

Letters lost

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Letters Lost: Capturing Appearance in Crowded Peripheral Vision Reveals a New Kind of Masking

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Abstract

Peripheral vision is strongly limited by crowding, the deleterious influence of flanking items on target perception. Distinguishing what is seen from what is merely inferred in crowding is difficult because task demands and prior knowledge may influence observers' reports. Here, we used a standard identification task susceptible to these influences, and next - to minimize them - an unconstrained full report and drawing paradigm. Three letters were presented in the periphery. In Experiment 1, ten observers were asked to identify the central target letter. In Experiment 2, 25 observers freely named and drew what they saw. When three *identical* letters were presented, performance was almost perfect in Experiment 1, but very poor in Experiment 2 where most observers reported only two letters. Our study reveals limitations of standard crowding paradigms, and it uncovers a hitherto unrecognised effect we call "redundancy masking".

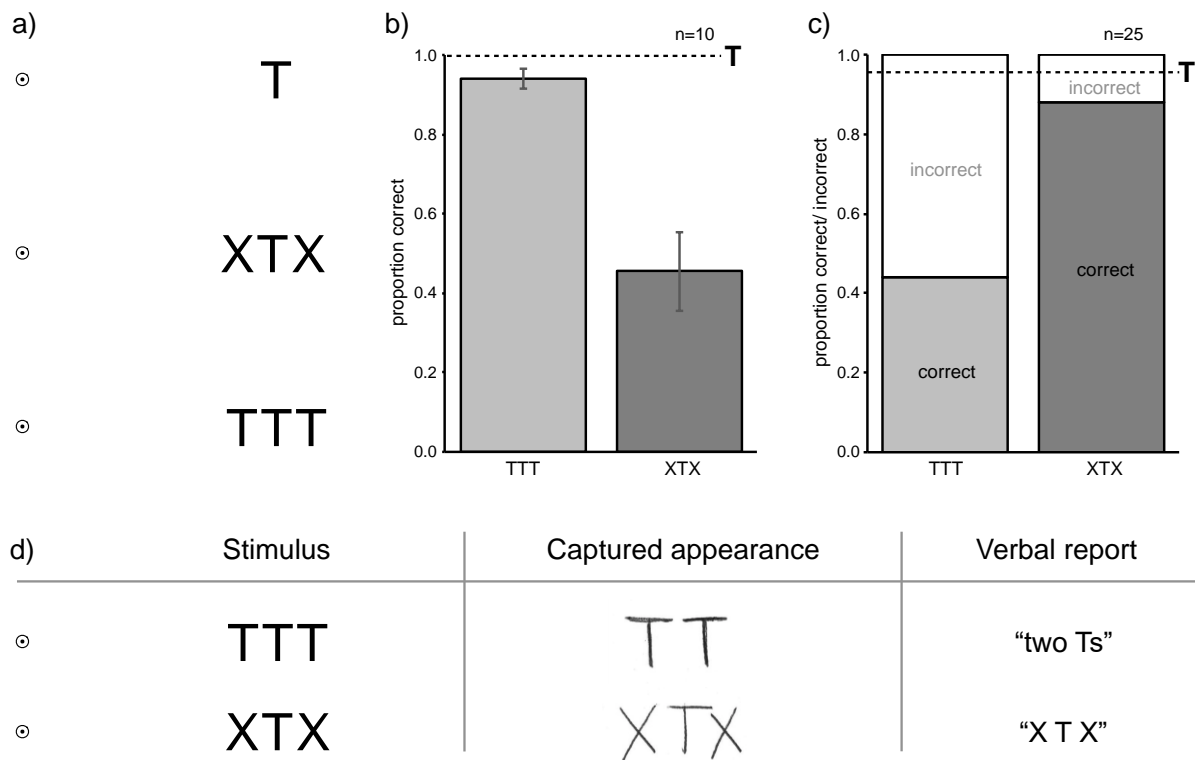
Introduction

We usually have the mistaken impression of unconstrained, high resolution access to the objects within our entire visual field. However, the largest part of the visual field is peripheral, and strongly limited by crowding, the deleterious influence of neighboring stimuli on target perception (Bouma, 1970; Levi, 2008). For example, letter identification deteriorates when the target is surrounded by flanking letters (Fig. 1a). Crowding is generally stronger when the target and the flankers are nearby (Toet &

35 Levi, 1992), similar (Kooi et al., 1992), and group together (Herzog et al., 2015; Sayim
36 et al., 2010).

37 In a special case of crowding, “identity-crowding” (Block, 2012), the target and
38 the flankers are the same (Fig. 1a). The strength of target disruption in identity-
39 crowding is poorly understood. On one hand, the disruptive effects of crowding are
40 stronger when target and flankers are similar, so we might expect that target
41 identification in identity-crowding is difficult. On the other, it was recently proposed that
42 target identification in identity-crowding is *superior* to normal crowding (Block, 2012;
43 cf. Taylor & Sayim, 2018). To evaluate these two hypotheses, an experimental
44 paradigm is needed that can test what is genuinely seen in (identity-) crowding.

45 Identity-crowding has unique methodological challenges. Since the target and
46 the flankers are the same, it is difficult to separate target from flanker reports, and,
47 crucially, reporting a flanker is a ‘correct’ response. Furthermore, observers often have
48 prior stimulus knowledge, for example, because they are informed that three letters
49 are presented. Here, using a standard crowding paradigm, we found almost perfect
50 performance in identity crowding. Next, to overcome the aforementioned challenges,
51 we used an unconstrained full report and drawing paradigm with gaze-contingent
52 stimulus presentation. Observers frequently reported only two instead of the three
53 presented identical letters, i.e., performance was poor. Our results reveal a new effect
54 we call “redundancy masking”, in which the number of perceived items is reduced.



55
 56 Figure 1: **a)** When fixating the upper disc, most observers are able to identify the T on
 57 the right. Identification is more difficult when the target is flanked by letters (middle).
 58 In ‘identity-crowding’, the target is flanked by identical items (bottom). **b)** Results of
 59 Experiment 1. Proportion correct was higher when the target and the flankers were
 60 the same (TTT) compared to when they were different (XTX). The dashed line shows
 61 unflanked proportion correct. Error bars indicate standard errors of the mean. **c)**
 62 Results of Experiment 2. Proportion correct was lower when the flankers were the
 63 same as the target (TTT) compared to when they were different (XTX), the opposite
 64 results of Experiment 1. **d)** Illustration of ‘redundancy masking’. Three Ts presented
 65 in the periphery appeared and were reported as two Ts. When Xs flanked the target,
 66 no redundancy masking occurred. Two representative drawing results are shown
 67 under “Captured appearance”.

68

69

Methods

70 Participants

71 In Experiment 1, ten paid students participated (5 female, 5 male; mean age = 23.1).
 72 In Experiment 2, 25 students participated for course credit (16 female, 9 male; mean
 73 age = 26.0). The sample sizes were based on studies using similar methodologies,
 74 with a significant increase of the number of participants in Experiment 2 to compensate
 75 for the comparably small number of trials (Sayim & Wagemans, 2017). All participants
 76 had normal or corrected-to-normal visual acuity.

77

78 **Apparatus and Stimuli**

79 Stimuli were presented on a CRT monitor (HP, P1230 with a refresh rate of 110 Hz in
80 Exp. 1, and Sony Trinitron GDM-F520 with a refresh rate of 120 Hz in Exp 2; resolution:
81 1152 x 864). A head and chin rest was used to stabilize the head position. Participants
82 viewed the monitor from a distance of 57 cm. The main target stimulus consisted of
83 the letter T, presented at 10 degrees eccentricity. In three conditions, the target was
84 presented alone, flanked by two Xs, (XTX) or flanked by two Ts (TTT; Fig. 1a). In
85 Experiment 1, the letters E, F, H, K, L, N, V, X, Z were used as additional targets (see
86 procedure). All letters were of Microsoft Yi Baiti font (redrawn in Exp. 2). The letters
87 were 1.4 degrees high and 1.1 degrees wide (with small deviations depending on the
88 letters in Experiment 1). The center-to-center spacing between the target and each
89 flanker was 1.3 degrees. A fixation dot was presented in the center of the screen. All
90 elements were black with a luminance of 0.48 cd/m² (0.1 cd/m², in Experiment 2)
91 presented on a gray background (50.1 cd/m²; 50.5 cd/m² in Experiment 2). In
92 Experiment 2, observers' gaze was tracked with an EyeLink 1000 (SR Research). A
93 drawing board was positioned in front of the head/ chin rest. Drawings were made on
94 paper with a standard pen. Verbal reports were recorded by the experimenter.

95

96 **Procedure**

97 In Experiment 1, stimuli were presented for 150 ms, randomly to the left or right of
98 fixation. Subjects were informed that three letters were presented and were instructed
99 to indicate the central letter by pressing the corresponding key on a keyboard.
100 Observers completed 10 blocks with 100 trials. Each letter (E, F, H, K, L, N, T, V, X,
101 Z) was presented 10 times per block. In eight blocks, the target was flanked in random
102 order by Xs in half of the trials and Ts in the other half. There were two conditions of
103 interest. "Normal crowding", using the XTX stimulus and "identity-crowding", using the
104 TTT stimulus. Each block contained 5 times the main target stimuli XTX and TTT,
105 hence, each was presented 40 times in total. In the remaining two blocks, unflanked
106 performance was measured (20 trials per target letter). Note that the non-T target
107 letters were only used as filler stimuli to be able to measure performance on the main
108 targets (XTX and TTT) without obvious repetitions.

109 In Experiment 2, each participant completed one trial with the XTX, TTT, and T
110 stimulus, respectively. Stimuli were presented in the right visual field at the same
111 eccentricity as in Experiment 1 (10°). We used eye tracking to present the stimuli only
112 when participants kept central fixation. Viewing time was unconstrained. Observers
113 were asked to draw with free viewing, and verbally report what they saw without any
114 constraints. Crucially (unlike in Experiment 1) no instructions were given that allowed
115 subjects to infer that three letters were present. The drawings were made at the center
116 of the drawing board, approximately aligned with fixation, requiring eye movements
117 along the vertical to alternate between looking at the screen and the drawings. Half of
118 the participants started with the XTX condition, the other half with the TTT condition.
119 The unflanked target was always presented last. The verbal response was classified
120 as correct if it fulfilled two criteria: subjects reported that there was a central letter
121 (requiring that three items were reported), and that it was a T. The drawings were
122 made to avoid reliance on a single measure, i.e. the free verbal reports, and to get a
123 good understanding of how the stimuli appeared to the subjects. Before each
124 experiment, participants performed a number of training trials to get familiarized with
125 the method. In Experiment 1, the training stimuli were randomly selected from the
126 stimulus set. In Experiment 2, they consisted of the same elements as the target and
127 the flankers, arranged in abstract geometric configurations.

128

129

Results

130 In Experiment 1, the proportion of correctly reporting “T” in the identity-crowding
131 condition (TTT) was high (0.94, SE=0.03; Fig. 1b). In the normal crowding condition
132 (XTX), performance was clearly worse (proportion correct=0.46, SE=0.10; t-test:
133 $t(9) = 5.60$, $p < 0.001$; Cohen’s $d = 2.15$). Proportion correct for the unflanked T was 1.
134 The proportion of erroneously reporting a flanker (X) was 0.33 (SE=0.04) in the XTX
135 condition. Importantly, the flanker report rate cannot be determined in the TTT
136 condition. The average proportion correct for the other target letters was 0.62
137 (SE=0.06) with X-flankers, and 0.82 (SE=0.04) with T-flankers (unflanked proportion
138 correct was 0.98; SE=0.004). This result seems to support the hypothesis that
139 crowding is comparatively weak when all items are the same. However, the use of a
140 standard crowding paradigm to measure performance when the target and the
141 flankers are identical has - as outlined above - several shortcomings to do with task

142 demands, prior knowledge and the fact that report of a flanker is counted as 'correct'
143 (see also Sayim & Cavanagh, 2013). We addressed these in Experiment 2.

144 The results of Experiment 2 showed that targets were not reported more
145 accurately in identity- compared to normal crowding (Fig. 1c). To the contrary,
146 proportion correct in the free verbal report was lower in identity-crowding (0.44)
147 compared to normal crowding (0.88; Odds-Ratio=0.107, Fisher's Exact Test,
148 $p < 0.005$). Most remarkably, all errors in the identity-crowding condition were due to
149 missing one of the three items, reporting two Ts instead of three. The participants'
150 drawings matched their free verbal responses, confirming that they perceived two Ts
151 rather than three in the identity-crowding condition (Fig. 1d). Hence, the perceived
152 number of items in the identity-crowding condition was lower than the number of
153 presented items, revealing a strong case of diminishment by crowding (Coates,
154 Wagemans, & Sayim, 2017; Sayim & Wagemans, 2017). We call this effect
155 'redundancy masking' – a 'redundant' item (the T) is not (consciously) perceived, or
156 'masked'. Notably, 96% of the responses in the identity-crowding condition contained
157 the letter 'T' and 92% no other letter than 'T'. Hence, it is not surprising that standard
158 identification tasks as in Experiment 1 result in 'correct' responses (reporting the letter
159 'T'), and thereby miss the pronounced misperception of the total number of items (two
160 T's instead of three).

161 Compared to Experiment 1, the rate of correct responses in the normal
162 crowding condition of Experiment 2 was relatively high, presumably due to long
163 presentation times (Styles and Allport, 1986), and multiple views of the same stimulus
164 (Sayim & Wagemans, 2017). Remarkably, accuracy in the identity-crowding condition
165 was nevertheless very poor, suggesting that redundancy masking (see below) is
166 strong even under conditions that benefit performance in normal crowding.

167 In an additional experiment (Experiment 3), we used printouts of the XTX and
168 TTT drawings from Experiment 2, and asked 100 naïve participants (four participants
169 per drawing; 61 female, mean age = 23.8) to indicate what was the central - or
170 hypothetically central – target letter (Fig. 1d shows two representative drawings). In
171 the identity-crowding condition (TTT), 84% (SE=0.05), and in the normal crowding
172 condition (XTX), 90% (SE=0.05) of the participants responded that the target letter
173 was a T. Hence, even when there were only two Ts in a drawing (and therefore no
174 central T), participants mostly reported the letter T. This result supports the finding of

175 Experiment 1. When asked to report the central of three letters, and participants only
176 see two Ts, the best response (or guess) is still that it was a T.

177 Overall, the results show that stimuli in identity-crowding were not perceived
178 better than in normal crowding. Rather, a remarkable and highly consistent error
179 characterized identity-crowded appearance – only two instead of three Ts were
180 reported by the majority of participants (Experiment 2; see also Fig. 1d). This type of
181 diminishment error cannot be captured with a standard crowding task as in Experiment
182 1. Using the drawings of Experiment 2 as representations of stimulus appearance, and
183 asking naïve participants to report the (hypothetical) central target letter, confirmed
184 that correct responses are very likely in identity-crowding even when only two items
185 are perceived.

186

187

Discussion

188 These results demonstrate a strong diminishment effect in crowding (Sayim &
189 Wagemans, 2017). Unlike normal crowding, stimuli in identity-crowding are
190 characterized by maximum target-flanker similarity, high regularity, and redundancy,
191 which, we suggest, yields a new type of error through a mechanism we call
192 ‘redundancy masking’. Instead of the perceived ‘jumble’ that is seen in normal
193 crowding, poor performance in identity-crowding is mainly caused by the
194 ‘disappearance’ or masking of an entire item (Tye, 2014).

195 Our results provide strong evidence against the hypothesis that targets in
196 identity-crowding are identified better than in normal crowding (Block, 2012).
197 Conversely, they support the hypothesis that target disruption is stronger in identity-
198 than in normal crowding (Taylor & Sayim 2018).

199 The unconstrained free-report paradigm is crucial to revealing this new effect
200 as standard forced-choice methods as in Experiment 1 conflate cases of genuinely
201 perceiving the central target, and mistaking three for two letters. By contrast, in
202 Experiment 2, participants were allowed to report the number of letters and their
203 identity, thereby providing insight into unbiased stimulus appearance. The result of
204 Experiment 3, with a high rate of ‘correct’ target identifications in drawings containing
205 only two letters, supports the view that subjects will report a central T when all they
206 really see is two Ts, and that this may underlie the seemingly better performance in
207 identity-crowding (Taylor, 2013).

208 Redundancy masking shares characteristics with crowding, masking, and
209 statistical summary representations. Regarding crowding, our findings are at odds with
210 the assumption that it only hinders feature integration and not feature detection (Pelli
211 et al., 2004). While we did not use a classic detection task, our results show the
212 perceived absence of one of the items akin to a ‘miss’ in masking paradigms. However,
213 the temporal and spatial features of our stimuli diverge from those used in traditional
214 masking studies (Breitmeyer & Öğmen, 2007). Although statistical summary
215 representations may occur for as few as two items, they are usually assumed to be
216 effective when larger numbers of items are displayed (Whitney & Yamanashi Leib,
217 2018). A limit of attentional resolution (He et al., 1996), may play a role in redundancy
218 masking, but the failure to detect all of three items is not predicted by this account.
219 What are the underlying mechanisms of redundancy masking, whether items lost by
220 redundancy masking still prime (Yeh et al., 2012) or bias observers (Kouider et al.,
221 2011; Manassi & Whitney, 2018), and whether redundant elements are lost also in
222 normal crowding, are open questions. By revealing unbiased visual appearance, our
223 findings demonstrate a remarkably strong illusion with crowded stimuli, suggesting a
224 mechanism that reduces the perceived number of redundant elements.

225

226

227 **Declaration of Conflicting Interests**

228 The authors declare no conflicts of interest with respect to their authorship and the
229 publication of this article.

230

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235

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