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1 **Typical visual-field locations facilitate access to awareness for everyday objects**

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18

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21

22 **Abstract**

23 In real-world vision, humans are constantly confronted with complex environments that
24 contain a multitude of objects. These environments are spatially structured, so that
25 objects have different likelihoods of appearing in specific parts of the visual space. Our
26 massive experience with such positional regularities prompts the hypothesis that the
27 processing of individual objects varies in efficiency across the visual field: when objects
28 are encountered in their typical locations (e.g., we are used to seeing lamps in the upper
29 visual field and carpets in the lower visual field), they should be more efficiently perceived
30 than when they are encountered in atypical locations (e.g., a lamp in the lower visual field
31 and a carpet in the upper visual field). Here, we provide evidence for this hypothesis by
32 showing that typical positioning facilitates an object's access to awareness. In two
33 continuous flash suppression experiments, objects more efficiently overcame inter-ocular
34 suppression when they were presented in visual-field locations that matched their typical
35 locations in the environment, as compared to non-typical locations. This finding suggests
36 that through extensive experience the visual system has adapted to the statistics of the
37 environment. This adaptation may be particularly useful for rapid object individuation in
38 natural scenes.

39 1. Introduction

40 Human visual perception is tailored to the world around us: it is most efficient when the
41 input matches commonly experienced patterns. This is evident from low-level vision,
42 where previously experienced regularities determine perceptual interpretations of the
43 input (Purves, Wojtach, & Lotto, 2011). Such influences of typical patterns are also
44 observed for more complex stimuli, such as faces. Face perception is specifically tuned to
45 the typical configuration of facial features (Maurer, Le Grand, & Mondloch, 2001), and a
46 disruption of this configuration (e.g., through face inversion) drastically decreases
47 perceptual performance (Valentine, 1988). Recent studies have suggested that not only
48 the concerted presence of multiple features facilitates face perception, but that also
49 individual facial features profit from typical positioning in the visual field (Chan, Kravitz,
50 Truong, Arizpe, & Baker, 2010; de Haas et al., 2016; Moors, Wagemans, & de Wit, 2016):
51 for example, it is easier to perceive an eye when it falls into the upper visual field (where
52 it more often appears when looking at a face) than when it falls into the lower visual field
53 (where it is not encountered so often).

54 Like faces, natural scenes are spatially structured. Scenes consist of arrangements
55 of separable objects, which follow repeatedly experienced configurations (Bar, 2004): for
56 instance, lamps appear above dining tables, and carpets tend to lie on the floor. Previous
57 research has suggested that such typical configurations can facilitate multi-object
58 processing (Draschkow & Võ, 2017; Gronau & Shachar, 2014; Kaiser, Stein, & Peelen, 2014,
59 2015). It has been proposed that just like in faces, spatial regularities in scenes may also
60 impact the perception of individual objects (Kaiser & Haselhuhn, 2017). As we navigate
61 around, the likelihood of encountering different objects varies across the visual field: for
62 instance, lamps – unless directly fixated – are most often seen in the upper visual field

63 and carpets most often appear in the lower visual field. Because of this repeated expose,
64 typically positioned objects should be processed more efficiently than atypically
65 positioned objects.

66 To test this hypothesis, we used a variant of continuous flash suppression (CFS;
67 Tsuchiya & Koch, 2005). In breaking-CFS paradigms, a stimulus presented to one eye is
68 temporarily rendered invisible by flashing a dynamic, high contrast mask to the other eye;
69 suppression times, i.e. the time a stimulus needs to break inter-ocular suppression and
70 reach visual awareness, are taken as a measure of processing efficiency (Stein, Hebart, &
71 Sterzer, 2011). Previous studies using this method have shown that suppression times
72 depend on spatial regularity patterns. For example, the typical configuration of faces and
73 bodies facilitates their access to awareness (Jiang, Costello, & He, 2007; Stein, Sterzer, &
74 Peelen, 2012). Similarly, breakthrough is facilitated for typically arranged multi-object
75 configurations (Stein, Kaiser, & Peelen, 2015), demonstrating that the spatial regularities
76 among different objects can facilitate processing under CFS.

77 To test whether such spatial regularities also impact the processing of individual
78 objects we investigated whether typical retinotopic positioning facilitates an object's
79 access to awareness. We used a stimulus set consisting of six everyday objects that were
80 either associated with upper or lower visual-field locations (Fig. 1). In two CFS
81 experiments, participants were shown individual exemplars of these objects in their
82 typical or atypical locations onto one eye; a dynamic mask was flashed onto the other eye
83 and temporarily rendered the object invisible (Fig. 2). Participants had to localize the
84 object as fast as possible, irrespective of its identity. In Experiment 1, suppression times
85 (i.e., times until successful localization) were significantly shorter for typically than for
86 atypically positioned objects. In Experiment 2, we replicated this finding, while

87 additionally controlling for potential response conflicts. These results demonstrate that
88 objects appearing in typical visual-field locations gain preferential access to visual
89 awareness, highlighting the influence of natural scene structure on individual object
90 perception.

91

92 2. Material and Methods

93 2.1. Participants

94 34 healthy adults participated in Experiment 1 (mean age 26.4 years, $SD=4.7$, 26
95 female) and another 34 participated in Experiment 2 (mean age 22.9 years, $SD=4.4$, 26
96 female). Participants were recruited from the online participant database of the Berlin
97 School of Mind and Brain (Greiner, 2005). All participants had normal or corrected-to-
98 normal vision, provided informed consent and received monetary reimbursement or
99 course credits for participation. All procedures were approved by the local ethical
100 committee and were in accordance with the Declaration of Helsinki.

101 Sample size was determined by an a-priori power calculation: assuming a
102 hypothetical, medium-sized effect of $d=0.5$, 34 participants are needed for a power of
103 80%¹.

104 2.2. Stimuli

105 The stimulus set consisted of six objects (Fig. 1A). Three of the objects were
106 associated with upper visual-field locations (lamp, airplane, and hat) and three were
107 associated with lower visual-field locations (carpet, boat, and shoe). For each object, we
108 collected ten exemplars. The objects were matched for their categorical content (two
109 furniture items, two transportation items, and two clothing items) to match high-level
110 properties (e.g., the objects' size, manipulability and semantic associations) across upper
111 and lower visual-field objects. To control for low-level confounds, stimulus images were
112 gray-scaled and matched for overall luminance (Willenbockel et al., 2010). Additionally,
113 we checked whether there was a consistent low-level difference across objects
114 associated with upper and lower visual-field objects. For this, we computed pair-wise

¹ A power analysis based on the effect obtained in Experiment 1 ($d=0.59$) revealed a power of 92% for a sample size of 34 in Experiment 2.

115 pixel correlations for all conditions, and compared results for objects associated with the
116 same visual-field locations versus objects associated with different visual-field locations.
117 This test was not significant, $t(1498)=0.50$, $p=0.62$, suggesting that there was no
118 consistent low-level difference across upper and lower visual-field objects.

119

120 >>> Fig. 1 <<<

121

122 To validate the objects' associations with specific locations, we used two
123 complementary approaches. First, we automatically queried a large database (>10,000
124 images) of labelled scene photographs (LabelMe; Russell, Torralba, Murphy, & Freeman,
125 2008). We assumed that the distribution of objects across a larger number of
126 photographs approximates their distribution under natural viewing conditions. For each
127 scene that contained one of the six objects, we extracted the within-scene location (the
128 mean coordinate of the labelled area) of the object (Fig. 1B). Second, we explicitly asked a
129 set of participants to place each object on a computer screen such that its on-screen
130 position mirrored its most probable real-world positioning (Fig. 1C). For both validation
131 approaches, vertical locations were significantly higher for upper than for lower visual-
132 field objects (all $t>6.04$, $p<.001$). Both measures thus confirmed the objects' associations
133 with specific, typical locations. A detailed report of our validation procedure can be found
134 in Kaiser, Moeskops, and Cichy (2018).

135

136 2.3. Experimental Design

137 The design was identical for both CFS experiments, unless otherwise noted.

138 During the experiment, participants wore red/blue anaglyph glasses, which allowed for a

139 separation of the two eye channels. Each stimulus display consequently consisted of a
140 combination of red and blue stimulus layers: One layer (“stimulus layer”) contained the
141 object stimulus, while the other layer (“mask layer”) contained a flashing noise mask.

142 The stimulus layer contained one exemplar of one of the six objects, shown on a
143 uniform-intensity background. In Experiment 1, the object (max. 3° visual angle) could
144 appear in one of two locations (3° eccentricity), either in the upper or the lower visual
145 field (Fig. 2A). In Experiment 2, the objects appeared in one of four locations, where the
146 upper and lower locations were additionally shifted either to the right or to the left (by
147 1.5° visual angle) (Fig. 2D). The stimulus layer was always presented to the participant’s
148 non-dominant eye².

149 The mask layer contained dynamic, contour-rich CFS masks consisting of randomly
150 arranged white, black, and gray circles (see Figure 2A/D). These masks were re-drawn
151 every 100ms, so that the mask layer flickered at a frequency of 10Hz. The mask layer was
152 always presented to the participant’s dominant eye.

153 During each trial, the stimulus display appeared within a square frame (12° visual
154 angle width/height, consisting of a black-and-white noise contour), placed on a black
155 background. In the center of the frame, a white fixation cross was overlaid onto the
156 stimulus; participants were instructed to maintain central fixation throughout the
157 experiment. To avoid abrupt gradients, the stimulus layer was gradually faded in over the
158 first second of each trial (by linearly increasing its contrast) and then remained constant
159 until the end of the trial. If participants had not responded after eight seconds, the mask
160 layer was faded out over the next four seconds (by linearly decreasing its contrast).
161 Participants had to indicate in which part of the screen they saw an object by using the

² Eye dominance was determined in a Porta test prior to the experiment.

162 arrow keys on the keyboard. In Experiment 1, participants had to indicate whether the
163 object appeared in the upper or lower position within the box (Fig. 2A). In Experiment 2,
164 participants had to indicate whether the object appeared to the right or the left of the
165 vertical midline (Fig. 2D). In both experiments, participants were instructed to respond as
166 fast as possible when any part of the target stimulus became visible, irrespectively of
167 their recognition of the object. Trials were terminated as soon as participants responded,
168 followed by an inter-trial interval of one second.

169 Before the start of the experiment, participants completed a short familiarization
170 block (around 5 minutes, containing a random subset of experimental trials). After this
171 familiarization block, mask contrast was adjusted for some participants, to avoid very
172 short or very long breakthrough times. Importantly, within participants, the mask
173 contrast remained identical for all trials of the subsequent experiment.

174 Both experiments contained 480 trials. In Experiment 1, each object exemplar
175 appeared four times in each of the two locations. In Experiment 2, each object exemplar
176 appeared two times in each of the four locations. Trial order was fully randomized.
177 Participants could take breaks after 120, 240, and 360 trials. Stimulus presentation was
178 controlled using the Psychtoolbox (Brainard, 1997).

179 2.4. Statistical analysis

180 Trials with wrong responses or suppression times <300ms were discarded from all
181 analysis. Suppression times were then averaged by typicality, i.e. separately for typically
182 and atypically positioned objects. Statistical significance was assessed using paired t-

183 tests³. Across the two experiments, effects were compared using an independent-
184 samples t-test. Cohen's *d* is reported as an effect-size measure for all t-tests.

185 Furthermore, to determine the evidential value for an effect across both
186 experiments, we ran a meta-analytic Bayes-Factor (BF) analysis (Rouder & Morey, 2011;
187 implemented in BayesFactor for R). The resulting BF indicates the odds in favor of a non-
188 zero, constant effect size across experiments. BFs >10 are considered strong evidence for
189 an effect.

190 In the object-specific analysis, we also corrected for bias towards either the upper
191 or lower visual field in individual participants' responses (e.g., caused by preferences in
192 attentional allocation)⁴. We first computed the suppression time difference between
193 objects appearing in the upper and lower locations (independently of positional
194 regularities). In both Experiments, participants on average responded faster to targets in
195 the lower location; this effect was more pronounced in Experiment 1 (110ms, SE=108ms)
196 than in Experiment 2 (18ms, SE=105ms). We subtracted away half of this difference from
197 all suppression times for the "slower" location, and added half of this difference to all
198 suppression times for the "faster" location. Effects were then compared across objects
199 using repeated-measures ANOVAs⁵. Partial η^2 is reported as an effect-size measure for
200 ANOVAs.

³ In both experiments, differences in suppression times were approximately normally distributed (*Shapiro-Wilk* tests: both $W > 0.96$, $p > .27$).

⁴ The bias correction was only applied for the individual-object analysis.

⁵ Notably, the statistical outcome of this analysis is not affected by our approach to control for bias.

201 **3. Results**

202 3.1. Experiment 1

203 In Experiment 1, we tested whether typical visual-field locations facilitate object
204 perception under inter-ocular suppression. Participants had to indicate as fast as possible
205 whether the object appeared above or below fixation (Fig. 2A). Localization accuracy was
206 very high (99%) and did not differ between typically and atypically positioned objects,
207 $t(33)=0.94$, $p=.36$. Crucially, suppression times were significantly shorter for typically
208 positioned objects (e.g., a hat in the upper visual field) than atypically positioned objects
209 (e.g., a hat in the lower visual field), $t(33)=3.45$, $p=.002$, $d=0.59$ (Fig. 2B), suggesting that
210 typical object positioning boosts access to visual awareness.

211

212 >>> Fig. 2 <<<

213

214 3.2. Experiment 2

215 In Experiment 2, we replicated the findings obtained in Experiment 1. We
216 additionally sought to exclude potential response biases: In principle, an “upper location”
217 object could conflict with a “down” motor response; conversely, a “lower location”
218 object could facilitate a “down” motor response. To rule out such response biases, we
219 asked participants to indicate whether the object appeared shifted to the right or left of
220 the vertical midline (Fig. 2D). Localization accuracy was very high (98%) and did not differ
221 between typically and atypically positioned objects, $t(33)=0.42$, $p=.68$. Suppression times
222 were again shorter for typically positioned objects, $t(33)=2.12$, $p=.042$, $d=0.36$ (Fig. 2E),
223 corroborating the finding that typical object locations facilitate access to awareness.

224 3.3 Comparison across experiments

225 To assess the effect of potential response biases in Experiment 1, we directly
226 compared the regularity effects (i.e., the difference between suppression times for
227 typically and atypically positioned objects) obtained in both Experiments. This
228 comparison revealed no statistical difference between Experiments, $t(66)=1.13$, $p=0.26$,
229 $d=0.28$, suggesting that potential motor response biases did not substantially influence
230 the effect.

231 Given the similarities amongst our two Experiments, we analyzed them together
232 using a meta-analytic Bayesian analysis. This analysis revealed very strong evidence for a
233 preferential perception of typically positioned objects under CFS ($BF=81.9$).

234

235 *3.4. Individual-object effects*

236 To compare the regularity benefit across objects, we examined suppression times
237 for individual objects when they were positioned typically or atypically (see Materials and
238 Methods). Notably, a net facilitation of detection was found for each object in
239 Experiment 1 (Fig. 2C), and for all but one objects (carpet) in Experiment 2 (Fig. 2F). In
240 both experiments, no modulation of this regularity benefit was found across individual
241 objects, Experiment 1: $F(5,165)=1.04$, $p=.40$, $\eta_p^2=0.03$, Experiment 2: $F(5,165)=0.37$, $p=.87$,
242 $\eta_p^2=0.01$. This pattern of results demonstrates that the effects were consistent across
243 objects and not driven by individual stimuli.

244

245 4. Discussion

246 Here, we provide evidence that typical visual-field locations facilitate the perception of
247 everyday objects under inter-ocular suppression. In two CFS experiments, objects
248 appearing in their typical visual-field locations had shorter suppression times than objects
249 appearing in atypical locations. In both experiments, this benefit was consistent across
250 individual objects. Experiment 2 additionally ruled out response bias as an alternative
251 explanation for the effect. By showing that conjunctions of objects and locations are
252 differentially likely to enter visual awareness, our findings highlight the impact of real-
253 world statistics on perceptual processing.

254 Our results complement a recent study showing that breakthrough under CFS is
255 modulated by regularities in multi-object arrangements (Stein et al., 2015). Together,
256 these studies show that visual object processing is tuned to spatial regularities at
257 different levels of complexity – from regularities in individual object positioning to spatial
258 dependencies among objects⁶. Interestingly, these findings suggest that the presence of
259 regularities may not only facilitate conscious and explicit interactions with the world (e.g.,
260 Wolfe, Võ, Evans, & Greene, 2011), but may also determine whether we perceive an object
261 in the first place. However, whether differences in breaking-CFS reflect differences in
262 unconscious processing or more general differences in stimulus detectability is a matter
263 of ongoing debate (Blake, Brascamp, & Heeger, 2014; Gayet & Stein, 2017; Gayet, Van der
264 Stigchel, & Paffen, 2014; Yang, Brascamp, Kang, & Blake, 2014). Under a more cautious
265 interpretation, our findings therefore reveal that typical positioning influences stimulus
266 detectability, potentially reflecting differences in unconscious processing.

⁶ It has also been suggested that congruencies between objects and their scene context influence access to awareness (Mudrik, Breska, Lamy, & Deouell, 2011), but it has recently become evident that such semantic relationships cannot be extracted during unconscious processing (Biderman & Mudrik, 2018; Moors, Boelens, van Overwalle, & Wagemans, 2016).

267 What allows typically positioned objects to overcome inter-ocular suppression
268 more efficiently? There is considerable agreement that processing under inter-ocular
269 suppression is unlikely to suffice for a full semantic analysis (Gayet et al., 2014; Lin & He,
270 2009; Moors, Hesselmann, Wagemans, & van Ee, 2017). However, numerous studies have
271 demonstrated that processing under CFS is modulated by experience: for example,
272 access to awareness is facilitated for familiar faces (Gobbini et al., 2013), own-race faces
273 (Stein, End, & Sterzer, 2014), objects of expertise (Stein, Reeder, & Peelen, 2016), and
274 typically arranged multi-object arrangements (Stein et al., 2015). Our results similarly
275 reflect a benefit of extensive experience, induced by life-long exposure to particular
276 object-location conjunctions.

277 It has been suggested that an object's ability to overcome inter-ocular suppression
278 is tied to the distinctiveness of its neural representation (Cohen, Nakayama, Konkle,
279 Stantic, & Alvarez, 2015). Interestingly, increased distinctiveness can result from a
280 sharpening of neural tuning properties through experience (Freedman, Riesenhuber,
281 Poggio, & Miller, 2006; Kobatake, Wang, & Tanaka, 1998). Consistent with this idea, we
282 have recently used the same stimuli as in the current study to provide evidence for more
283 distinctive cortical representations for typically, as compared to atypically, positioned
284 objects: These effects were observed after 140ms (Kaiser et al., 2018) and in object-
285 selective lateral-occipital (LO) cortex (Kaiser & Cichy, 2018). These findings suggest that
286 access to awareness is modulated by neural representations in LO, which reflect complex
287 features such as an object's shape (Grill-Spector, Kourtzi, & Kanwisher, 2001). By contrast,
288 recent accounts of CFS mechanisms primarily attribute differential access to awareness
289 to differences in early visual processing of simple features (Moors et al., 2016, 2017, Yuval-
290 Greenberg & Heeger, 2013). Whether the effects observed here can be directly linked to

291 features processed in LO or whether they originate from interactions between LO and
292 simple feature representations in early visual regions (see Kaiser & Cichy, 2018) needs to
293 be tested in future studies.

294 To conclude, our findings reveal how spatial regularities in natural environments
295 impact perceptual processing of individual objects: when objects appear in typical
296 locations, their access to visual awareness is facilitated. This facilitation may be a valuable
297 prerequisite for fast object individuation in complex real-world scenes.

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302

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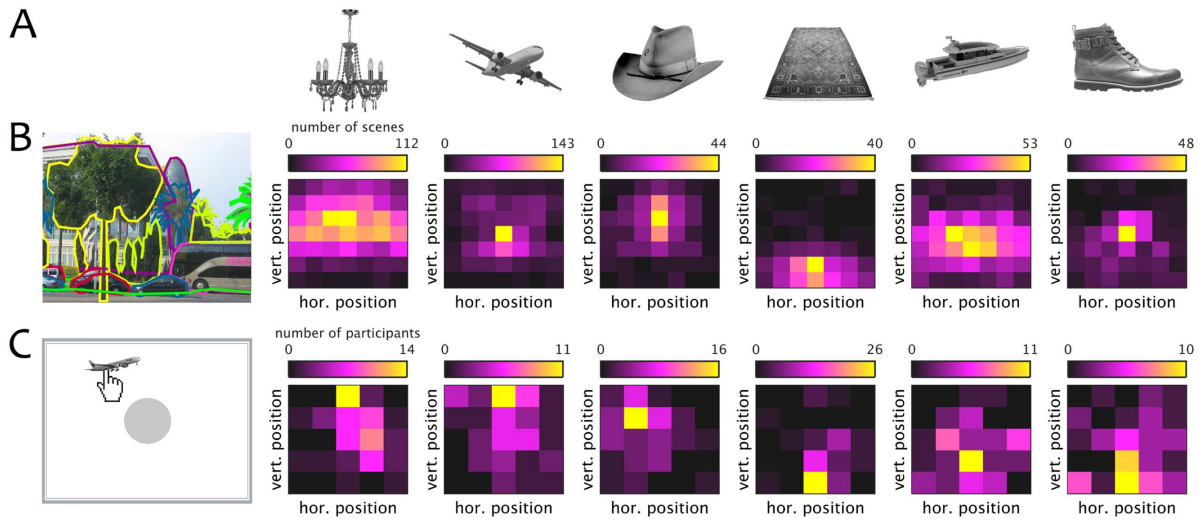
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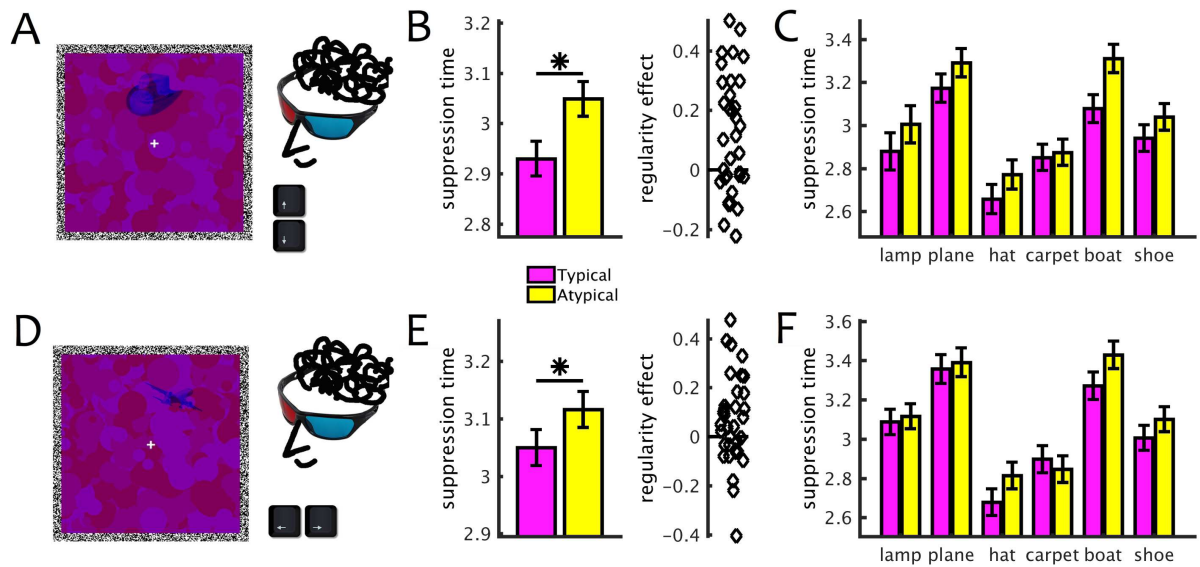
411 **Figures**



412

413 **Fig. 1.** The stimulus set consisted of six objects (10 exemplars each), of which three (lamp,
414 airplane, hat) were associated with upper visual-field locations and three (carpet, boat,
415 shoe) were associated with lower visual-field locations (A). The visual-field associations
416 were validated by computing two measures (see Materials and Methods for details):
417 First, we used a large set of labelled scenes (Russell et al., 2008) to extract typical within-
418 scene positions for each object (B). Second, we asked a set of participants to freely place
419 the object on the screen so that its position best matches its typical real-world position
420 (C). Heatmaps reflect the distribution of locations across a scene (B) or the screen (C).

421



422

423 **Fig. 2.** In two CFS Experiments, participants had to localize objects presented to one eye,
 424 which were temporarily rendered invisible by dynamic masks presented to the other eye.
 425 In Experiment 1, participants had to indicate whether the object appeared in an upper or
 426 lower location (A); in Experiment 2, they had to indicate whether it appeared on the left
 427 or on the right (D). Crucially, the object could be positioned in its typical location (e.g., hat
 428 in the upper visual field) or in an atypical location (e.g., hat in the lower visual field). In
 429 both experiments, suppression times were significantly shorter for typically positioned,
 430 as compared to atypically positioned, objects (B/E). This effect was numerically consistent
 431 across individual objects (but the carpet in Experiment 2) (C/F).