SUPPLEMENTARY MATERIAL

HUMAN EXPERIMENTS PARALLELING THE MONKEY EXPERIMENTS

The results of human experiments paralleling the monkey experiments are presented in the main text and depicted in Fig. S3. We describe in this section the methodology of the human experiments.

Two right-handed adults, both female, completed tests conducted under a protocol approved by the Institutional Review Board of Carnegie Mellon University. Subject 1 is an author (EC). The other subject was unaware of the specific purpose of the experiment. All spatial conditions, including screen distance and the configuration, size and eccentricity of the stimuli, were identical to those imposed during the monkey experiment. Procedures for data analysis were likewise identical to those employed in the monkey experiment. We used a chin rest to enforce viewing distance and stabilize the head.

For each experiment, the subject completed five blocks. A block consisted of 192 trials conforming to the same conditions as in the corresponding monkey experiment. Each block used two pairs of targets just as in the monkey experiment. Across the five blocks, each of the five pairs of targets was employed twice. At the beginning of each block, to solidify the target-response associations, the subject performed 16 practice trials with singleton targets. These were not included in the analytic dataset.

A trial began with onset of a fixation point in the center of the screen (Fig. 1A). When the subject had attained fixation and was ready to view the array, she pressed the spacebar. This triggered the immediate appearance of the display. The duration of the display was restricted to 100 ms so as to negate any contribution from reflexive saccades. The subject reported the identity of the target by pressing a key on a keyboard. Responses on the up and down arrow keys were mapped onto the targets according to the same rules that governed upward and downward saccades in monkey 1 (Fig. 1B). Feedback was given on each trial in the form of a click if the response was correct and silence otherwise. A trial in which the subject hit neither key was repeated later in the block. Trials in which the response was incorrect were not repeated.

HUMAN EXPERIMENT WITH NARROW SPACING

We carried out an additional set of tests in subject 1 to determine whether measurements of critical spacing would be significantly altered by expanding the set of test conditions to include smaller target-flanker spacings.

Experiment 2 was repeated with center-to-center spacings that included, in addition to the six used previously, a narrower spacing of 0.4°. We reduced the letter size to 0.3° so that at even the narrowest spacing the targets and flankers would not touch. The principles of blocking and trial structure were the same as in the original version of the experiment. A run encompassed 32 trials at each of seven flanker spacings for a total trial count of 224. The subject completed five runs just as in the original version of the experiment. Critical spacing for subject 1 in the original experiment was 0.60° ± 0.02°. Critical spacing in the modified experiment was 0.64° ± 0.04°. The difference was not signficant (two-sample ttest, $t(8) = 0.79$, $p = 0.45$).

Experiment 3 was repeated with center-to-center spacings that included, in addition to the six used previously, a narrower spacing of 0.75°. The principles of blocking and trial structure were the same as in the original version of the experiment. A run encompassed 32 trials at each of seven flanker spacings for a total trial count of 224. The subject completed five runs just as in the original version of the experiment. Critical spacing for subject 1 in the original experiment was 1.55° ± 0.12°. Critical spacing for the same subject in the modified experiment was 1.19° ± 0.21°. The difference, although not significant (two-sample ttest, $t(8) = 1.43$, $p = 0.19$), was in the direction expected from previous demonstrations that training can ameliorate crowding within limits (Chung, 2007). To determine whether the critical spacing of subject 1 had achieved stability at this point, we repeated the experiment modified to include seven flanker spacings. The resulting measure of critical spacing (1.30° ± 0.20°) was not significantly different from the measures obtained in the original experiment (two-sample ttest, $t(8) = 1.12$, $p = 0.30$) and the previous run of the modified experiment (two-sample ttest, $t(8) = 0.45$, $p = 0.66$).

To summarize: including in the test set a condition with especially narrow spacing led to a an increase in measured critical spacing in one case and a decrease in the other case, with neither change statistically significant. We conclude that including a condition with narrower spacing in the test set did not produce a systematic change in critical spacing.

ANALYSIS OF DATA FROM PRIOR STUDIES

Measuring critical spacing in Toet and Levi (1992). We based our analysis on Figure 6 of the cited paper. For each subject, we measured the distance from the central point to the circle at 10° eccentricity along the horizontal axis. We computed the average of the six measured lengths to get X, the distance in the figure corresponding to 10°. For each subject, we measured the horizontal extent of the interaction polygon for a target placed at 10° horizontal eccentricity (L_{10}) and did likewise for targets placed at 5° (L_5) horizontal eccentricity and 2.5° ($L_{2.5}$) horizontal eccentricity. From these widths, we computed critical spacing (c) as a fraction of eccentricity (ϕ) using the formula given below. The term of 0.5 in the numerator adjusts for the fact that each horizontal line encompassed two center-to-center distances.

$$c\phi = \frac{0.5 L_\phi}{\frac{\phi}{10} X} \qquad \text{Eq. S1}$$

The mean across all subjects and eccentricities was 0.27 ϕ with a standard deviation of 0.13 ϕ. The results for the individual subjects are given in Supplementary Table 1.

Supplementary Table 1

Subject	**cϕ, ϕ = 2.5°**	**cϕ, ϕ = 5°**	**cϕ, ϕ = 10°**
AT	0.48	0.46	0.35
JT	0.24	0.25	0.49
MS	0.08	0.12	0.20
JE	---	0.17	0.39
JW	0.27	0.18	0.18
PB	0.32	0.20	0.17

Measuring critical spacing in Chung (2007). The aim of this analysis was to compute in units of eccentricity (ϕ) the pre-test spatial extent of crowding provided for each subject in Table 1 of the cited paper. The eccentricity of the target was always 10°. The spatial extent of crowding (*S*) is given in units of letter size. Letter size for each subject was 1.4 times the critical print size. The critical print size (*P*, in degrees) is provided for each subject in Table 1. We used the following conversion formula:

$$c\phi = \frac{1.4SP}{10} \qquad \text{Eq. S2}$$

The mean across all subjects was 0.20 ϕ with a standard deviation of 0.05 ϕ. The values for the individual subjects are provided in Supplementary Table 2.

Supplementary Table 2

Subject	S	P	cϕ
AS	0.97	0.95	0.13
LG	1.08	1.38	0.21
MM	1.08	1.64	0.25
NV	1.26	1.4	0.25
SA	1.2	1.26	0.21
SU	1.33	1.5	0.28
SW	1.12	0.97	0.15
TN	0.93	1.17	0.15

Measuring critical spacing in Põder *(2007)*. The aim of this analysis was to compute in units of eccentricity (ϕ) the spatial extent of crowding for “same colour” data presented in Figure 2 of the cited paper. We measured the height of each point on the plot and and linearly transformed each height into the appropriate units. Then we applied our inflection point method for calculating critical spacing (Eq. 1). The resulting critical spacing was 0.23 ϕ. The curve fit is depicted according to our conventions in Supplementary Figure 5.

Measuring distractor cost in Chung (2007). We quantified distractor cost by taking measurements from Figure 4 of the cited paper. In the plot for each subject, we inferred the percent correct in the absence of distractors (A) from the height of the horizontal dashed line by taking the ratio of this height to the height of the y-axis. Likewise, we inferred the percent correct in the presence of distractors at the largest spacing tested (D) from the height of the rightmost open symbol. The distractor cost was given by A-D. The mean of A-D across all subjects was 16.1% with a standard deviation of 7.0%. The values for the individual subjects are provided in Supplementary Table 3.

Supplementary Table 3

Subject	A	D	A-D
AS	99.8	90.2	9.6
LG	99.8	90.2	9.6
MM	99.5	76.0	23.5
NV	95.2	85.4	9.7
SA	99.8	80.4	19.4
SU	94.8	71.0	23.8
SW	99.5	76.0	23.5
TN	100.0	90.2	9.8

Expressing widest spacing relative to critical spacing in Chung (2007). The widest spacing tested (*W*, in units equal to 1.4 times the critical print size) was 2.0 in all subjects except AS, in whom it was 1.6. The critical spacing (*S*, in units equal to 1.4 times the critical print size) is given for each subject in column 1 of Chung's Table 1. To express the widest spacing tested as a ratio of the critical spacing, we computed *W/S*. The mean of *W/S* across all subjects was 1.76 with a standard deviation of 0.20. The values for the individual subjects are provided in Supplementary Table 4.

Supplementary Table 4

Subject	W	S	W/S
AS	1.6	0.97	1.65
LG	2.0	1.08	1.85
MM	2.0	1.08	1.85
NV	2.0	1.26	1.59
SA	2.0	1.2	1.67
SU	2.0	1.33	1.50
SW	2.0	1.12	1.79
TN	2.0	0.93	2.15

REFERENCES

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Toet, A., & Levi, D. M. (1992). The two-dimensional shape of spatial interaction zones in the parafovea. *Vision Research*, *32*(7), 1349–1357.

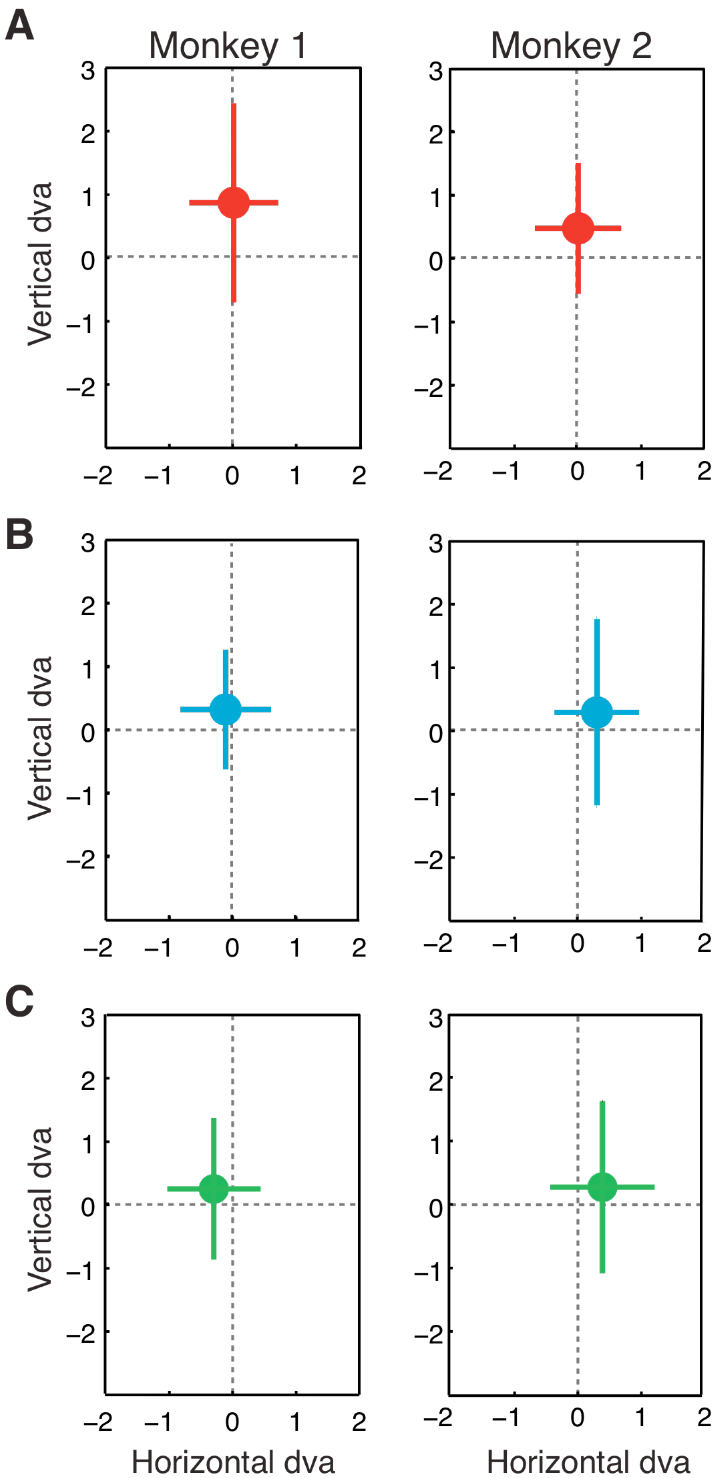

Figure S1. Gaze angle. For each monkey, during each trial, we measured the mean eye position during the period in which the letter array was on the screen. Each panel shows the grand mean and the horizontal and vertical standard deviations of the values obtained from one monkey in one experiment. Positive values on the vertical axis indicate displacement of gaze above the fixation point. Positive values on the horizontal axis indicate displacement of gaze toward the target. **A**, Experiment 1. **B**, Experiment 2. **C**, Experiment 3.

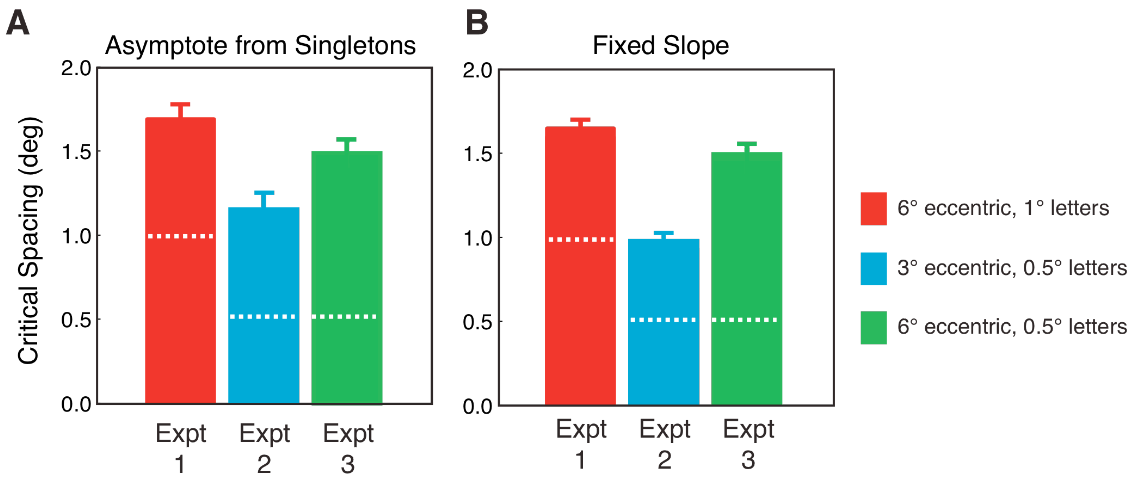

Figure S2. Varying the curve-fitting procedure had only a minimal effect on estimates of critical spacing. **A**, Critical spacing estimated using a model in which the asymptote of the accuracy curve was fixed at the accuracy measured for singleton targets. **B**, Critical spacing estimated using a model in which the slope was fixed at the average value measured across all three experiments. Conventions as for Fig. 5.

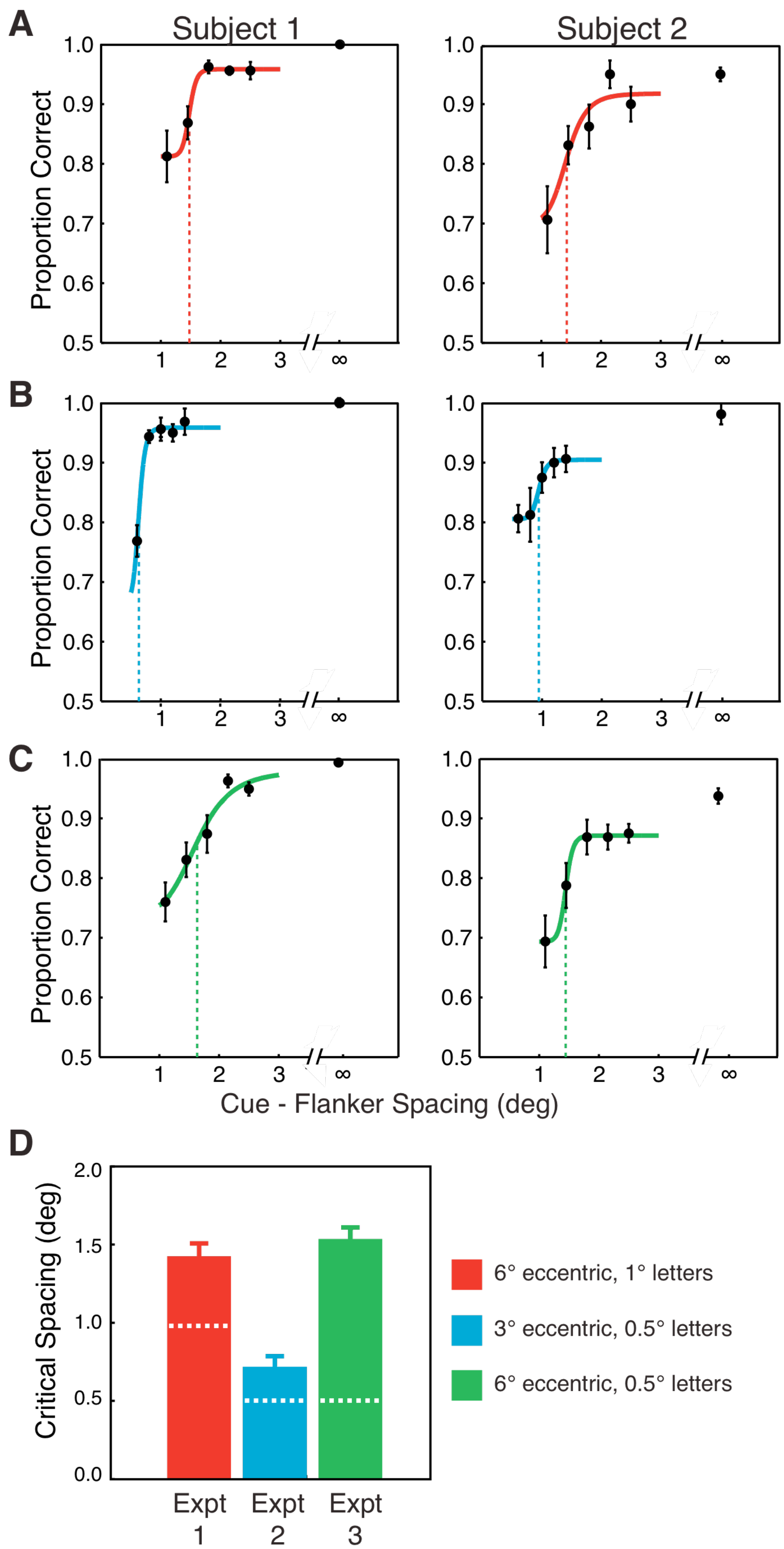

Figure S3. Results from human subjects performing the same tasks as the monkeys. **A**, Experiment 1. Conventions as in Fig. 2. **B**, Experiment 2. Conventions as in Fig. 3. **C**, Experiment 3. Conventions as in Fig. 4. **D**, Comparison across experiments 1-3. Conventions as in Fig. 5.

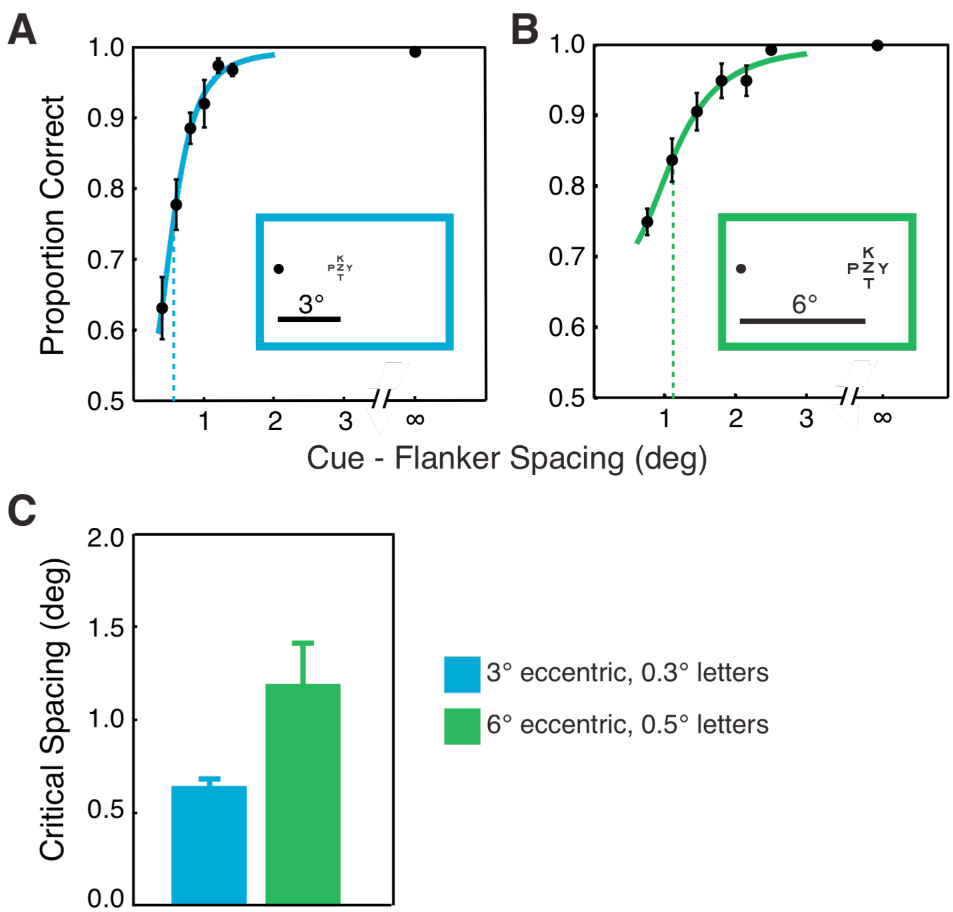

Figure S4. Results from human subject 1 collected under conditions in which the set of center-to-center spacings had been expanded to include an especially small spacing. Details in Supplementary Materials: Human Experiment with Narrow Spacing. **A**, Modified experiment 2. **B**, Modified experiment 3. **C**, Critical spacings measured in the two experiments. Conventions as in Fig. S3.

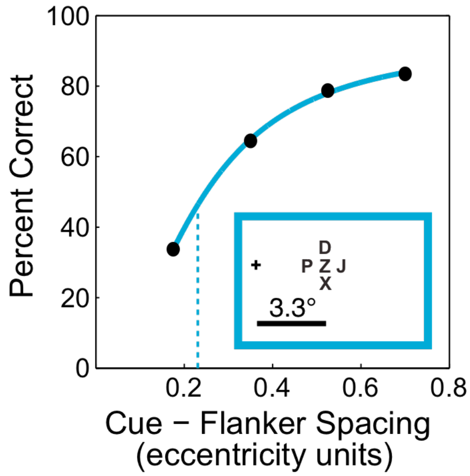

Figure S5. Application of our method for estimating critical spacing to data from Fig. 2 of Põder (2007). Inset indicates the geometry of the display in the task on which the figure is based. Conventions as in Fig. S4.