Zivony, Alon and Eimer, Martin (2022) Expectation-based blindness: predictions about object categories gate awareness of focally attended objects. Psychonomic Bulletin & Review 29 , pp. 1879-1889. ISSN 1069-9384.

IN PRESS
PSYCHONOMIC BULLETIN AND REVIEW

Expectation-based blindness:
Predictions about object categories gate awareness of focally attended objects

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Word count for introduction, results and discussion: 3216

Abstract

Selective attention gates access to conscious awareness, resulting in surprising failures to notice clearly visible but unattended objects ("inattentional blindness"). Here, we demonstrate that expectations can have a similar effect, even for fully attended objects ("expectation-based blindness"). In three experiments, participants (*N*=613) were presented with rapid serial visual presentation (RSVP) streams at fixation and had to identify a target object indicated by a cue. Target category was repeated for the first 19 trials but unexpectedly changed on trial 20. The probability of correct target reports on this surprise trial was substantially lower than on preceding and subsequent trials. This impairment was present for switches between target letters and digits, and also for changes between human and animal face images. In contrast, no drop in accuracy was observed for novel target objects from the same category as previous targets. These results demonstrates that predictions about object categories affect visual awareness. Objects that are task-relevant and focally attended often fail to get noticed when their category changes unexpectedly.

Introduction

Our visual experience is rich and full of detail and appears to provide a complete and accurate representation of the objects and events in our current field of view. However, this intuition is far from correct. There are many instances where people do not notice salient visual events while looking directly at them. A dramatic illustration of this limitation is the phenomenon known as "inattentional blindness", where many observers fail to detect the presence of clearly visible objects when these objects are unexpected and attention is directed elsewhere (Mack & Rock, 1998). Inattentional blindness (IB) demonstrates that phenomenal visual experience does not reflect a detailed and unbiased photographic image of the external world, but is highly selective and incomplete, and strongly determined by top-down task settings and observer expectations. Many studies have shown that IB arises when attention is diverted. Here, we demonstrate a new type of impaired visual awareness that is exclusively linked to expectation: Even focally attended objects often fail to get noticed and reported when they are unexpected.

In IB experiments, objects escape awareness when observers engage in an attentionally demanding primary task, such as monitoring dynamic real-world scenes (e.g., the number of passes made by a basketball team; Simon & Chabris, 1999), tracking moving objects on a computer screen (Most et al., 2001), or discriminating visual features in static displays (Rock et al., 1992; Harris et al., 2020). When a task-unrelated object (e.g., a gorilla in the basketball video) appears during task performance, many observers fail to detect and report it, in spite of the fact that it is highly salient and easily noticed when attention is not diverted to the primary task. When this task is less demanding and therefore requires less attention, the surprising object is more likely to be noticed (see Jensen et al., 2011, for review). A second important feature of most IB tasks is that the appearance of the critical object is unexpected. The role of expectations was documented in a study where objects unrelated to the primary task were presented repeatedly (Ward & Scholl, 2015). Most observers who failed to spot this critical object when it first appeared correctly reported its presence on two subsequent trials where it appeared again. Importantly, when the shape of this object then changed on a fourth trial, it was missed more frequently than when it remained unchanged, demonstrating that IB is also associated with expectations about object features. This is also illustrated by the fact that critical objects are detected more often when its features are relevant for the primary task (Most et al., 2005; Most, 2013; Simons & Chabris, 1999). For example, Most (2013) found that an unexpected "3" was noticed more often than an "E" by participants who tracked moving digits, while the reverse pattern was found for participants who tracked letters. This suggests that IB can be affected by higher-level object attributes, such as their alphanumeric category.

The role of expectations about object attributes for IB raises the question whether such expectations might directly cause failures to detect visual objects, even when focal attention is not diverted to a different primary task. Resolving this question would be theoretically important, as there is currently much controversial debate about whether expectations can modulate sensory processes that give rise to conscious awareness in ways that are independent of attention (e.g., Alink & Blank, 2021; Press et al., 2020; Rungratsameetaweemana & Serences, 2019). It is well known that expectations modulate the selective processing of visual signals (Feldman & Friston, 2010; Summerfield & de Lange, 2014; de Lange et al., 2018), and this may also affect conscious access. However, it is generally assumed that expectations do not cause IB directly, but modulate awareness only by having an effect on the allocation of attention (e.g., Jensen et al., 2011). The sensitivity of IB to expectations about specific object attributes and their task-relevance (e.g., Most, 2013; Ward & Scholl, 2015) can be explained by assuming that critical objects with these attributes will often attract attention, thereby increasing the probability that they will be detected, even when their location is not known in advance (see also Firestone & Scholl, 2016).

In this study, we challenge this assumption that any effects of expectation on visual awareness are always mediated by attentional mechanisms. We do this by demonstrating that expectations about the category of an object affect the probability that this object will be detected, even when it is task-relevant, its appearance is fully expected, its location is known, and in the absence of other simultaneous competing objects or another demanding primary task. We used a procedure similar to a typical IB experiment, where a sequence of standard trials was followed by a surprise trial with an unexpected target. Participants monitored a rapid stream of successive objects to identify a target indicated by a selection cue (a specific shape). On the surprise trial, the category of the target changed unexpectedly from the preceding standard trials. However, there were several critical differences to standard IB tasks. First, the unexpected object was not task-irrelevant, but was clearly indicated as the target by the shape cue, and its appearance on the surprise trial was entirely expected. Second, the task performed in response to the unexpected target (identification) remained the same as on the preceding trials (i.e., attention was not engaged with any different primary task on the surprise trial). Finally, the unexpected target appeared at a known task-relevant location (at fixation), and was not accompanied by any other objects in the visual field, so that no attentional guidance was required to locate it. In other words, the target on the surprise trial was unexpected only with respect to its category, while all relevant attentional task settings remained the same as on the preceding standard trials.

Two additional aspects of the task ensured that targets on standard trials and on the surprise trial differed only in terms of expectations, and not in the amount of attention allocated to them. First, surprise was induced by changing the target's category, rather than a basic visual feature like colour or size. This was done in order to avoid the use of this feature as an efficient selection cue, which could facilitate target processing on standard trials, and result in performance costs when this feature changes unexpectedly. In addition, the target was embedded among many distractors that shared its category, and could therefore only be differentiated from distractors using the shape cue, but not on the basis of its category.

If expectation-induced modulations of visual awareness are always mediated by differences in selective attention, the probability that observers would detect and report the target should not differ between the surprise trial and preceding and subsequent trials, as all attentional factors remained unchanged. To preview our results, this is not what we found. Instead, we observed robust evidence for impaired awareness of the target object on the surprise trial. The probability of accurate perceptual reports on this trial was consistently lower relative to the preceding and subsequent trials. Thus, category-related expectations alone are sufficient to modulate the ability to detect and identify visual objects - a novel phenomenon we term “expectation-based blindness”.

Experiment 1

Method

In all experiments, we employed a rapid serial visual presentation (RSVP) procedure where a single stream of successive objects appeared at fixation. Items were presented every 100 ms, and participants had to identify a target that was indicated by a circle (see Figure 1). In Experiments 1 and 2, RSVP streams contained letters and digits. The critical expectation manipulation concerned the alphanumerical category of each target. For the first 19 standard trials, all targets came from the same category (letters or digits). The 20th trial was the surprise trial where the target category changed unexpectedly from letters to a digit, or vice versa. The surprise trial was followed by five additional trials where targets belonged to the new category. Similar to standard IB experiments (e.g., Rock et al., 1992), we predicted that the probability of correct target reports would drop on the surprise trial than the preceding trials, and recover again on the trial following the surprise trial, indicating that observers now expect targets from the new category. To test whether such a drop would also be present for real-world visual objects, Experiment 3 employed photographs of human and animal faces as the two target categories.

Sample Size Selection

Because this was the first experiment examining IB-related effects with task-relevant unexpected items, no precise power analysis could be conducted to justify sample size. Therefore, we treated Experiment 1 as an exploratory study. A rough estimate of required power was based on data from the original IB article (Rock et al., 1992; IB rate: 25%) and from a similar RSVP experiment (Bowman & Wyble, 2007), suggesting a baseline accuracy after practice of 85% and a drop to 60% accuracy on the surprise trial. Using these estimates in a chi-square for goodness of fit resulted in an effect size of w=0.28. A power analysis conducted in G*power (Faul et al., 2013) indicated that with this effect size, 80% power would require a sample of 102 observations (i.e., 51 participants). Due to the differences in stimuli, paradigm, and analysis, we used a considerably larger sample size (128 participants), to allow for the detection of smaller effects.

Participants

In all experiments, participants from the United States or United Kingdom were recruited via Prolific for £1 payment. All reported being fluent in English and having normal or corrected-to-normal visual acuity. Participants were dropped from the sample if they had accuracy lower than 50% (7 participants) or if their computers could not produce the prespecified stimulus presentation durations (12 participants; see below). All significant results in this and the following experiments did not change when these participants were included in the sample. The final sample included 128 (73 women) volunteers (*Mage*=27.9, *SD*=6.8).

Apparatus

The experiment was conducted using participants' own computers. They downloaded and accessed the experiment via E-Prime Go cloud service, and were instructed to sit approximately 60 cm from the screen (approximately an arms' length), in a quiet and distraction-free environment. Manual responses were given through computer keyboards.

Procedure and stimulus

Participants entered a Qualtrics webpage where they were informed how to access the study. They provided consent and downloaded the experimental file. Their task was to report as accurately as possible the identity of an alphanumeric character that appeared inside a circle, presented unpredictably in an RSVP stream of grey digits and letters. Manual responses were executed without time pressure at the end of each trial. The sequence of events is illustrated in Figure 1A and 1B. Each trial began with the presentation of a fixation display (a grey 0.2°× 0.2° "+" sign at the centre of the screen). After 500 ms, the fixation cross was replaced by an RSVP stream including 5 to 9 alphanumeric characters (1.3° in height). To reduce any effect of trial length on the critical comparisons, the surprise trial (trial S), the immediately preceding trial (S-1) and the immediately following trial (S+1), all contained 7 frames.

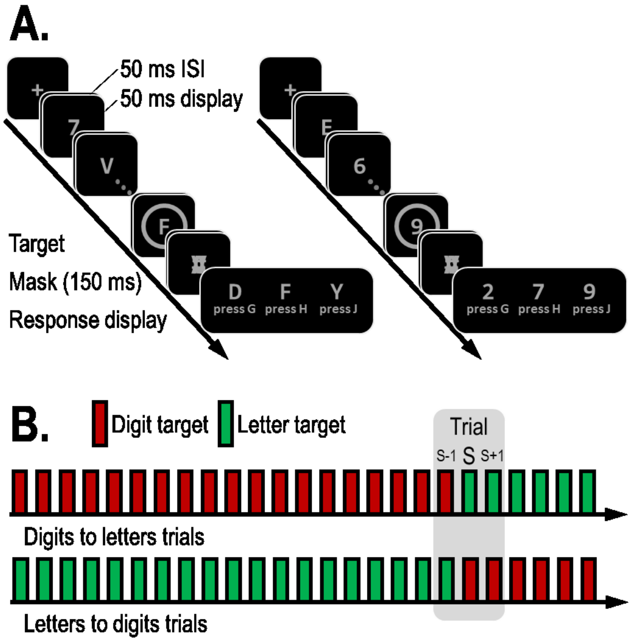

Figure 1. Stimuli (A) and trial sequence (B) in Experiment 1. The target was a digit or a letter, indicated by a circle cue, appeared in frame 5-9, and was followed by a mask. B: On trials 1-19, the target was always selected from the same alphanumeric category. On the 20th trial (surprise trial S), target category switched from letters to digits or vice versa, and this category was repeated on the final five trials.

All characters in the RSVP streams were grey and were randomly selected without replacement from a 24-letter set (all English alphabet letters, excluding I and O) and a set of 8 digits (2-9), with the restriction that letters and digits appeared equally often (or with a frequency difference of one in trials with uneven frame numbers). The target appeared on the last frame, enclosed by a circle (1.68° in diameter; 4 pixel line width). The target was followed by a mask comprised by superimposing a random digit, a random letter, and the hash symbol (#). Each frame appeared for 50 ms, and was followed by an interval of 50 ms by the post-target mask (150 duration). Exact presentation times varied across participants' computers, as recorded by E-prime Go. Twelve participants were excluded because the target or the immediately preceding item were presented for less than 45 ms or more than 55 ms on one of the three critical trials (trials 19-21). For all remaining participants, mean frame duration was 49.9 ms (*SD*=2.2 ms), and mean between-frame interval was 50.2 ms (*SD*=2.3 ms). At the end of each trial, a response screen appears until a response was recorded. This screen included the target and two additional non-target items from the same category with their associated response key labels at a horizontal distance of 3°, sorted from left to right based on their numerical or alphabetical order. One of the two non-targets did not appear in the stream, and the other was randomly selected from distractors in the stream (excluding the distractor that immediately preceding the target, to prevent pre-target distractor intrusion errors).

For one group of participants (*n*=63) all targets on trials 1-19 were letters, and switched to digits on trial 20-25 (Figure 1B). This assignment was reversed for the other group (*n*=65). The instruction screen shown prior to the first trial included the information that the target would be a letter/digit “throughout most of the experiment”. Before starting the experiment, participants were presented with a slow-motion RSVP stream to familiarize them with the stimuli, which they were allowed to repeat. Each experiment took approximately 5 minutes to complete.

Statistical analysis

Since the relevant data were binary observations (correct/incorrect) on the critical trials 19-21, we could not use parametric tests (e.g., ANOVA) for analyses. To account for random subject effects, we used generalized linear mixed-effects model (GLMM) with a binomial distribution and a logit link function (Jaeger, 2008). Trial (S-1 vs. S vs. S+1) was entered as a within-subject predictor, category-group (letters-to-digits vs. digits-to-letters) as a between-subjects predictor, and subject intercepts as a random effect. Random subject-specific slopes for the within-subject predictor could not be added to the model, as there was only one observation for each subject\condition combination, and therefore the full model could not converge. Chi Square is reported for main effects and interactions, which were evaluated using likelihood ratio tests, and Z-values are reported for contrasts, based on estimated means. Main effects of the trial were subsequently broken down to two planned contrasts that compared between (*i*) trial S-1 vs. trial S, and (*ii*) trial S vs. trial S+1. In Experiments 2 and 3, these planned comparisons were conducted using one-tailed tests. All statistical analyses in this and the following experiments were carried out using JASP (0.14.1) statistical software.

Results

Accuracy on the first 19 trials was 92.8% for letter target and 95.0% for digit targets, and this difference was not significant, *p*=.17 (Figure 2A). Critically, average accuracy was lower on trial S (79.7%) than on the preceding S-1 trial (93.7%), and immediately returned to baseline levels on trial S+1 (93.8%). Analyses of GLMM-estimated means and standard errors on these three trials (Figure 2B) revealed a main effect of trial, $\chi^2(2)=18.54$, $p<.001$. Crucially, the presence of a drop in accuracy on trial S was confirmed by significant contrasts to trials S-1 and S+1, $Z=2.90$, $p=.004$ and $Z=2.96$, $p=.003$. There was no main effect of participant group, $\chi^2(2)=0.069$, $p=.79$, and no interaction between both factors, $\chi^2(2)=3.18$, $p=.20$, indicating this drop occurred for changes for digits to letters, and vice versa.

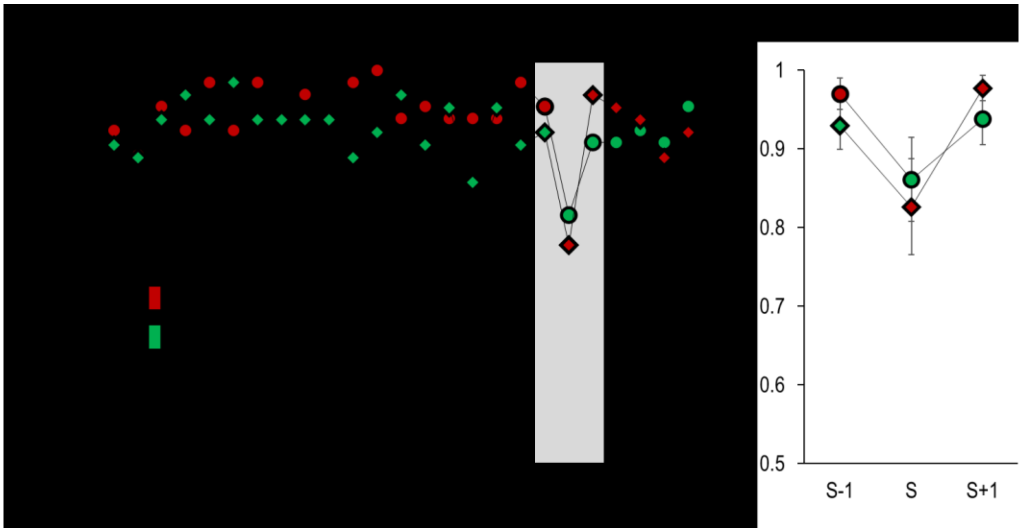

Figure 2. Experiment 1: Observed accuracy on each trial (A) and estimated mean accuracy on trials S-1, S, and S+1, modelled using a generalized linear mixed model (B). Results are shown separately for the two groups of participants (digits to letters vs. letters to digits).

Discussion

The fact that significantly fewer observers were able to report the identity of the target on trial S where its category changed unexpectedly relative to previous and subsequent trials demonstrates that expectation can affect awareness for visual objects even when they are task-relevant and focally attended. However, the nature of the expectations that produced this drop on trial S remains unclear. It may be caused by the unexpected category of the target, or simply by the novelty of the target item (i.e., the fact that this item did not appear as target on any of the preceding 19 trials). We tested this in Experiment 2, where only three possible target letters appeared on trials 1-19. One group of participants saw an unexpected target digit on trial S (category change), and the other a novel target letter. If the novelty of the target item impairs identity reports on trial S, this drop should be present for both groups. If it was linked to expectations about target category, only the category switch should produce this drop.

Experiment 2

Method

Power analysis

We estimated the sample size needed to replicate the main effect of trial (S-1 vs. S vs. S+1) in Experiment 1 by using the simr package (Green & MacLeod, 2016) and the powerCurve function in R (R Core Team, 2021) to simulate the likelihood to find this effect with different sample sizes. This analysis indicated that a sample of 75 participants provided 81% power. We therefore recruited a sample of *n*=75 in the letters-to-digits group and another sample of *n*=75 for the letters-to-letters group.

Participants

Participants were recruited until the sample size of analyzable results reached our pre-defined sample size. Participants were once again eliminated if they had accuracy lower than 50% (13 participants) or if their computers could not produce the required presentation durations (14 participants). The final sample included 150 (90 women) volunteers (*Mage*=26.3, *SD*=6.6).

Apparatus, procedure and stimulus

The apparatus, procedure and stimulus were the same as in Experiment 1, except for the following differences. Prior to the first trial, a screen informed participants about the identity of the three most likely (randomly selected) target letters (Figure 3A). Responses were mapped to different keys (Figure 3B). On trials 1-19, one of the three pre-specified letters served as target, and these three letters also appeared in the response screen. From the surprise trial onwards, targets were selected from a new set of three items, which also appeared in the response screen. These were either three randomly selected digits (letters-to-digits group, *n*=75), or three different randomly selected letters (letters-to-letters group, *n*=75). One of the two non-target items in the response screen also appeared in the RSVP stream, but never in the frame immediately before the target.

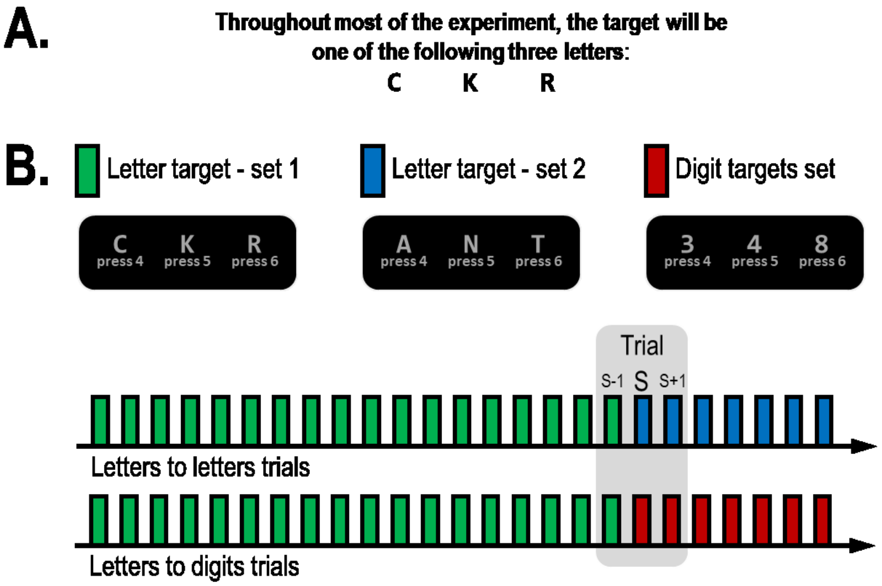

Figure 3. Stimuli and trial sequence in Experiment 2. A: Specification of target letter set for trials 1-19. B: On trials 20-25, a new target set (three different letters or three digits) was introduced.

Results

Accuracy on the first 19 trials was 93.5% for the letters-to-letters group and 94.1% for the letters-to-digits group. This difference was no significant, *t*<1 (Figure 4A). In the letters-to-digits group, accuracy dropped on trial S relative to preceding S-1 trial and recovered on trial S+1. In contrast, no such drop was found for the letters-to-letters group (Figure 4A). Trial (S-1 vs. S vs. S+1) was entered as a within-subject predictor into a GLMM, with category-switch (letters-to-letters vs. letters-to-digits) as a between-subjects predictor, and subject intercepts as a random effects groups factor (Figure 4B). Crucially a significant interaction between trial and category-switch was present, $\chi^2(2)=10.05$, $p=.007$. Within the letters-to-digits group, accuracy was lower on the surprise trial relative to trials S-1 and S+1, $Z=3.79$, $p<.001$ and $Z=2.98$, $p=.005$, respectively. No such drop was found for the letters-to-letters group, both *Z*s<1.

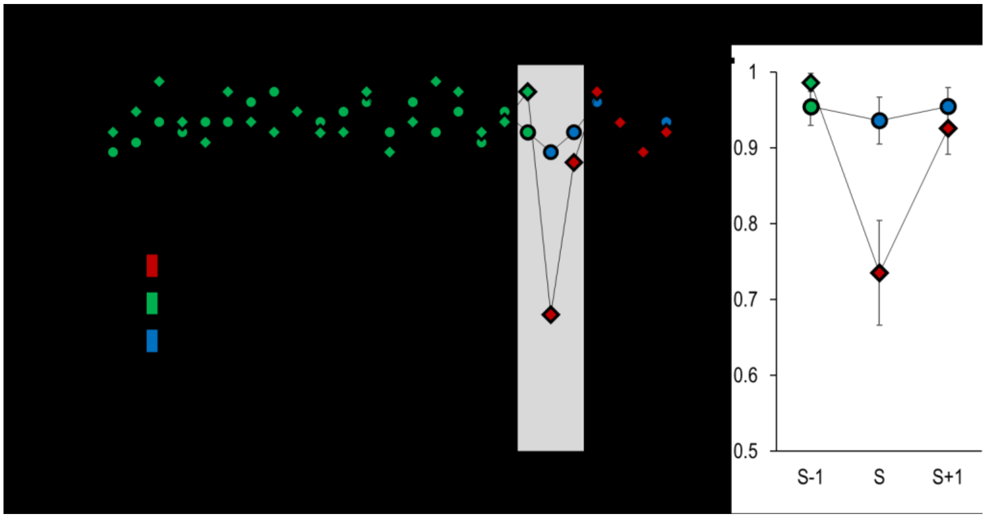

Figure 4. Experiment 2: Observed accuracy (A) and estimated mean accuracy modelled using a generalized linear mixed model (B), as a function of trial number and stimulus group (letters to letters vs. letters to digits).

Discussion

The drop in the probability of correct target reports on trial S when the target category changed from letters to digits confirmed the findings of Experiment 1. The absence of any drop for novel target letters demonstrates that this effect was caused by expectations about target category, and not by the novelty of the target item on trial S. In Experiment 3, we tested whether this link between category-selective expectation and visual awareness is specific to simple alphanumeric characters and the highly overlearned digit/letter category boundary, or also applies to naturalistic real-world images (human and animal faces).

Experiment 3

Method

Power analysis

Based on the results from Experiment 2, we used the powerCurve function to estimate the sample size needed to replicate the interaction between trial and category switch. A sample of 150 participants (75 per group) was found to provide 81.7% power to detect this interaction. However, given the change from alphanumerical items to real-world images in Experiment 3, we chose a substantially larger sample size (*n*=125 for each one of the three groups included; totaling *N*=375 prior to rejections).

Participants

Participants were once again rejected if they had accuracy lower than 50% (11 participants) or if their computers could not produce the required presentation durations (29 participants; see below). 335 participants were retained (184 women; *M*age=29.1, *SD*=6.3).

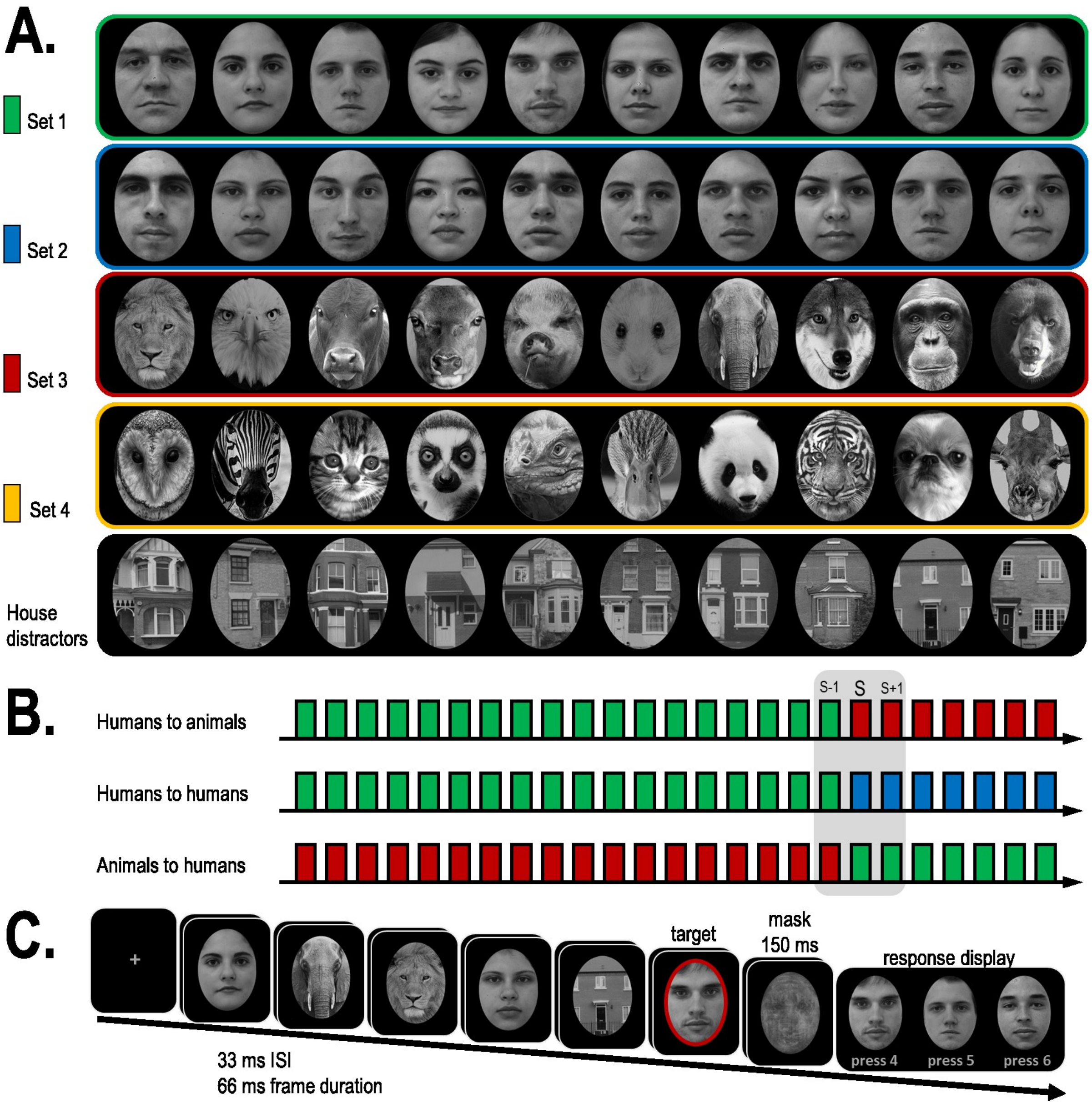

Figure 5. Stimulus sets (A), sequence of trials (B), and illustration of an RSVP stream (C) in Experiment 3. Target objects belonged to the same set on trials 1-19, and changed to a different set on trial 20. Response screens contained the target and two nontarget objects from the same category.

Procedure and Stimuli

RSVP streams contained human faces, animal faces, and houses, all cropped as oval shapes against a black background (2° width × 2.8° height; Figure 5A). 20 face images (10 male, 10 female) were chosen from the FEI Face Database (Thomaz & Giraldi, 2010), and 20 animal faces from LHI-Animal-Faces database (https://vcla.stat.ucla.edu/people/zhangzhang-si/HiT/exp5.htm) and Unsplash.com. 10 images of houses used in previous experiments in our lab (Eimer et al., 2011) were also used. Colors were homogenized across all images using Adobe Photoshop. The interval between successive frames remained at 100 ms, but stimulus duration was increased to 66 ms (and the interval between stimuli reduced to 33 ms), to facilitate image encoding. Because fewer monitors can produce this exact refresh rate, a more liberal criterion for rejecting participants was used (i.e., when the target or the immediately preceding image on the three critical trials appeared for less than 56 ms or for longer than 76 ms). 33 participants whose results on one of the three critical trials were not included in the analysis. Following rejections, the average frame duration was 64.8 ms (*SD*=3.1) and the average interstimulus interval (ISI) was 34.7 ms (*SD*=4.4).

Targets were either human or animal faces, indicated by a red circle. They were followed by a mask generated by overlaying 10 animal faces, 10 human faces and 10 houses. The targets on trials 10-19 were randomly selected without replacement from one image set, and the targets on trials 20-25 from a different set. Response screens contained the target and two other faces from the currently used image set that did not appear in the stream. For two groups of participants, an image category change occurred on trial 20, either from animal to human faces (animals-to-humans group, *n*=111), or vice versa (humans-to-animals group, *n*=116). They were informed that the target would be a human face or an animal face. A third group (humans-to-humans, *n*=108) was presented with human target faces throughout, but the set from which these faces were selected changed on trial 20 (i.e., the target on this trial was never previously shown as the target or a possible target on the response screen). Distractor images were selected randomly from the three nontarget stimulus sets (including houses), with the restriction that members of each set appeared approximately equally often.

Results

Accuracy on the first 19 trials was 76.2% for the humans-to-animals group and 89.4% for the animals-to-humans group, demonstrating that animal face recognition was easier (*p*<.001; see Figure 6A). A switch between image categories on trial S produced a clear performance drop and subsequent recovery in these two groups (Figure 6B). Analyses of GLMM-derived estimated accuracy as a function of trial (S-1 vs. S vs. S+1) and type of category switch (humans-to-animals or animals-to-humans) showed a significant main effect of trial, $\chi^2(2)=27.86$, *p*<.001. The performance drop from trial S-1 to S and the recovery from S and S+1 were reliable, both *ps*<.001. There was an interaction between type of switch and trial, $\chi^2(2)=13.19$, *p*=.001. The fact that target recognition was generally easier for animal than human faces resulted in a steeper accuracy drop from trial S-1 to S for animals-to-humans relative to humans-to-animals, *Z*=5.38, *p*<.001 and *Z*=1.88, *p*=.031, respectively (Figure 6B).

To ascertain that the accuracy drop on surprise trials was linked to the image category change, we compared performance on the three critical trials in the humans-to-humans group who saw a novel human target face on trial S with performance across the other two groups (Figure 6C). No clear drop and recovery between trials S-1, S, and S+1 was found in the humans-to-humans group (both ps>.40), while these effects were clearly present across the two category-switch groups, p<.001 and p=.001, respectively. As a result, the interaction between category-switch (present versus absent) and trial (S-1 vs. S vs. S+1) was significant, $\chi^2(2)=11.88$, p=.003. This interaction remained significant when only the humans-to-humans and humans-to-animals groups were compared. The presence of clear drops in the probability of correct face identity reports for unexpected target category changes between animal and human faces, and the absence of such effects for novelty alone, shows that category-specific expectation-based blindness is not limited to letters and digits, but is also triggered by naturalistic real-world visual objects.

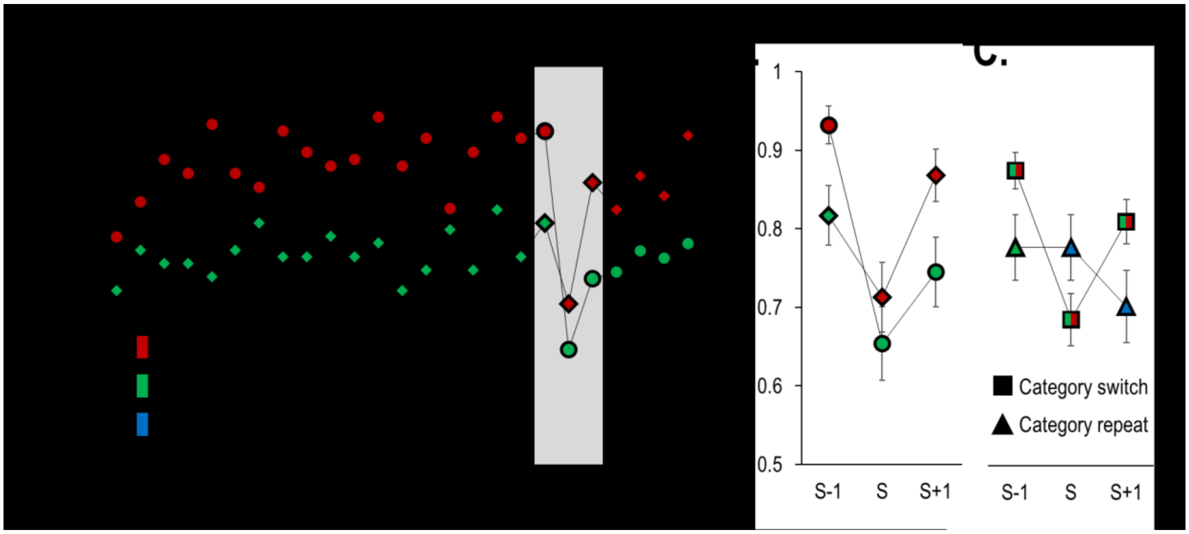

Figure 6. Experiment 3: Accuracy on all trials (A) and GLMM-estimated mean accuracy on critical trials (B), for the humans-to-animals and animals-to-humans groups, and for groups with and without a category switch on trial S (C).

General Discussion

In three experiments, we documented a new kind of phenomenon that is similar to inattentional blindness. Unlike IB, it is exclusively based on expectation and unrelated to attentional diversion, and we therefore termed it "expectation-based blindness". Observers were less likely to report target objects in RSVP streams when their category changed unexpectedly. This drop in performance was found for an unexpected switch from target digits to letters, or vice versa (Experiments 1 and 2), and also with real-world images (human and animal faces, Experiment 3), demonstrating that this phenomenon is not restricted to a specific type of visual objects. Unlike other types of IB, it is not caused by attention being diverted to an unrelated task, because it is elicited for task-relevant and focally attended target objects. The performance drop on surprise trials was also not the result of object novelty, as no such drop was found for new target objects from the same category as previous targets. In contrast to previously observed task-dependent modulations of IB for letters versus digits (Most, 2013), our results cannot be attributed to category-based spatial guidance of attention, since several distractors shared the target's category, and target objects always appeared at the same central location. Instead, they reflect purely expectation-based effects triggered by an unexpected target category change. The results also demonstrate that expectations can play an important role in determining whether an attended object will gain access to awareness and whether it can be reported.

It is notoriously difficult to comprehensively dissociate expectation-induced effects and attentional effects on object perception and detection. The possibility remains that in the specific context of our RSVP procedures, category-specific expectations, or expectations about a shape cue / item category conjunction, may have contributed to temporal attention (i.e., the ability to select target objects at the right moment in time). This could have resulted in performance decrements when the target category changed unexpectedly on the surprise trial. To provide additional evidence against this possibility, we conducted a control experiment that was identical to Experiment 2, except that the selection cue (circle) now preceded the target frame by 50 ms. This manipulation ensured that attentional selectivity in the time domain was triggered by the cue and not the category of the target. Importantly, this manipulation did not change the pattern of results in any way. Observers (n=75) who encountered an unexpected target digit instead of a letter on trial S showed the usual drop in report accuracy (58.7% relative to 78.7% and 78.7% on trials S-1 and S+1; both Zs=6.49, ps<.001), whereas observers (n=75) who saw an unexpected novel target letter on trial S did not (70.7% relative to 74.7% and 78.7% on trials S-1 and S+1; Z=0.55, p=.58 and Z=1.14, p=.26, respectively). These results confirm that failures to report the target on the surprise trial were not caused by impaired temporal attention on surprise trials.

Expectations about future objects and events can affect different stages of perceptual processing (De Lange et al., 2018; Stein & Peelen, 2015) and selectivity (Summerfield & Egner, 2009; Summerfield & de Lange, 2014). The expectation-based failure of target awareness demonstrated here could therefore be produced at early sensory-perceptual or at later processing stages. One possibility is that this effect is generated during memory encoding or maintenance. An unexpected category switch might result in a failure to encode the target, or to retain a durable working memory trace (i.e., attribute "amnesia"). For example, Chen and Wyble (2015; 2016) found that the category of target objects was often not reported on a surprise trial when category had previously only been relevant for the discrimination between targets and nontargets but not for target reports (e.g., "name the colour of the letter among digits"). Similar to the current study, these results show a link between expectation and the awareness of visual objects that are both attended and task-relevant. However, whereas Chen and Wyble changed the to-be-reported target feature on the surprise trial from colour to category, no such change was present in the present study, where the task (identity report) remained constant throughout. Instead of producing amnesia, the category expectations manipulated here might activate long-term memory representations of category-matching objects. This would facilitate their encoding and impair the encoding of unexpected non-matching objects (e.g., Oberauer, 2009; Oberauer et al., 2017).

Our recent work on distractor intrusion errors in RSVP tasks (Zivony & Eimer, 2020) provides some evidence for such an account by showing that on trials where a post-target distractor was incorrectly reported, the target was often not encoded in working memory. This suggests that in the present study, observers who failed to report the target on the surprise trial only encoded the subsequent item (i.e., the mask). Our previous results also indicate that while spatial attention speeds up the accumulation of sensory evidence about target features and improves perceptual object representations (see Zivony & Eimer, in press, for details), expectations may primarily reduce the amount of evidence that is required for an object to be encoded in working memory. An analogous dissociation between attention and expectations was observed by McCarley et al. (2004) in a baggage scanning task, where practice with a set of similar target objects (knifes) improved performance, but not the efficiency of attentional guidance as reflected by eye movements. The hypothesis that expectations and attention have distinct effects during the sensory processing and encoding of visual objects may also explain why spatial attention plays a more prominent role in determining the contents of awareness than feature-specific expectations (Most et al., 2005; see also Ward & Scholl, 2015). Whereas a task-irrelevant object that appears unexpectedly is missed by more than half of all observers in typical IB experiments (e.g., Simons & Chabris, 1999), accuracy on surprise trials was reduced by only 10-20% in our experiments. The fact that there were any performance costs for unexpected targets remains notable, as surprising events are often assumed to attract attention (e.g., Itti & Baldi, 2009). This is likely to be linked to the fact that targets were presented only briefly and subsequently masked. As recently argued by Press et al. (2020), perception is initially biased towards expected events, whereas unpredicted events can be selectively highlighted at later stages.

To summarize, this study provides novel evidence for a critical role of expectations about target categories for conscious awareness that is not mediated by selective attention. Our paradigm may be useful for future research on the representation of object categories in visual cognition (e.g., by manipulating expectations at the level of basic, superordinate, and subordinate categories). They also reveal that expectations can have costs as well as benefits. While expectations about the features or identity of visual objects can facilitate their recognition by biasing input processing, in particular when visual signals are noisy or ambiguous (see De Lange et al., 2018, for review), there is also a darker side to prediction. When expectations are wrong, observers often fail to detect and recognize visual objects that they would have noticed in the absence of any predictive bias.

Author’s note

This work was supported by a grant from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 896192 to Alon Zivony. The data for all experiments are posted at https://figshare.com/s/0e27fcbdbfe41e14f571.

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