Supplemental Inventory

Supplemental Figures
Figure S1 shows data from a pilot experiment in which we established standard crowding and remapped crowding effects, and the timing of stimuli according to saccade onset in the main experiments. Figures S2–S4 show results from analyses of the Gabor orientation judgment task, saccadic latencies, and saccade amplitudes for the three main experiments. In Figures S2–S4, pre-saccade trials included only those in which the probe was presented within 100 ms of saccade onset, when remapped crowding was strongest in all experiments. All differences in Gabor accuracy were analysed with 2 x 2 repeated measures ANOVAs, and pairwise t-tests were used to explore any significant interactions. Saccadic latencies and saccade amplitudes were evaluated using two-tailed paired t-tests with α = 0.05.

Supplemental Results
Here we report results from a Supplemental Experiment in which we tested for remapped crowding with vertical saccades (see Discussion in the main text).

Supplemental Experimental Procedures
Figure S1, Related to Figure 1. Standard Crowding, Remapped Crowding, and Stimulus Timing

(A and B) Data from a pilot experiment (N = 10). (A) While observers remained fixated in the center of the display, identification accuracy for a probe flanked by letters (red bar) was significantly lower than for a probe presented alone (blue bar; p = 0.004). (B) In the no-saccade condition, the presence of distractors in the hemifield opposite the probe had no effect on probe identification accuracy relative to probe-alone trials (p > 0.10). For trials in which an eye movement had to be executed, however, participants’ accuracy in identifying probes during the pre-saccade interval was significantly reduced when distractors occupied the probe’s remapped location relative to probe-alone trials. Statistical analyses confirmed a significant two-way interaction between saccade condition (no-saccade versus pre-saccade) and flanker condition (probe-alone versus remapped crowding; F₁,₉ = 7.97, p = 0.02). Specifically, the difference in accuracy

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C

remapping

probe onset

fixation offset

gaze position

saccade onset
between probe-alone and remapped crowding conditions was significant only during the pre-saccade interval ($t_9 = 3.58, p = 0.006$). Furthermore, while the decrease in accuracy from no-saccade to pre-saccade trials was significant for the remapped crowding condition ($t_9 = 3.29, p = 0.009$), there was no such difference for the probe alone condition ($t_9 = 0.99, p = 0.347$). The dashed black line shows performance for the standard crowding condition. Note that it was only in the pilot experiment that the “remapped crowding” display contained two probe letters, one in each hemifield, as shown here. Error bars in (A) and (B) represent one SEM. *** $p = 0.001$; ** $p < 0.01$.

(C) Overview of the timing of probe onset relative to fixation offset in critical “remapped crowding” trials, aligned to saccade onset on the x-axis.

(D) Saccade data from a representative observer in Experiment 1. Frequency of saccadic latency is plotted in orange. Onset asynchrony between probes and saccades is shown in pink. Probe onset latencies were normally distributed around 100 ms prior to the saccade. This method yielded an approximately equal number of observations across 100 ms time bins (see Supplemental Experimental Procedures).
Figure S2, Related to Figure 2. Experiment 1: Gabor Judgment Accuracies, Saccadic Latencies, and Saccade Amplitudes

(A) Gabor judgment accuracy. There were no significant differences in Gabor judgement accuracy across conditions.

(B) Saccadic latencies. Saccadic latencies were equivalent for nonshared- and shared-feature conditions. This implies spatial attention was deployed to the Gabor equally across conditions.

(C) Saccade amplitudes. There was no difference in saccade amplitude across conditions. This implies the Gabor was equally attended across saccade and fixation trials. Error bars in all panels show one SEM.
Figure S3, Related to Figure 3. Experiment 2: Gabor Judgment Accuracies, Saccadic Latencies, and Saccade Amplitudes

(A) Gabor judgment accuracy. We found a marginally significant interaction between flanker condition (nonshared vs shared) and saccade condition (no-saccade vs pre-saccade) for Gabor judgment accuracy ($F_{1,4} = 6.83$, $p = 0.059$). Follow-up pairwise t-tests (without correction for multiple post-hoc comparisons) revealed that, compared with fixation, observers were marginally more accurate at judging the orientation of the Gabor during the pre-saccade interval with shared-feature distractors ($t_{4} = 2.33$, $p = 0.081$). Furthermore, during the pre-saccadic interval, Gabor judgments were more accurate in the shared-feature condition than in the nonshared-feature condition ($t_{4} = 3$, $p = 0.04$). It may have been the case, therefore, that improved performance in the Gabor task for the shared-feature condition led to worse performance in the probe identification task during the pre-saccade interval. Indeed, we found a marginally significant correlation between improvement in Gabor accuracy and reduction in probe identification accuracy in the shared-feature condition ($r = 0.82$, $p = 0.089$). However, Gabor judgment accuracy was not causally related to probe identification accuracy: there was no such correlation for the nonshared-feature condition ($r = -0.21$, $p = 0.73$); nor was this correlation present in the shared-feature condition of either of the other main experiments (Experiment 1: $r = -0.46$, $p = 0.439$; Experiment 3: $r = -0.18$, $p = 0.623$).

(B) Saccadic latencies. Saccadic latencies were equivalent in the two remapped crowding conditions.

(C) Saccade amplitudes. There was no difference in saccade amplitude across conditions. Error bars in all panels show one SEM. * $p < 0.1$, ** $p < 0.05$. 
Figure S4, Related to Figure 4. Experiment 3: Gabor Judgment Accuracies, Saccadic Latencies, and Saccade Amplitudes

(A) Gabor judgment accuracy. There was a main effect of saccade condition (no-saccade vs pre-saccade) on Gabor judgement accuracy ($F_{1,9} = 8.97, p = 0.015$). Critically, however, there was no interaction between flanker condition and saccade condition.

(B) Saccadic latencies. Saccadic latencies were equivalent for nonshared- and shared-feature conditions.

(C) Saccade amplitudes. There was no difference in saccade amplitude across conditions. Error bars in all panels show one SEM.
**Supplemental Results**

**Supplemental Experiment**
To test whether the findings from Experiments 1–3 might be unique to horizontal saccades, we ran a Supplemental Experiment (N = 10) to test whether remapped crowding also occurs for vertical saccades. The critical displays used were similar to the remapped crowding display shown in Figure 4A, but were rotated 90° such that all placeholders fell on the vertical meridian. The saccade target was 7.8° from the center of the display, and the probe was 3.9° from the center of the display. Flankers only appeared within the critical distance of the probe’s actual location or remapped location. All other stimulus and timing details were as per Experiment 3 (see Supplemental Experimental Procedures). When flankers surrounded the probe’s remapped location, the proportions of letters correctly identified in no-saccade trials and pre-saccade trials were 0.56 ± .05 (M ± SEM) and 0.45 ± .05, respectively. That is, relative to no-saccade trials, probe performance was significantly reduced during the pre-saccade interval when flankers surrounded the probe’s remapped location (p = 0.006). Thus, remapped crowding also occurs for vertical saccades and is not unique to horizontal saccades or situations in which stimuli are presented on the horizontal meridian.

**Supplemental Experimental Procedures**

**Observers**
Twelve observers (4 females, 2 authors) participated in the experiments (five observers in Experiments 1 and 2, and 12 observers in Experiment 3). All observers had normal or corrected-to-normal vision. The study was approved by The University of Queensland’s School of Psychology Ethical Review Committee.

**Materials**
Participants sat with their head in a head and chin rest positioned 57 cm from a 22-inch widescreen Dell LCD monitor (1920 x 1200 pixels, 60 Hz) in Experiments 1 and 2, and a 20-inch Dell CRT monitor (1600 x 1200 pixels, 60 Hz) in Experiment 3. Stimulus presentation, eye movement recording and response collection were programmed using the Psychophysics Toolbox Version 3 [38, 39] and Eyelink Toolbox [40] for MATLAB (MathWorks). Eye movements were recorded at 500 Hz with an EyeLink 1000 (SR Research) infrared eye tracker, calibrated using a 5-point calibration procedure.

**Stimuli and Procedure**
Each trial began with the presentation of a fixation dot (width = 0.2°) at the center of a uniform gray display (31.2 cd/m²). Four placeholders (0.9° x 0.9°) in Experiments 1 and 2, and six placeholders in Experiment 3, were positioned to the left and right of the fixation spot, along the horizontal meridian. The distance from the fixation dot to the center of the nearest placeholder, and between the centers of adjacent placeholders, was 1.3°. There was a gap of 0.4° between adjacent placeholders. All placeholders
were outlined in black with the exception of either the far left or far right placeholder, which was outlined in green to indicate the saccade goal and the location of the Gabor. The side of the saccade goal was selected with equal probability across trials and presented in a pseudorandom order. The distance from the fixation dot to the center of the saccade goal was 5.2° in Experiments 1 and 2, and 7.8° in Experiment 3. To reduce perceptual distortions of space around the time of the saccade (e.g. [41]), and to eliminate transients associated with the onset and offset of the probe and any flankers, all placeholders were filled continuously with animated white noise [2], except during the target frame (Figure 1C). White noise was randomised on each screen refresh (each pixel value was pseudorandomly and independently drawn from a normal distribution, \(M = 128, SD = 50\)).

Each trial began only if gaze was maintained within a 2° x 2° area centered around the fixation spot for 500 ms. The fixation spot disappeared after a uniformly variable delay (750-1250 ms), cueing participants to execute the saccade. The saccade target (a Gabor oriented 22.5° left or right from vertical), letter probe, and any distractors were presented in a single frame during the pre-saccade interval (see below), and were immediately followed by dynamic white noise inside each placeholder. After 500 ms of white noise, participants reported the Gabor orientation with a button press (left or right arrow). If the orientation of the Gabor was reported correctly, the text, “T L or H?” was presented; participants then made a three-alternative forced-choice judgment on the identity of the letter probe via button press (left, down, or right arrow, for T, L and H, respectively). Observers were instructed that the letter probe to be identified would always appear in the placeholder located mid-way between fixation and the saccade target (i.e., the third placeholder from the end of the array in Experiments 1 and 2, and the fourth placeholder from the end of the array in Experiment 3). During testing, no feedback was given about letter probe performance. To control for any effects of flankers on probe identification that were not specific to an impending saccade, we included blocks of trials in which observers undertook the same task but were required to maintain their gaze centrally at the offset of the fixation point.

The saccade target was always located at the extreme left or right end of the array of placeholders. Participants practiced until they could execute the required eye movement and judge the orientation of the saccade target while performing above chance on the letter probe task (see below). If participants reported the orientation of the Gabor incorrectly, they were provided with on-screen feedback and informed that the trial would be repeated at the end of the block. After responses were made and any feedback given, the next trial commenced immediately. Saccade and fixation blocks of at least 16 trials were alternated, giving a minimum of 480 trials per participant. The colour of the fixation spot changed to indicate whether the observer was required to execute a saccade (indicated in blue) or remain fixated (indicated in red).

The target frame, including the letter probe, Gabor, and any distractors, was presented for 17 ms. Letter probes, distractor letters (Experiment 1) and square Landoldt Cs (Experiments 2 and 3) were constructed from rectangles (0.9° x 0.3°) arranged to form each symbol (T, H, L, C). Oval distractors in Experiments 1 and 2 had a diameter of
0.9°, and a line width of 0.3°. In Experiment 2, Landoldt Cs were always oriented with the gap on the right to ensure their identities were as consistent over trials as the dissimilar feature distractor identities (Os). In Experiment 3, the direction of each Landoldt C was randomised from trial to trial. In all experiments, probes and distractors were white (100% contrast). Based on data from a pilot study, the Gabor (1.4 cpd, 100% contrast) was oriented 22.5° left or right off vertical. Correct identification of the saccade target required close allocation of spatial attention toward the saccade goal, and away from the letter stimuli in the remapped crowding condition [42].

The interval between the saccade cue (the offset of the fixation spot) and the target frame was adjusted so the target frame was presented during the pre-saccade interval on the majority of trials (see Figure S1B and S1C) [23]. This interval was calculated by subtracting 100 ms from the median saccadic latency. To time the target frame, saccadic latencies were calculated online as the time between the offset of the fixation spot and the moment gaze deviated from this fixation point by more than 2°. Each experiment began with a block of saccade trials, and the median saccadic latency of the first trial of the first saccade block was estimated at 200 ms. Median saccadic latencies were calculated from all preceding saccades in the current block only. Reported saccadic latencies, and those used for all analyses, were re-calculated offline using the native EyeLink saccade detection criteria. This method of timing target presentations worked well and yielded close to 50% of trials in each time bin (see below and Figure S1D). The interval between the saccade cue and target frame from the most recent saccade trial was used for the following block of no-saccade trials.

Observers completed a minimum of 60 trials per distractor condition in all experiments, collapsed across probe side (left or right). The same number of trials was completed for each condition during fixation. All participants completed at least one block of 20 trials in which all stimuli were displayed as described above, but the task was to execute a saccade and report the orientation of the Gabor only. This practice block was repeated until accuracy at the Gabor orientation task exceeded 75%. Observers also completed at least one practice block of saccade and letter identification tasks, and then an entire run of trials as practice. For the pilot experiment, participants did not complete an entire run of practice trials. This difference in practice likely accounts for the overall higher accuracy in “no-saccade” trials for the main experiments (e.g. Figure 2B) relative to the pilot experiment (Figure S1B). Data from practice blocks were discarded.

Data Preprocessing and Statistical Analyses
Only trials in which observers correctly identified the orientation of the Gabor were included in analyses. Trials were discarded for the following reasons: (1) no saccade was executed or the saccade endpoint was greater than 2° from the center of the saccade target in saccade trials; (2) saccadic latency was shorter than 100 ms; (3) a saccade greater than 2° was executed within 500 ms of the removal of the fixation spot on fixation trials; (4) the target frame was presented during an eye-blink. Of the remaining trials, “pre-saccade” trials were those in which the onset of the target frame preceded the saccade by more than 17 ms, and by less than 200 ms. Trials in which the target frame onset occurred outside of these periods were excluded. For Experiment 3,
data were excluded for one observer due to poor performance at identifying the orientation of the Gabor (mean accuracy = 67%), and for one observer for whom there were less than 10 observations for each of two conditions. In total, 86.3% of trials were included in Experiment 1, 88.8% in Experiment 2, and 89.3% in Experiment 3. Pre-saccade trials were binned according to their onset time relative to the saccade (see Figure S1D). Of all included pre-saccade trials meeting the above criteria, 48.1% occurred 0-100 ms prior to the saccade in Experiment 1, 51.7% occurred 0-100 ms prior to the saccade in Experiment 2, and 49.4% occurred prior to the saccade in Experiment 3.

Supplemental References