

Crowding with detection and coarse discrimination of simple visual features

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Some recent studies have suggested that there are actually no crowding effects with detection and coarse discrimination of simple visual features. The present study tests the generality of this idea. A target Gabor patch, surrounded by either 2 or 6 flanker Gabors, was presented briefly at 4 deg eccentricity of the visual field. Each Gabor patch was oriented either vertically or horizontally (selected randomly). Observers' task was either to detect the presence of the target (presented with probability 0.5) or to identify the orientation of the target. The target–flanker distance was varied. Results were similar for the two tasks but different for 2 and 6 flankers. The idea that feature detection and coarse discrimination are immune to crowding may be valid for the two-flanker condition only. With six flankers, a normal crowding effect was observed. It is suggested that the complexity of the full pattern (target plus flankers) could explain the difference.

Keywords: crowding, detection, coarse discrimination

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Introduction

Perception of a target object is impaired when there are other objects located nearby in the visual field. This is known as the crowding effect. In the fovea, this effect is small or absent but it is a major limiting factor of peripheral vision. Traditionally, crowding has been studied with letters and numerals as stimuli (Bouma, 1970; Strasburger, Harvey, & Rentschler, 1991). It has also been demonstrated with discrimination of simple features like contrast, orientation, and spatial frequency (Andriessen & Bouma, 1976; Wilkinson, Wilson, & Ellemberg, 1997). With simple detection, however, the effect seems to be much smaller (Andriessen & Bouma, 1976).

Two recent studies (Levi, Hariharan, & Klein, 2002; Pelli, Palomares, & Majaj, 2004) suggest that there is actually no crowding effect with detection (or coarse discrimination) of simple visual features. They found some drop of performance at small target–flanker distances but attributed it to an “ordinary” masking. They argued that detection (or coarse discrimination) tasks can be carried out by low-level feature detectors, without involvement of the next integration stage that causes crowding with recognition and fine discrimination. This explanation looks fine at first glance but becomes problematic when applied to certain stimulus conditions.

Obviously, the detection of a unique feature in a display is computationally easy. Even after a spatial pooling of signals from detectors of similar features, the information about the presence of the feature is retained, although the information about its exact location is lost (e.g., Treisman & Gelade, 1980; Treisman & Gormican, 1988). But with

possibly identical flankers in adjacent positions, it is not enough just to detect a presence of the target feature. In order to say whether the target was present in a predefined position, we have to conjoin the feature with its location. This is a kind of “feature integration,” and it is hard to imagine how this task can bypass the integration stage.

Interestingly, He, Cavanagh, and Intriligator (1996) report a strong crowding effect with a coarse orientation discrimination task, similar to that where Pelli et al. (2004) found no crowding. There are several differences between these experiments, with number of flankers (two in Pelli et al., 2004, and four in He et al., 1996) being the most salient one. On the other hand, there are only few and contradictory results on the effect of the number of flankers on crowding. For example, Pelli et al. (2004) found no difference in crowding between two and four flankers in a letter recognition experiment, whereas Strasburger et al. (1991) reported quite a strong effect of the number of flankers in similar conditions. In a detection task, Levi et al. (2002) also tried 10 flanking Gabors instead of the usual two and found no difference in the effects (although this was based on the data from one observer only).

The goal of this study was to determine whether there is a crowding effect with a simple feature detection and coarse orientation discrimination task, and whether this effect depends on the number of flankers.

Methods

In this study, Gabor patches (cosine gratings windowed by a circular Gaussian) were used as stimuli. The sigma of

the window was equal to half of the period. The size of stimuli was adjusted individually for each observer. As a result, the spatial frequency was in the range from 6.5 to 8.1 cpd (EP—6.5, JW—7.4, LP—8.1, GN—6.7, BO—7.4), and sigma varied approximately from 0.06 to 0.08 deg. The orientation of the Gabors was either vertical or horizontal. The stimuli were presented on a gray background (with the luminance about 45 cd/m²). The contrast of stimuli was 90%. The luminance function of the monitor was measured by Minolta photometer and approximated by a power function. The inverse of this function was used for the gamma correction.

On each trial, a group of Gabor patches was presented for 60 ms, unpredictably either left or right from the fixation point. The Gabor positioned in the center of the group was the target. It was surrounded by either 2 or 6 flankers. Orientations of the all objects were random and varied independently. The eccentricity of the target was 4 deg. The distance of the flankers from the target (measured from center to center) was varied from 0.4 to 2 deg, in steps of 0.4 deg (from 0.1 to 0.5 relative to the target eccentricity). The flankers were located in equal steps around the target; the angular position of the first flanker was selected randomly. Examples of stimuli are shown in [Figure 1](#).

In Experiment 1, the observer had to identify the orientation of the target and to indicate it by clicking one of the two icons in the response panel. In Experiment 2, the target was present in half of the trials (in the other

half, the central location was blank). The observer's task was to determine whether the target was present or not by pressing 1 or 2 on the keyboard. A feedback message informed whether the response was right or wrong. The number of flankers and the target–flanker distance were held constant within a block of trials.

Before the main experiment, the observers ran a staircase procedure in order to determine an approximate size of stimulus for 95% correct performance without flanker objects. In this staircase, the size of the target Gabor was increased by a factor of 1.2 after each incorrect response and decreased by the same factor after 13 consecutive correct responses, the procedure that converges to approximately 95% correct (Levitt, 1971). The observer's task was identical to that of the main experiments: coarse orientation discrimination (Experiment 1) or detection (Experiment 2). Each observer ran 60–100 trials, and the average of all size levels after the second reversal point was calculated. These sizes of stimuli were used in the main experiment.

Five observers took part in the experiments. They had normal or corrected-to-normal vision. The observers had very little experience with these particular stimuli but had participated in similar psychophysical experiments earlier. Each of them ran 800–1000 trials in the experiment he/she participated (80 or 100 trials per data point).

Results

The results of Experiment 1 ([Figure 2](#)) show that the conditions with two and six flankers are very different. With two flankers, there is a drop of performance at the smallest target–flanker distance only (observers LP and JW) or not at all (observer EP). With six flankers, however, there seems to be a quite normal crowding effect that vanishes at near 0.5 E. The results of Experiment 2 ([Figure 3](#)) are qualitatively similar. The present results with two flankers are more or less consistent with Pelli et al.'s (2004) and Levi et al.'s (2002) finding that there is no or only a small crowding effect with simple detection and coarse orientation discrimination. However, the idea that feature detection and coarse discrimination are immune to crowding seems to be wrong because the same tasks exhibit normal crowding effects with a larger number of flankers.

With random angular position of flankers, it is possible that the effect of the number of flankers (or a part of it) can be explained by the difference of crowding in the radial vs. tangential direction of the visual field (e.g., Toet & Levi, 1992). When two flankers happen to fall above and below of the target, there should be less crowding (because there are no flankers in the radial direction, where the crowding effect is strongest). With 6 flankers, there is always a pair of flankers near the difficult radial

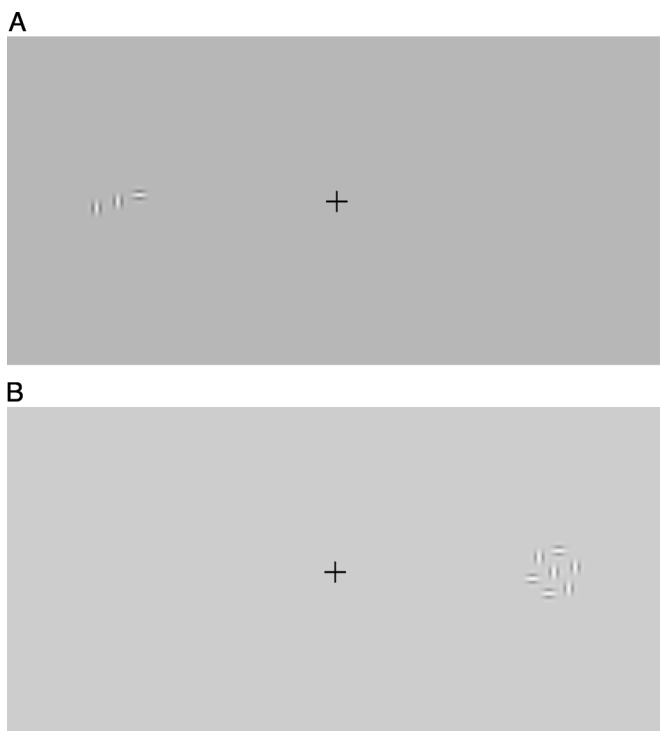


Figure 1. Examples of stimuli. Target surrounded by two (A) and six (B) flankers. The stimuli were presented unpredictably either left or right from the fixation point.

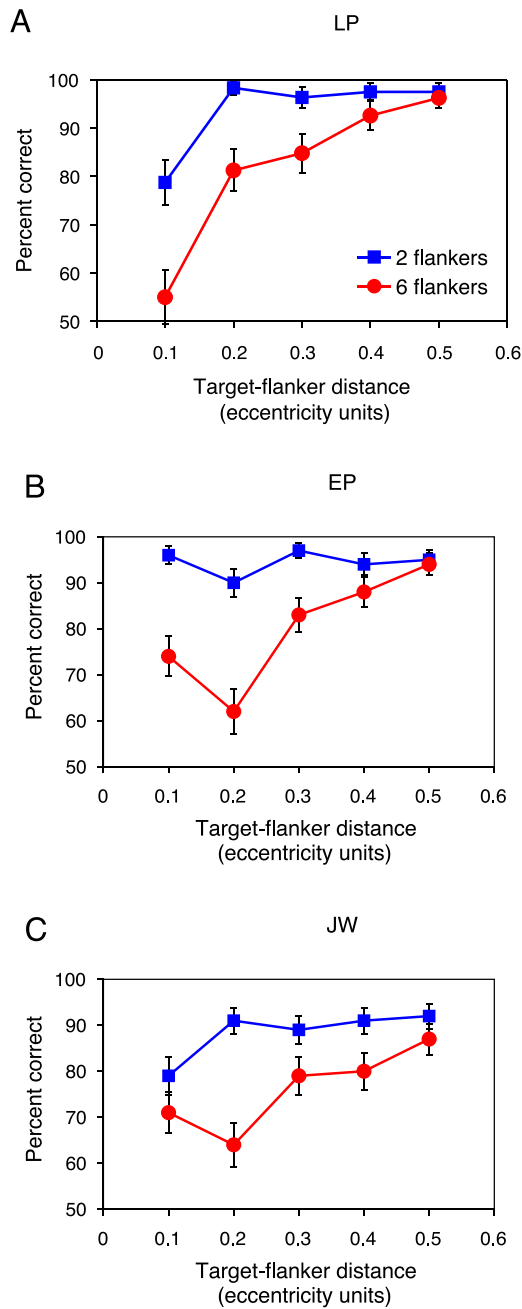


Figure 2. Results of Experiment 1 (coarse orientation discrimination). Percentage correct as dependent on target–flanker distance for two and six flankers. Error bars represent the standard errors of percentages.

direction. In order to check this possibility, the trials of the two-flanker condition were partitioned in groups based on the angular position of flankers. The comparison of performance for near radial ($\pm 30^\circ$ from horizontal) and near tangential ($\pm 30^\circ$ from vertical) position of flankers is depicted in Figure 4. The difference is about 8 percentage points across all target–flanker distances. The same effect for different distances is somewhat surprising and suggests that the radial–tangential difference here may not be

caused by a usual crowding (which should exhibit a strong effect of target–flanker distance) but by some other mechanism. Anyway, there is no evidence that the effect of two flankers with the radial position could be similar to the effect of six flankers.

Trying to find some hints on mechanisms of crowding, performance was analyzed across trials with different combinations of target and flanker orientations. Figure 5 shows how the target orientation and the orientations of flankers together determine the observers’ responses in the orientation discrimination task. It seems that orientations of flankers have two different effects.

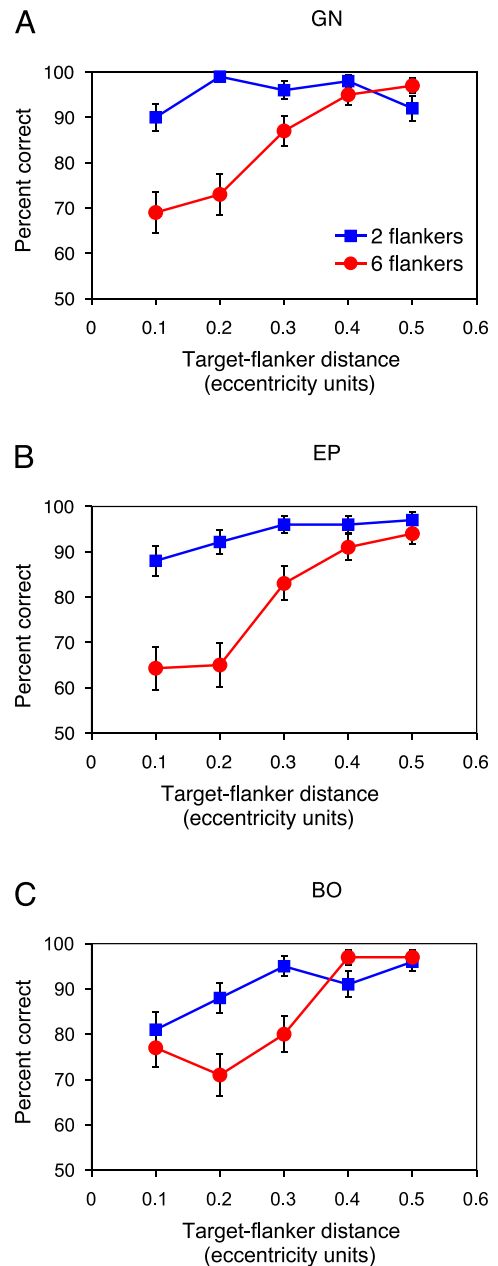


Figure 3. Results of Experiment 2 (detection). Percentage correct as dependent on target–flanker distance for two and six flankers. Error bars represent the standard errors of percentages.

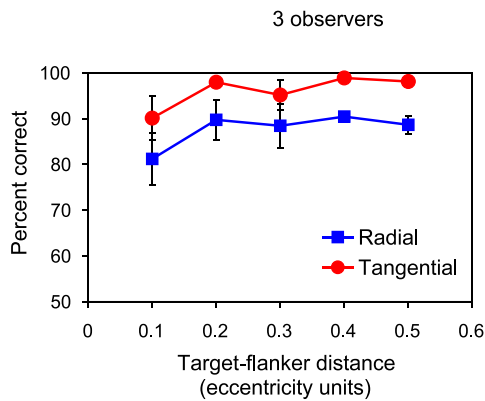


Figure 4. Comparison of performance when two flankers were located in radial vs. tangential direction relative to the target. This graph is based on the orientation discrimination results (Experiment 1) of the three observers. Error bars represent the standard errors of the mean.

With six flankers, the most salient is an effect of “pooling” (e.g., Parkes, Lund, Angelucci, Solomon, & Morgan, 2001): With increasing number of vertical flankers in a display, the probability of response “vertical” increases, more or less linearly. The linear effect was highly significant for two observers ($F(1, 497) = 11.3, P = 0.001$ and $F(1, 497) = 12.8, P < 0.001$ for EP and JW, respectively) but not significant for LP ($F(1, 397) = 0.94, n. s.$). This effect can be explained also by a probabilistic model that selects a single object on each trial, with some preference for the target. With two flankers, this effect is less pronounced (significant for JW ($F(1, 497) = 4.1, P < 0.05$), nearly significant for EP ($F(1, 497) = 3.3, P = 0.07$), not significant for LP ($F(1, 397) = 0.48, ns$).

Another effect is that of homogeneity—the correct responses are more probable when the orientation of (all) the flankers is the same. This effect was consistently significant for the two-flanker condition ($F(2, 494) = 3.7, P < 0.05$; $F(2, 436) = 10.9, P < 0.001$; $F(2, 494) = 5.3, P = 0.005$; for EP, LP, and JW, respectively) and not significant for six flankers. A similar increase of accuracy for homogeneous patterns has been found by Petrov and Popple (2007) in the full-report task where observers had to identify the orientations of all three Gabor patches in a row presented at 6 deg eccentricity (their Gabors were oriented $\pm 45^\circ$ from vertical).

For the detection task, however, no systematic effects of the orientation of the flankers were found. It is obvious that the orientation of the flankers cannot bias the detection responses in a way similar to that of the orientation discrimination task. However, there seems to be no such a simple explanation for the absence of the homogeneity effect. Anyway, these differences between the detection and orientation discrimination tasks suggest that the observed pooling and homogeneity effects are not directly related with the effect of number of flankers, because that was similar for the two tasks.

Discussion

The present study reproduces the results of several earlier studies. The small extent of crowding with two flankers in detection and coarse discrimination experiments is well in accord with Levi et al. (2002) and Pelli et al. (2004). The coarse discrimination results with six flankers are consistent with He et al. (1996), although their stimuli were a bit different. Also, the detection results with six flankers are comparable with these of the detection experiment from Andriessen and Bouma (1976) with 8 flanking objects.

A reasonable explanation why Levi et al. (2002) found no effect of additional flanking Gabors in their detection experiment could be that their 10 Gabors were packed densely in two columns and could best be perceived as two flanking objects.

At present, it seems difficult to reconcile the results of my detection experiment with those obtained by Livne and Sagi (2007). These authors used quite similar stimuli, and a majority of their observers exhibited very little threshold elevation in the detection task with 8 flankers. There were some differences between these studies that

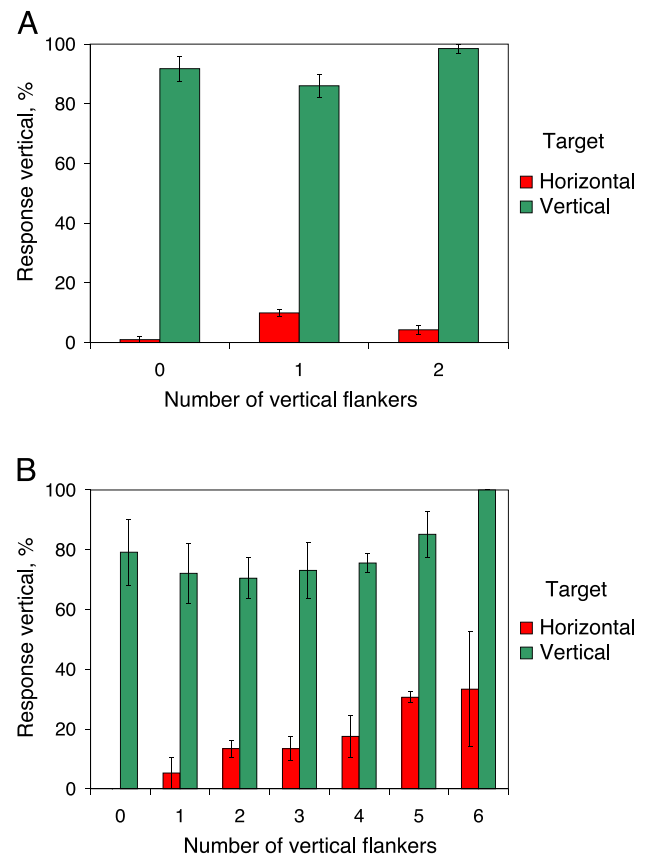


Figure 5. Percentage of “vertical” responses as dependent on the target orientation and the number of vertical flankers in a display, for two- and six-flankers conditions of Experiment 1. Data were averaged across three observers. Error bars represent the standard errors of the mean.

potentially can explain the different results. The target orientation as well as the orientations and positions of flankers were varied unpredictably in my experiment while these parameters were fixed within blocks in the Livne and Sagi (2007) experiment. This could make my task more difficult. Also, in the Livne and Sagi stimuli with 8 flankers, the distances between adjacent flankers were smaller than the target–flanker distances (by a factor of about 1.3). This could facilitate the grouping of flankers and increase the saliency of their target.

The large difference in crowding between the two- and six-flanker conditions is in accord with some earlier studies where a stronger crowding effect has been found with 4 or 6 flankers as compared with usual two-flanker condition (Felisberti, Solomon, & Morgan, 2005; Pöder & Wagemans, 2007; Strasburger et al., 1991) but seems to contradict some others, where such differences were not found (Pelli et al., 2004; Wilkinson et al., 1997). At this point, I have no good explanation for these different results.

It is difficult to explain the present results by any simple integration field model. Why should we integrate over a larger receptive field with six flankers when there is a smaller receptive field available with two flankers? Earlier studies have shown that the extent of crowding can be significantly reduced when the target has a clearly visible unique feature among homogeneous flankers (Kooi, Toet, Tripathy, & Levi, 1994; Pöder, 2006). Obviously, there are no such differences in the target–flanker feature contrast in this study that could generate a pop-out of the target with two flankers and not with six flankers. Also, the crowding effects with six flankers imply that observers have no direct access to local feature detectors, and there must be another reason why detection and coarse discrimination have been found free from crowding.

The most reasonable explanation seems to be one based on a visual complexity of the full pattern (target plus flankers) presented within a receptive field. This explanation follows Cavanagh's (2004) idea that visual attention is constrained in both minimal area of selection and amount of information obtainable from the selected area. If there are several objects within that minimal area, then we cannot select any particular object out from that group and have to include all of them into a single "object description." And this description cannot be arbitrarily complex; it is limited to very few labels, features, or visual properties. When there are three Gabors within the selected area, then the overall pattern is relatively simple, and its description includes, with a high probability, the information about orientation of the central object. With seven Gabors, the pattern is much more complex and the limited description less frequently happens to include the orientation of the central object. At present, this explanation is only qualitative. We do not know exactly how to measure the complexity of a visual pattern and which pieces of information are included into its description. The same idea can be

extended to explain even larger crowding effects with fine discrimination task. Although an internal description could include the information about coarse orientation of the target for some simple patterns, the likelihood that it includes the reliable information about the fine orientation is much lower.

This account is consistent with the present and Petrov and Popple's (2007) findings that patterns consisting of identical objects are perceived more accurately. Indeed, these patterns are the most simple. This explanation fits well with a large crowding effect with more complex objects (e.g., letters) even if there are no more than two flankers. This also appeared to be the case in a recent study with Gabor patches that could vary in multiple feature dimensions (Pöder & Wagemans, 2007). The inability to select the central object and ignore flankers was also demonstrated by Huckauf and Heller (2002), who found that accuracy of reporting the central letter was even better when observers had to report two flanking letters as well. It is possible that the same idea can be applied also to Livne and Sagi (2007) results who found less crowding when flankers formed a smooth circular pattern. Indeed, co-circularity of the elements seems to lead to a simpler configuration.

The present account may also have some interesting neurobiological correlates. Cavanagh and his co-authors (He et al., 1996; Intriligator & Cavanagh, 2001) have suggested that the minimal area of selection (or spatial resolution of attention) is determined by receptive field sizes at some intermediate level of the visual system. Similarly, the kind and amount of available visual information from a selected area could be determined by the pattern selectivity of neurons at the same (or closely related) level. Both computational considerations (e.g., Lowe, 2004; Ullman, Vidal-Naquet, & Sali, 2002) and single cell studies (e.g., Hegdé & Van Essen, 2003; Pasupathy & Connor, 1999) suggest that neurons in visual areas beyond V1 are selective to some relatively simple (or moderately complex) visual patterns. These may be both contour- and texture-like. It seems quite probable that neurons sensitive to curved lines, angles, crosses, and so on are able to discriminate the three-Gabor patterns with a vertical vs. horizontal central object or patterns consisting of two vs. three Gabors (as in the detection experiment). Images comprising seven Gabors might more effectively activate neurons that are sensitive to gratings or textures. These, however, cannot reliably discriminate the orientation of one particular target Gabor or tell apart patterns consisting of six vs. seven objects.

In conclusion, detection and coarse orientation discrimination are not immune to crowding. The crowding effects with these tasks depend on the number of flankers—performance is worse in the presence of more flankers. Crowding may be largely determined by the complexity of the visual pattern (target plus flankers) within the integration field.

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