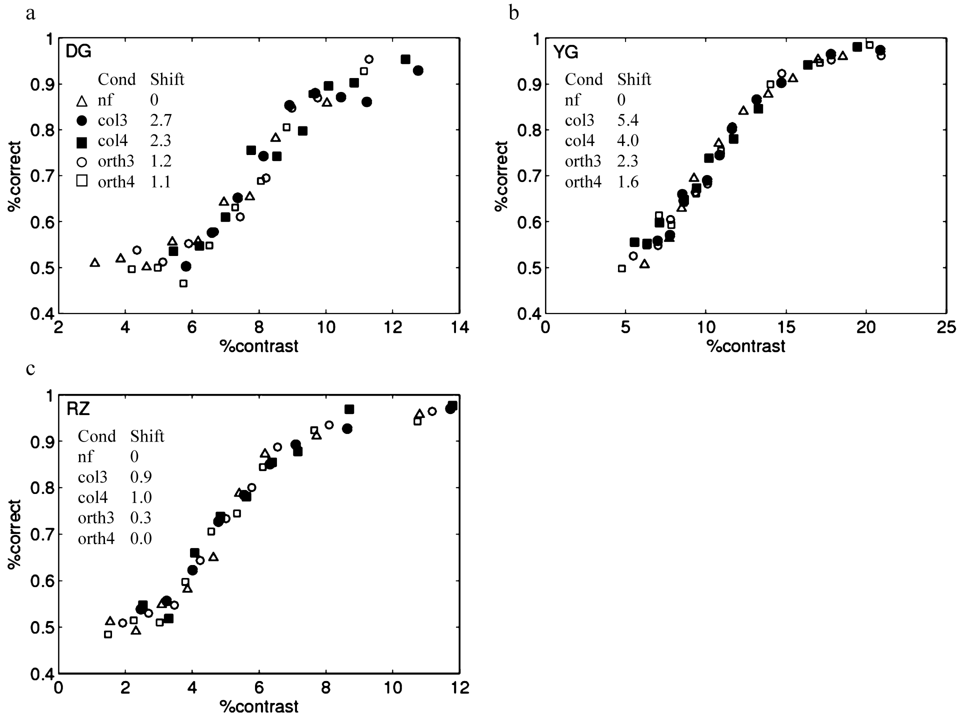

Figure 2. (a)–(c) The psychometric curves shifted horizontally to overlap that of the no-flank (nf) condition. The shift value (%contrast) for each condition is designated in the graphs. Abbreviations: Cond, condition; nf, no-flank (triangles); col3, collinear flankers 3λ from target (filled circles); col4, collinear 4λ (filled squares); orth3, orthogonal 3λ (open circles); orth4, orthogonal 4λ (open squares).

Table 2.
Errors of shifting/scaling each condition to no-flank, err $= \sum_C (P_{\mathrm{nf}}(C) - P_{\mathrm{cond}}(C))^2$

Condition	Shift (Fig. 2)			Scale (Fig. 3)		
	DG	YG	RZ	DG	YG	RZ
col3	0.001	0.004	0.006	0.015	0.050	0.010
col4	0.000	0.006	0.004	0.009	0.040	0.010
orth3	0.005	0.000	0.000	0.001	0.007	0.001
orth4	0.009	0.000	0.001	0.003	0.005	0.000

which are an order of magnitude worse than those in the additive case (Table 2). Nevertheless, the orthogonal curves fit well with the no-flank ones when scaled since they have similar steepness (Fig. 3 and Table 2).

We also generated a prediction derived from the nonlinear transducer function used by Legge and Foley (1980), $R(C) = C^p/(K^q + C^q)$, assuming that lateral interactions add to the effective contrast (Model 1) the equivalent of K_{f} contrast (R, internal response; $0 \leqslant C \leqslant 1$, contrast; K, p and q are constants). Thus, in the

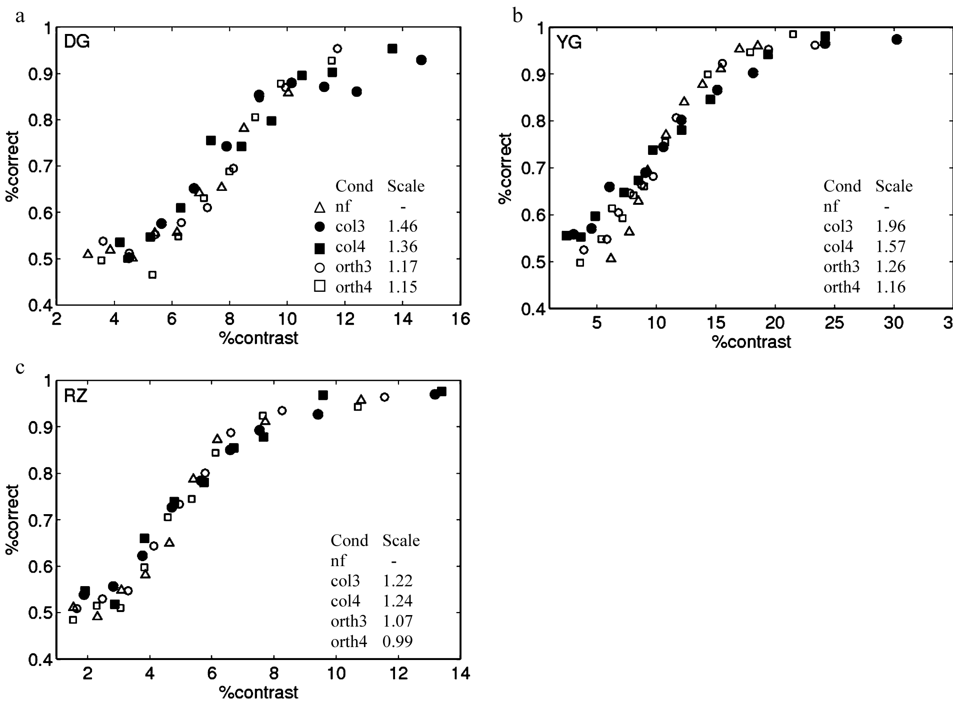

Figure 3. (a–c) The psychometric curves with their contrast rescaled to overlap that of the no-flank condition. The scaling factor for each condition is designated in the graphs. Abbreviations are as in Fig. 2. Note that the collinear data points (filled symbols) do not overlap with the no-flank and orthogonal ones (empty symbols).

presence of flankers, we assume that $R_{\mathrm{f}}(C) = R(C + K_{\mathrm{f}}) = (C + K_{\mathrm{f}})^p/(K^q + (C + K_{\mathrm{f}})^q)$. To generate psychometric functions we assumed an additive noise source with normal distribution, thus, for our 2AFC task, $\Psi(C) = (1 + \Phi(R(C)/\sqrt{2\sigma}))/2$ where Φ is the cumulative normal distribution. These predictions (constants used: $p = 4, q = 3.5, K = 0.1, K_{\mathrm{f}} = 0.04, \sigma = 0.1$) produce psychometric curves (Fig. 1d) very similar to that observed and show the expected dependency between threshold and steepness when fitted with the Weibull function, as shown in Fig. 1e (fitting error, 2-norm residual, is less then 1% of the total variance).

4. DISCUSSION

In this study we compared the psychometric curves of contrast detection in the presence of collinear, orthogonal, or no flankers. Remote collinear flankers shifted the psychometric curves on linear contrast scale toward lower thresholds. When plotted on logarithmic contrast scale, their effect was to reduce both the threshold and steepness of the psychometric curves. Threshold reduction may be explained by a pedestal-like effect in which the collinear flankers provide additional input to the target-responsive filters (Model #1). Multiplicative effects on contrast (Model #2) are ruled out. Alternatively, the results are also in agreement with the uncertainty model (Model #3) which predicts a correlation between threshold and log–log slope of the psychometric curve (Pelli, 1985).

4.1. Spatial interactions

The data can be explained quite well by a model assuming additive effects of flankers on the target (Solomon *et al.*, 1999; Zenger and Sagi, 1996), as indicated by the constant width of the psychometric curve when plotted against linear contrast (Fig. 2).

A model assuming a non-linear transducer function and change of operating point in the presence of collinear flankers (see Results), predicts Weibull parameters that are within the spread of the experimental data. These results are consistent with both models assuming spatial integration within the target's receptive-field (RF) and from the outside of the RF. Lateral effects from within the target's RF are constrained by the RF shape and do not account for facilitation from larger distances (6λ, e.g. Solomon *et al.*, 1999). Long-range effects are also less sensitive to the relative phase of target and flankers (Zenger and Sagi, 1996). Zenger and Sagi (1996) found using two flankers with opposite contrast polarity, resulting in a null effect at target location, phase sensitive facilitation at distances of 2–3λ, but not at 4λ and above.

4.2. The uncertainty model

Our results are in general agreement with a model assuming facilitation due to uncertainty reduction (Pelli, 1985). The β parameter derived from the Weibull fit to our data is 3.2–4.3 for the detection task without flankers and for the orthogonal flankers condition, in agreement with previous results (e.g. Mayer and Tyler, 1986), while in the presence of collinear flankers β is reduced to 1.5–2.9. According to Pelli's uncertainty model (1985), a value of β between 1.5 and 3 estimates 1–100 monitored channels, whereas a value of β of 3–4.3 estimates 100–10,000 channels. Thus, if the uncertainty model applies to the data, there is an uncertainty increase of 100-fold between the collinear and orthogonal (and no-flank) conditions (see also Tyler and Chen, 2000). Although, according to the psychometric curves obtained in this study, the uncertainty reduction explanation cannot be ruled out, some aspects of the data favor the non-linear transducer-based account for foveal collinear facilitation. Still, uncertainty reduction may add to the pedestal effect. The only parameter in which collinear and orthogonal flankers differ is local orientation. This suggests that spatial uncertainty reduction cannot explain collinear facilitation, because orthogonal flankers do not have a significant effect on the psychometric curve, relative to the isolated target (Fig. 1e), although they carry the same spatial information as the collinear flankers. This latter argument applies to any stimulus parameter other than orientation, such as spatial–frequency. Thus, although most uncertainty regarding the stimulus can be eliminated with the orthogonal flankers, the predicted uncertainty reduction (based on the data) is minimal. An explanation based on orientation uncertainty reduction should explain the large reduction ($\times 100$ in population size) predicted by the present data, an order of magnitude larger than the number of orientation channels in the system, considering an orientation tuning width of 30°–40° (for primates recordings see Schiller *et al.* (1976) and De Valois *et al.* (1982), and for evidence from psychophysics see Polat and Sagi (1993)). Also, the dependency of facilitation on global configuration (Polat and Sagi, 1994; Freeman *et al.*, 2004) argues against an orientation-based account, since it was found that orientation equality between target and flankers is not a sufficient condition for lateral facilitation.

Some important predictions of the uncertainty account fail in experimental tests. (1) Adding flankers with the same orientation as the target to the collinear ones should further reduce orientation uncertainty and thus, regarding the extent of uncertainty, increase facilitation. Nevertheless, facilitation is attenuated or abolished with additional flankers, as was shown for the chain (Adini *et al.*, 1997), and the collinear together with the parallel (Polat, 1999; Solomon and Morgan, 2000) configurations. (2) Uncertainty as for target parameters is expected to increase the false-alarm rates in experiments employing the detection task, thus the presence of proximal flankers should reduce the false-alarm rate. A recent study shows the opposite. Polat and Sagi (2006) find an increase in false-alarm rate with flankers presented within the facilitation range, a result that supports excitatory lateral interactions. (3) In experiments employing external noise to limit detection performance, using the image classification method, uncertainty is not an efficient predictor for the detection efficiency measured in contrast detection tasks (Murray *et al.*, 2005). Finally, uncertainty fails to explain the shape of the perceptual filter derived for flanked detection (Kurki *et al.*, 2006).

Note that the way that our detection task was carried out minimizes uncertainties regarding the stimulus parameters. The stimulus contrast was blocked in a descending order, starting above the threshold level. Thus, the observers knew the location and spatial frequency of the target, which were fixed throughout the experiment. Moreover, there was a temporal cue in the form of four high-contrast crosses appearing simultaneously with the stimulus, which together with the high-contrast flankers reduced temporal uncertainty. There is a possibility that the blocked (and ordered) presentation of the different contrast affected the psychometric curves and introduced the relationship found between threshold and steepness. Such an effect can be explained in terms of dynamic processes affected by task difficulty or by an adaptive attentional window of varied size. A theory of visual attention incorporating variable attentional window was proposed by Kontsevich and Tyler (1999) and was shown to have predictions similar to that of the uncertainty model.

4.3. Lateral masking curves in fovea versus *periphery*

In a previous study we obtained psychometric curves of lateral masking in which targets were placed at 4° eccentricity (Shani and Sagi, 2005). Lateral facilitation was found to be smaller and task-dependent in the periphery (Garcia-Perez *et al.*, 2005; Shani and Sagi, 2005). Whereas in the periphery facilitation can be obtained both with orthogonal and collinear flankers, our study showed that the main effect of collinear lateral flankers is a change in the steepness parameter relative to that of the orthogonal configuration, with smaller effects occurring regarding the threshold parameter. Since the uncertainty model predicts similar effects regarding steepness and threshold, the peripheral collinear effect cannot be accounted for by an uncertainty-reduction mechanism, counter intuitively, since the periphery suffers from greater positional uncertainty. However, positional uncertainty may be eliminated by both collinear and orthogonal flankers. The difference noted here between fovea and periphery may indicate a difference in the operation of lateral interactions across eccentricity. It may be explained by the higher contrast threshold obtained at the periphery that shifts the operating point on the transducer function to the linear area, resulting in no facilitation of collinear thresholds relative to orthogonal ones.

4.4. Comparison with other studies

Levi *et al.* (2002) also examined the psychometric curves of masking experiments. Although they did not test an orthogonal condition (but included a parallel condition), their results and conclusions are consistent with ours. Importantly, they found that in the fovea, both threshold and steepness are lower with collinear flankers than without flankers (Levi *et al.*, 2002). Although they greatly emphasized the explanation that collinear flankers reduce uncertainty, they concluded that physiological interactions are also involved in foveal facilitation.

Recently Petrov *et al.* (2006) reported on an analysis of psychometric curves of contrast detection with collinear flankers. They claimed that the mechanism of collinear facilitation is uncertainty reduction based on a similar facilitation that was observed in the presence of a low-contrast circle surrounding the target. Such a spatial cue may affect the detection threshold differently from the remote high-contrast flankers. It may alter the filter's response and have attentional effects that are different from those the flankers may cause. Thus, we find their study to lack a more diagnostic condition such as flankers with a different orientation than the target. Using orthogonal flankers solves much more easily and elegantly the question as to what extent do orientation-specific lateral interactions versus uncertainty reduction govern collinear facilitation. In addition, they base their uncertainty explanation on the shallower slopes of both the collinear and circle conditions. However, the shallower slopes of the collinear condition may have several mechanistic explanations, only one of which is uncertainty reduction. Other explanations include increased noise coming from the additional input that the collinear flankers provide to the target filter, or the non-linearity of the transducer.

4.5. Lateral facilitation and localization

There is empirical evidence for collinear facilitation of localization in a 3-Gabor alignment task relative to orthogonal (Popple and Levi, 2002; Popple *et al.*, 2001), although other results argue against such an effect (Keeble and Hess, 1998, 2002). The absence of a collinear effect in localization can be taken as being against positional uncertainty reduction in detection, since the uncertainty reduction is expected to depend on our localization acuity. On the other hand, a close similarity between detection and localization (both depend on the flankers' orientation and distance from target) may support a common neuronal mechanism (Popple *et al.*, 2001). In that case positional uncertainty reduction would be due to a low-level mechanism, presumably utilizing the long-range horizontal connections, and not due to uncertainty reduction at the decision stage as some uncertainty-based models refer to. A clear difference between collinear facilitation of detection and localization is that in localization there is more variability between observers and between studies, whereas in detection the results are more robust and consistent.

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