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

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Abstract

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

1. Introduction

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

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

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

To test whether such spatial regularities also impact the processing of individual objects we investigated whether typical retinotopic positioning facilitates an object's access to awareness. We used a stimulus set consisting of six everyday objects that were either associated with upper or lower visual-field locations (Fig. 1). In two CFS experiments, participants were shown individual exemplars of these objects in their typical or atypical locations onto one eye; a dynamic mask was flashed onto the other eye and temporarily rendered the object invisible (Fig. 2). Participants had to localize the object as fast as possible, irrespective of its identity. In Experiment 1, suppression times (i.e., times until successful localization) were significantly shorter for typically than for atypically positioned objects. In Experiment 2, we replicated this finding, while additionally controlling for potential response conflicts. These results demonstrate that objects appearing in typical visual-field locations gain preferential access to visual awareness, highlighting the influence of natural scene structure on individual object perception.

2. Material and Methods

2.1. Participants

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

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

2.2. Stimuli

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

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[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.

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

>>> Fig. 1 <<<

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

2.3. Experimental Design

The design was identical for both CFS experiments, unless otherwise noted. During the experiment, participants wore red/blue anaglyph glasses, which allowed for a separation of the two eye channels. Each stimulus display consequently consisted of a combination of red and blue stimulus layers: One layer ("stimulus layer") contained the object stimulus, while the other layer ("mask layer") contained a flashing noise mask.

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

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

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

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

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

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

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

2.4. Statistical analysis

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

tests[3]. Across the two experiments, effects were compared using an independent-samples t-test. Cohen's *d* is reported as an effect-size measure for all *t*-tests.

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

In the object-specific analysis, we also corrected for bias towards either the upper or lower visual field in individual participants' responses (e.g., caused by preferences in attentional allocation)[4]. We first computed the suppression time difference between objects appearing in the upper and lower locations (independently of positional regularities). In both Experiments, participants on average responded faster to targets in the lower location; this effect was more pronounced in Experiment 1 (110ms, SE=108ms) than in Experiment 2 (18ms, SE=105ms). We subtracted away half of this difference from all suppression times for the "slower" location, and added half of this difference to all suppression times for the "faster" location. Effects were then compared across objects using repeated-measures ANOVAs[5]. Partial η^2 is reported as an effect-size measure for ANOVAs.

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[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.

3. Results

3.1. Experiment 1

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

>>> Fig. 2 <<<

3.2. Experiment 2

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

3.3 Comparison across experiments

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

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

3.4. Individual-object effects

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

4. Discussion

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

Our results complement a recent study showing that breakthrough under CFS is modulated by regularities in multi-object arrangements (Stein et al., 2015). Together, these studies show that visual object processing is tuned to spatial regularities at different levels of complexity – from regularities in individual object positioning to spatial dependencies among objects[6]. Interestingly, these findings suggest that the presence of regularities may not only facilitate conscious and explicit interactions with the world (e.g., Wolfe, Võ, Evans, & Greene, 2011), but may also determine whether we perceive an object in the first place. However, whether differences in breaking-CFS reflect differences in unconscious processing or more general differences in stimulus detectability is a matter of ongoing debate (Blake, Brascamp, & Heeger, 2014; Gayet & Stein, 2017; Gayet, Van der Stigchel, & Paffen, 2014; Yang, Brascamp, Kang, & Blake, 2014). Under a more cautious interpretation, our findings therefore reveal that typical positioning influences stimulus detectability, potentially reflecting differences in unconscious processing.

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[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).

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

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

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

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Figures

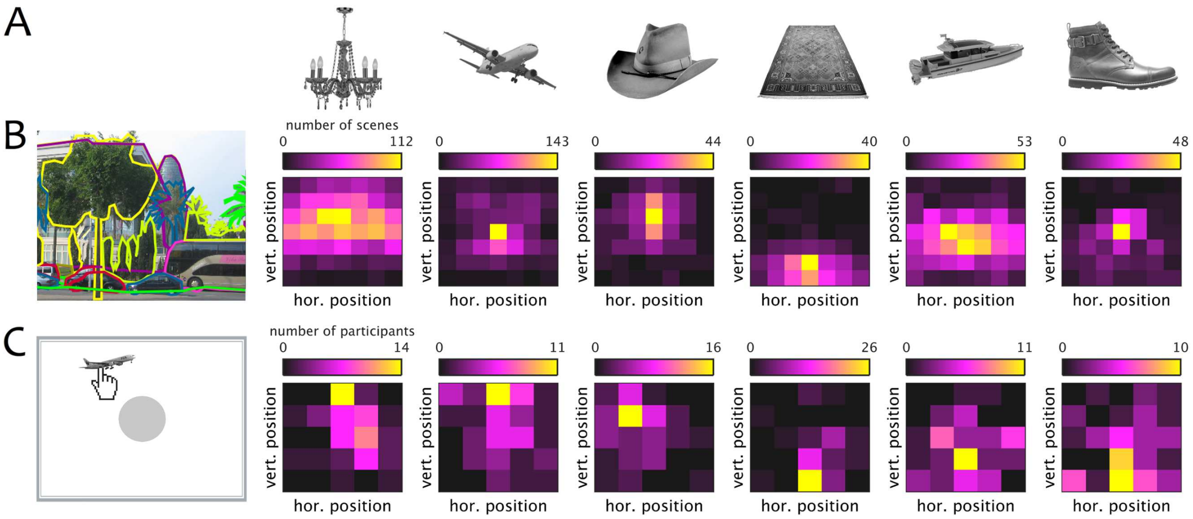

Fig. 1. The stimulus set consisted of six objects (10 exemplars each), of which three (lamp, airplane, hat) were associated with upper visual-field locations and three (carpet, boat, shoe) were associated with lower visual-field locations (A). The visual-field associations were validated by computing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

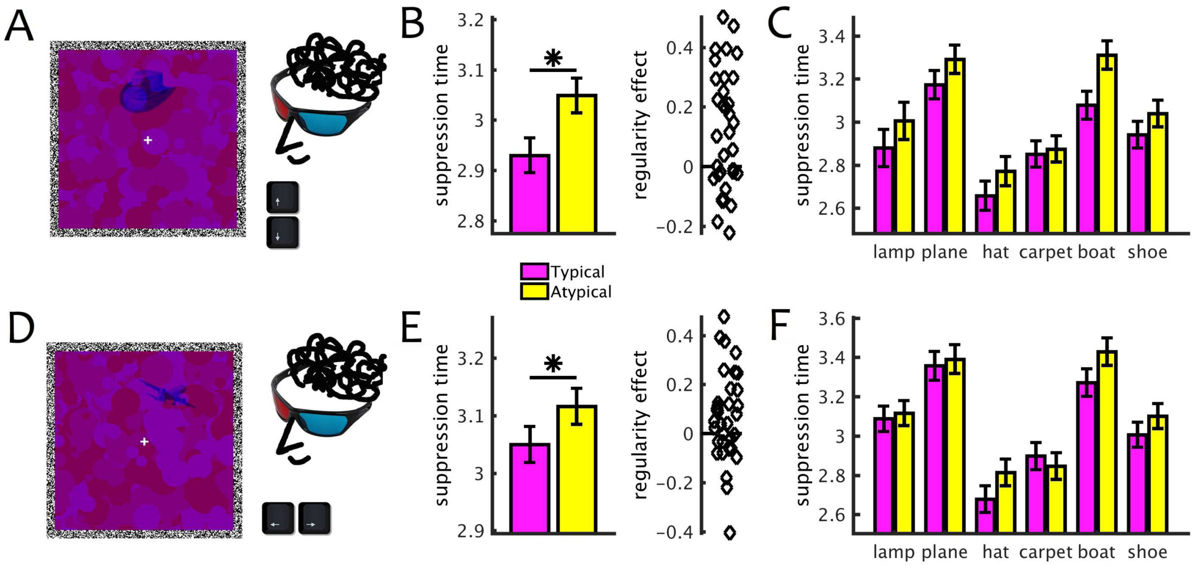

Fig. 2. In two CFS Experiments, participants had to localize objects presented to one eye, which were temporarily rendered invisible by dynamic masks presented to the other eye. In Experiment 1, participants had to indicate whether the object appeared in an upper or lower location (A); in Experiment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