Neuroscience

Sensitivity to visual features in inattentional blindness

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Abstract

Summary

The relation between attention, perception and awareness is among the most fundamental problems in the science of the mind. One of the most striking and well-known phenomena bearing on this question is *inattentional blindness* (IB; Neisser & Becklen, 1975; Mack & Rock, 1998; Most et al., 2001, 2005). In IB, naïve observers fail to report clearly visible stimuli when their attention is otherwise engaged—famously even missing a gorilla parading before their eyes (Simons & Chabris, 1999). This phenomenon and the research programs it has motivated carry tremendous theoretical significance, both as crucial evidence that awareness requires attention (Cohen et al., 2012; Prinz, 2012; Noah & Mangun, 2020) and as a key tool in seeking the neural correlates of consciousness (Rees et al., 1999; Pitts et al., 2014; Hutchinson, 2019). However, these and other implications critically rest on a notoriously biased measure: asking participants whether they noticed anything unusual (and interpreting negative answers as reflecting a complete lack of visual awareness). Here, in the largest ever set of IB studies, we show that inattentionally blind participants can successfully report the location, color and shape of the stimuli they deny noticing. This residual visual sensitivity shows that perceptual information remains accessible in IB. We further show that subjective reports in IB are conservative, by introducing absent trials where no IB stimulus is presented; this approach allows us to show for the first time that observers are systematically biased to report not noticing in IB—essentially 'playing it safe' in reporting their sensitivity. This pair of results is consistent with an alternative hypothesis about IB, namely that subjects retain awareness of stimuli they fail to report. Overall, these data provide the strongest evidence to date of significant residual visual sensitivity in IB, and even cast doubt on claims that awareness requires attention.

eLife Assessment

This study presents **valuable** findings to the field interested in inattentional blindness (IB), reporting that participants indicating no awareness of unexpected stimuli through yes/no questions, still show above-chance sensitivity to specific properties of these stimuli through follow-up forced-choice questions (e.g., its color). The results suggest that this is because participants are conservative and biased to report not noticing in IB. The authors conclude that these results provide evidence for residual perceptual awareness of inattentionally blind stimuli and that therefore these findings cast doubt on the claim that awareness requires attention. Although the samples are large and the analysis protocol novel, the evidence supporting this interpretation is still **incomplete**, because effect sizes are rather small, the experimental design could be improved and alternative explanations have not been ruled out.

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Main

One of the most pervasive and compelling intuitions about perception is that we see what is right in front of us: If a large enough stimulus were to appear directly before our eyes (with good lighting, a well-functioning sensory apparatus, no special camouflage, etc.), we would see it and could easily report features such as its color, shape, and location. However, this seemingly secure assumption is challenged by perhaps the best-known result in contemporary perception science: The phenomenon of inattentional blindness (IB). In IB, engaging in an attentionally demanding task (e.g., judging the relative lengths of two briefly presented lines, or counting basketball passes) causes observers to miss large, highly visible, but unexpected stimuli appearing right before their eyes (e.g., a high-contrast novel shape, or a parading gorilla; **Figure 1**). Whereas in ordinary circumstances these stimuli would be extremely salient and easily noticed, under conditions of inattention we seemingly do not see them at all.

IB is an extremely robust phenomenon, demonstrated in a stunning variety of laboratory and real-world contexts across half a century of research (Neisser & Becklen, 1975; Moore & Egeth, 1997; Mack & Rock, 1998; Simons & Chabris, 1999; Most et al., 2005; Drew et al., 2013; Murphy & Greene, 2016). Although the proportion of subjects demonstrating IB (the “IB rate”) varies widely depending on the protocol, it can be remarkably high (e.g., 50% in the case of the famous gorilla, and up to 80% in some of Mack & Rock’s studies; for reviews see Simons, 2000; De Brigard & Prinz, 2010; Jensen et al., 2011; Nobre et al., 2020; Redlich et al., 2021).

IB is also an extremely significant phenomenon. According to the “consensus view” (Noah & Mangun, 2020; see also Mack & Rock, 1998; Dehaene et al., 2006; Cohen et al., 2012; Prinz, 2012, 2015; though see Koch & Tsuchiya, 2007; Maier & Tsuchiya, 2020), subjects undergoing IB “have no awareness at all of the stimulus object” (Rock et al., 1992), such that “one can have one’s eyes focused on an object or event … without seeing it at all” (Carruthers, 2015). This interpretation has endowed IB with numerous theoretical and practical implications. First, IB is a key piece of evidence for the more general claim that awareness requires attention (or, conversely, that “without attention, conscious perception cannot occur”; Dehaene et al., 2006), and so has been used to support various leading theories of consciousness on which attention plays a critical role, such as global neuronal workspace theory (Dehaene & Naccache, 2001), attended intermediate representation (AIR) theory (Prinz, 2015), and attention schema theory (Webb &

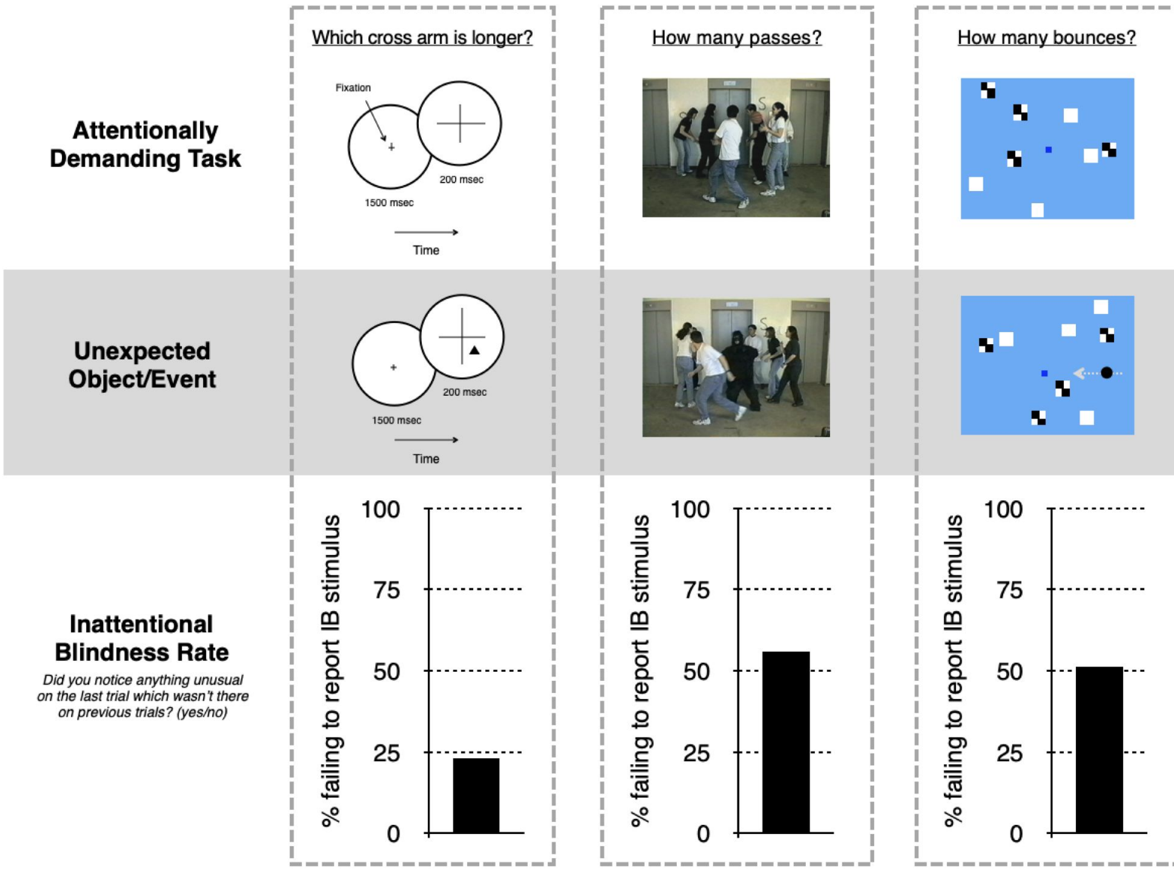


Figure 1.

Influential inattentional blindness paradigms and their results.

(Left) In a representative study from Mack & Rock (1998), subjects fixated in the center of the circle and reported which arm of a centrally presented cross was longer. On the critical trial, an unexpected shape appeared in the near periphery at the same time as the cross and subjects were asked whether they noticed anything unusual. **(Center)** In Simons & Chabris (1999), subjects counted the number of basketball passes made by individuals wearing white shirts. (Images drawn from Simons and Chabris, 1999, reprinted with permission Dan Simons.) On the critical trial, a woman in a gorilla suit paraded through the display for five seconds, and subjects were asked whether they noticed anything unusual. **(Right)** In Wood & Simons (2017; based on Most et al., 2001), subjects fixated on the blue square and reported the number of times the white or checkerboard squares bounced off the walls of the display. On the critical trial, a black circle entered from the right and crossed the display for several seconds, and subjects were asked whether they noticed anything unusual. In all three experiments (and many others in this literature), a considerable proportion of subjects reported not noticing these unexpected stimuli.

Graziano, 2015). Second, conceived as a tool to abolish awareness, IB is frequently used by neuroscientists to measure neural activity in the absence of consciousness (Rees et al., 2000; Pitts et al., 2014; Hutchinson, 2019), in the hope of isolating the neural correlates of consciousness. Third, IB challenges cherished assumptions about our ability to perceive the world around us—inspiring substantial theoretical and philosophical debate (e.g., O'Regan & Noë, 2001; Lamme, 2003; Block, 2011; Cohen & Dennett, 2011) and rightly contributing to its status as one of the few results in perception science that has captured public interest and imagination (Chabris & Simons, 2011; Cloud, 2010; Murphy, 2017).

Crucially, however, this interpretation of IB and the many implications that follow from it rest on a measure that psychophysics has long recognized to be problematic: simply asking participants whether they noticed anything unusual. In IB studies, awareness of the unexpected stimulus (the novel shape, the parading gorilla, etc.) is retroactively probed with a yes/no question, standardly, "Did you notice anything unusual on the last trial which wasn't there on previous trials?". Any subject who answers "no" is assumed not to have any awareness of the unexpected stimulus.

However, yes/no questions of this sort are inherently and notoriously subject to bias, because they require observers to set a *criterion* in order to decide whether they have enough evidence to answer "yes" or instead answer "no" (Dulany, 2001; cf. Eriksen, 1960; Holender, 1986; Irvine, 2012). Under the framework of Signal Detection Theory (Tanner & Swets, 1954; Green & Swets, 1966), observers who are asked to determine whether a signal is or is not present must in setting such a criterion consider tradeoffs between the various possible outcomes of their decision (i.e., the relative costs of hits, misses, false alarms, and correct rejections). Indeed, in an IB task (where the signal in question is the unexpected stimulus), observers may have reason to be conservative in their criterion-setting—i.e., to adopt a high standard for saying "yes" (and answer "no" if that standard isn't met). For example, observers might be under-confident whether they saw anything (or whether what they saw counted as unusual); this might lead them to respond "no" out of an excess of caution. Subjects might doubt that they could identify it if asked, and so respond "no" to avoid having to do so. Subjects may also worry that if they report noticing the unexpected object, the experimenters will take that to mean they weren't engaged in the task they had been given (e.g., judging which cross arm was longer or counting the passes; Dulany, 2001). On any of these possibilities, subjects who say they did not notice the critical stimulus may well have had some awareness of it, but simply underreported it given the constraints of traditional IB questioning.

Evidence for this alternative hypothesis would have dramatic consequences for the dominant interpretation of IB and the implications that follow from it: It would overturn the view that IB reflects a total failure to perceive and so undermine the case that attention is required for awareness. Remarkably, however, the hypothesis that subjects in inattentional blindness tasks actually see more than they say (but respond otherwise because they are conservative in reporting their awareness) remains empirically unsettled, and the powerful tools of signal detection theory unexploited in relation to IB.

A handful of prior studies have explored the possibility that inattentionally blind subjects may retain some visual sensitivity to features of IB stimuli (e.g., Schnuerch et al., 2016; see also Kreitz et al., 2020, Nobre et al., 2020). However, a recent meta-analysis of this literature (Nobre et al., 2022) argues that such work is problematic along a number of dimensions, including underpowered samples and evidence of publication bias that, when corrected for, eliminates effects revealed by earlier approaches, concluding "that more evidence, particularly from well-powered pre-registered experiments, is needed before solid conclusions can be drawn regarding implicit processing during inattentional blindness" (Nobre et al., 2022).

Here, five experiments provide this critical test for the first time. We achieve this by making four key modifications to classic IB paradigms. First, we add follow-up questions to the classic yes/no methodology to explicitly probe awareness of features of the IB stimulus (i.e., not just asking whether subjects noticed anything, but also querying features of the object they said they didn't notice). Second, we include “absent trials” in which some subjects are shown no additional stimulus on the critical trial but are still asked whether they noticed anything unusual, providing a false alarm rate to test whether subjects are conservative in reporting their awareness in the ways hypothesized above. Third, we leverage online data collection to massively increase sample size (running 25,000 subjects, each experiencing just a single critical trial), in order to make possible the crucial signal-detection analyses that separate bias from sensitivity. Finally, to overcome the fact that in IB each subject necessarily only contributes one trial (since following a critical trial, stimuli are no longer unexpected), we introduce a novel analytic approach by applying signal detection models to a “super subject”.

Altogether this approach reveals that subjects can report above-chance the features of stimuli (color, shape, and location) that they had claimed not to notice under traditional yes/no questioning, and that this underreporting of awareness is well-modeled in terms of a conservative criterion. In place of the dominant interpretation that IB abolishes awareness, the present results indicate that significant residual sensitivity remains in IB, and are even consistent with an alternative picture on which inattention instead *degrades* awareness. More generally, our findings motivate an approach to awareness which treats it as graded as opposed to all-or-nothing, which we further discuss below.

Results

Above-chance sensitivity to inattentional blindness stimuli: Location

Experiment 1 modified the canonical inattentional blindness task used by Mack and Rock (1998; **Figure 2a**). On three trials, subjects were presented with a cross randomly assigned on each trial to be directly above or below a central fixation point (for 200 msec), and their task was to report which arm of the cross (horizontal or vertical) was longer. The fourth, critical trial, proceeded in the same way, but with the addition of an unexpected red line appearing in the periphery simultaneous with the cross. After again reporting which arm of the cross was longer, subjects were asked the standard question used to measure inattentional blindness: “Did you notice anything unusual on the last trial that wasn't there on previous trials?” (yes or no). In line with established findings on IB, a considerable proportion of subjects (28.6%) responded “no” they didn't notice anything unusual (we refer to these subjects across all our experiments as ‘non-noticers’).

Following the standard IB question, our modification included an additional question: “In fact, the last trial you just saw contained one extra element—a vertical red line on either the left or the right side of the box. What side do you think it appeared on?” (left or right). Far more subjects were able to correctly locate the stimulus (87.4%) than said they noticed it (71.4%), raising the possibility that non-noticers—i.e., those who demonstrated inattentional blindness—might have performed significantly better than chance. This is precisely what we found: 63.6% of non-noticers answered the forced-choice question correctly (significantly different from the 50% correct expected by chance in a two-sided binomial probability test, 95% CI = [0.54, 0.73], BF10 = 9.9). In other words, nearly two-thirds of subjects who had just claimed not to have noticed any additional stimulus were then able to correctly report its location.

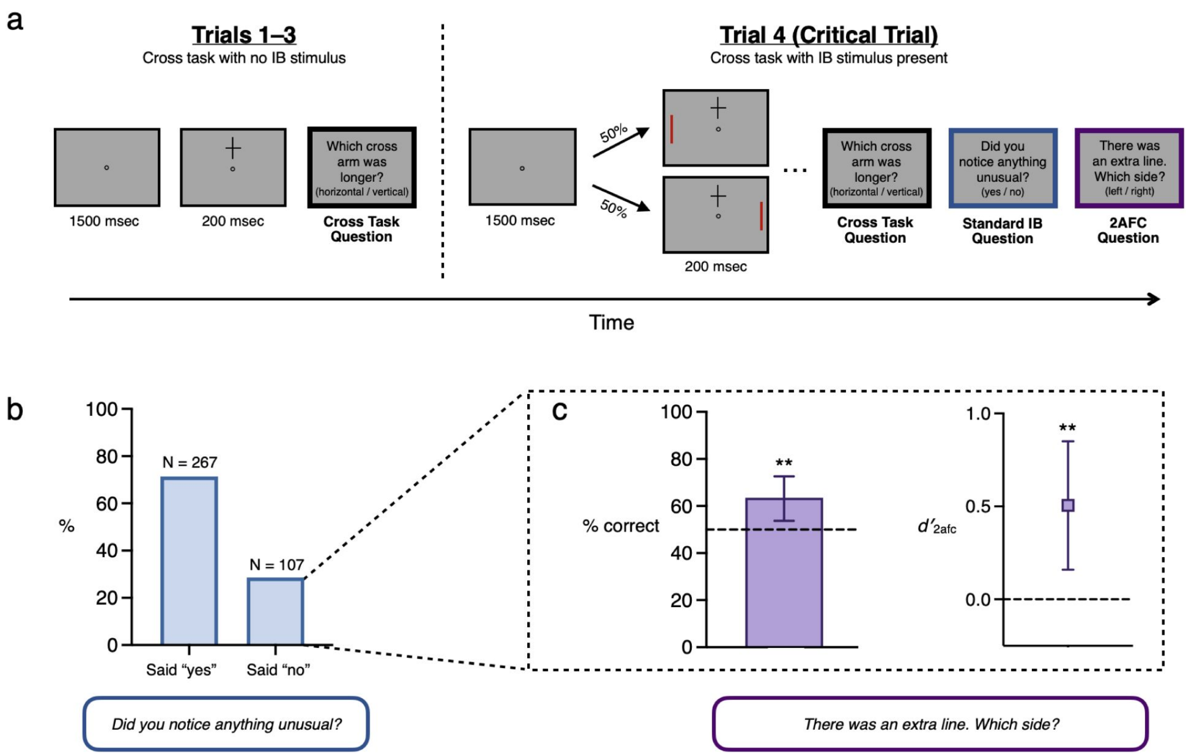


Figure 2.

Stimuli, procedure and results for Experiment 1.

a Schematic trial sequence for Experiment 1. On trials 1-3 subjects were presented with a cross above or below fixation for 200 msec and judged which arm was longer. On trial 4, an unexpected red line appeared in the periphery simultaneous with the cross. After reporting which cross-arm was longer, subjects were asked, "Did you notice anything unusual on the last trial that wasn't there on previous trials?" (yes/no), followed by a 2afc question concerning the location of the line (left/right). **b** Percentage of subjects who report noticing or not noticing the extra red line. 29% of subjects were 'non-noticers'. **c** Performance on the 2afc question (left/right location of the line), considering only those subjects who reported not noticing anything unusual. Remarkably, both %-correct and *d'* were significantly above chance among these subjects who met traditional criteria for inattentional blindness. In other words, subjects who answered "no" demonstrated sensitivity to the location of the stimulus they had just claimed not to have noticed. Error bars are 95% CIs.

Critically, this result also holds using d', an unbiased measure of sensitivity (d'_{2afc} = 0.51, 95% CI = [0.16, 0.85]; see **Box 1** on Signal Detection Theory), which we use in reporting all following results concerning sensitivity in non-noticers. An important novelty of our strategy is that it derives these statistics in relation to a "super subject" whose responses are comprised of individual subjects' responses in their single critical trials. See General Discussion for more on the assumptions behind this analytic approach.

Above-chance sensitivity to inattentional blindness stimuli: Color

Experiment 2 repeated the design of Experiment 1, except that the additional line could be either red or blue, and the question about the line's location was replaced with a one-interval forced-response question about the line's color. This experiment yielded similar results to Experiment 1: Only 72.3% of subjects shown an additional stimulus said they had noticed something, yet 81% were able to indicate the additional line's color correctly. And again non-noticers demonstrated above chance sensitivity, this time to color (d' = 0.38, 95% CI = [0.03, 0.73]; See our Supplementary Material for reason to think that this may actually *underestimate* subjects' true performance, which may be nearly double this figure.)—and the unbiased nature of this measure is especially critical here since subjects displayed a significant bias in favor of responding "blue" (c = 0.67, 95% CI = [0.49, 0.84]). In other words, consistent with the results of Experiment 1, subjects who had just claimed not to have noticed an additional stimulus were able to correctly report its color at rates well above chance. This pair of initial results is consistent with our alternative hypothesis about IB: Even subjects who answer "no" under traditional questioning can still correctly report various features of the stimulus they just reported not having noticed, suggesting that they were at least partially aware of it after all.

Conservative reporting of visual awareness

Our results raise a natural question: Why, if subjects could succeed at our forced-response questions, did they claim not to have noticed anything? Experiment 2 made an additional modification precisely to address this question—a modification which, to our knowledge, is unique in this literature: the introduction of 'absent' trials in which no additional line was shown but subjects were still asked the yes/no and one-interval forced-response questions. Absent trials provide an additional source of information about subjects' biases, by revealing how often they respond "yes" without any stimulus present (i.e., their false alarm rate). This allows for the computation of response bias (c) in relation to the crucial IB question, "Did you notice anything unusual on the last trial that wasn't there on previous trials?" (again, see **Box 1**). This analysis revealed evidence for the second aspect of our alternative hypothesis: Not only do subjects have residual sensitivity to unnoticed IB stimuli, they are *conservative* in reporting their awareness (c = 0.31, 95% CI = [0.22, 0.41]; d' = 1.81, 95% CI = [1.63, 1.99]; note that statistics here are for all subjects). In turn, this suggests that subjects may retain *awareness* of unreported IB stimuli corresponding to their residual visual sensitivity but that this awareness is systematically underreported.

Above-chance sensitivity in high-confidence non-noticers

Although the previous two studies support the hypothesis that "inattentionally blind" subjects retain at least partial awareness of unattended stimuli (and are conservative in reporting that awareness), it is possible that these results were driven by a subset of subjects, with other subjects remaining truly blind to the IB stimulus (i.e., having no sensitivity at all to its features). This might arise if above-chance sensitivity were restricted to subjects who were underconfident in responding "no" when asked whether they had noticed anything unusual. In that case, subjects who *confidently* answered "no" (i.e., felt certain they didn't notice any additional stimulus) might, as a group, fail to perform above chance on the subsequent discrimination task. Experiment 3 addressed this possibility directly, by (a) adding confidence ratings to the standard yes/no question, and (b) dramatically increasing the sample size, so as to separately analyze the

performance of high- and low-confidence subjects. The task proceeded in the same way as Experiment 1, except that after the yes/no question about noticing anything unusual, subjects were asked to rate their confidence in their answer, on a 4-point scale from 0–3 (0-not at all confident; 3-highly confident); finally, subjects were then asked the left/right discrimination question (and gave their confidence in that answer as well, though this was less crucial to our hypothesis). As shown in **Figure 3e**, answers to these questions ran the full spectrum of responses, with subjects expressing varying degrees of confidence in "yes" and "no" responses to the IB question. Of particular relevance was a group of "high-confidence non-noticers"—i.e., subjects who said "no" (they didn't notice anything unusual), and then rated their confidence in that answer as "3" (highly confident). Remarkably, even this group of subjects (N = 204) demonstrated significantly above-chance sensitivity to the location of the IB stimulus (d'_{2afc}= 0.34; 95% CI = [0.08, 0.60]). Further, as is evident from **Figure 3e**, subjects' confidence in their yes/no response predicted accuracy for that group on the discrimination task, suggesting that subjects have graded awareness of unattended stimuli in IB tasks (see Supplementary Materials for details).

Generalizing to dynamic inattentional blindness

Experiments 1-3 showed that subjects underreport their awareness of a brief (200 msec) IB stimulus. However, in classic studies of dynamic inattentional blindness (Simons & Chabris, 1999; Most et al., 2005; Ward & Scholl, 2015), the unexpected stimulus remains in view for an extended period. Here, it is tempting to think that subjects will not be conservative in reporting that they noticed an IB stimulus given they have many seconds to build confidence in what they saw. Experiment 4 tested this possibility by modifying a traditional sustained inattentional blindness paradigm in which the IB stimulus remains on screen for 5 seconds. Finding the same pattern of above-chance sensitivity and conservative response bias in this very different paradigm would be even more compelling evidence for our alternative hypothesis and further highlight the generality of our approach.

In Experiment 4, subjects' primary task was to count how often squares of a particular color (black or white) bounced off the perimeter of a gray rectangle (adapted from Wood & Simons, 2017, in turn based on Most et al., 2001; see **Figure 4a**). This task demands significant attention as each set of colored squares bounces an average of 28 times during a 17-second trial. For some subjects, on the third and critical trial, an additional shape (a triangle or circle, which was either black or white) entered the display (on the left or the right) and traversed the full height of the display in a straight path (from either top to bottom, or bottom to top), remaining on screen for 5 seconds before disappearing. When the trial ended, subjects reported how many times the squares of their assigned color bounced. They were then immediately asked the standard question used to measure inattentional blindness: "Did you notice anything unusual on the last trial that wasn't there on previous trials?" (yes or no). Following this, each subject answered *three* additional questions about the extra object that may or may not have appeared, in a random order: (1) What color was it? (black or white), (2) What shape was it? (circle or triangle), (3) What side was it on? (left or right).

Consistent with previous studies using dynamic stimuli (see **Figure 1b** and **1c**), a majority of subjects—57.3%—demonstrated IB. Put another way, just 42.7% of subjects who were shown something additional on the critical trial were correct on the yes/no detection question. However, despite the attentionally demanding primary task, non-noticers again demonstrated significant sensitivity to the features of the IB stimulus, choosing the correct color (d' = 0.82, 95% CI = [0.61, 1.04]) and shape (d' = 0.21, 95% CI = [0.01, 0.42]) significantly more often than would be predicted by chance. Given that all the objects were changing location constantly in Experiment 4, we did not pre-register a prediction about location discrimination being above-chance, and we did not find that non-noticers performed above chance on the left/right discrimination question (though we did observe a trend in this direction, d'_{2afc} = 0.07, 95% CI = [-0.08, 0.22]).

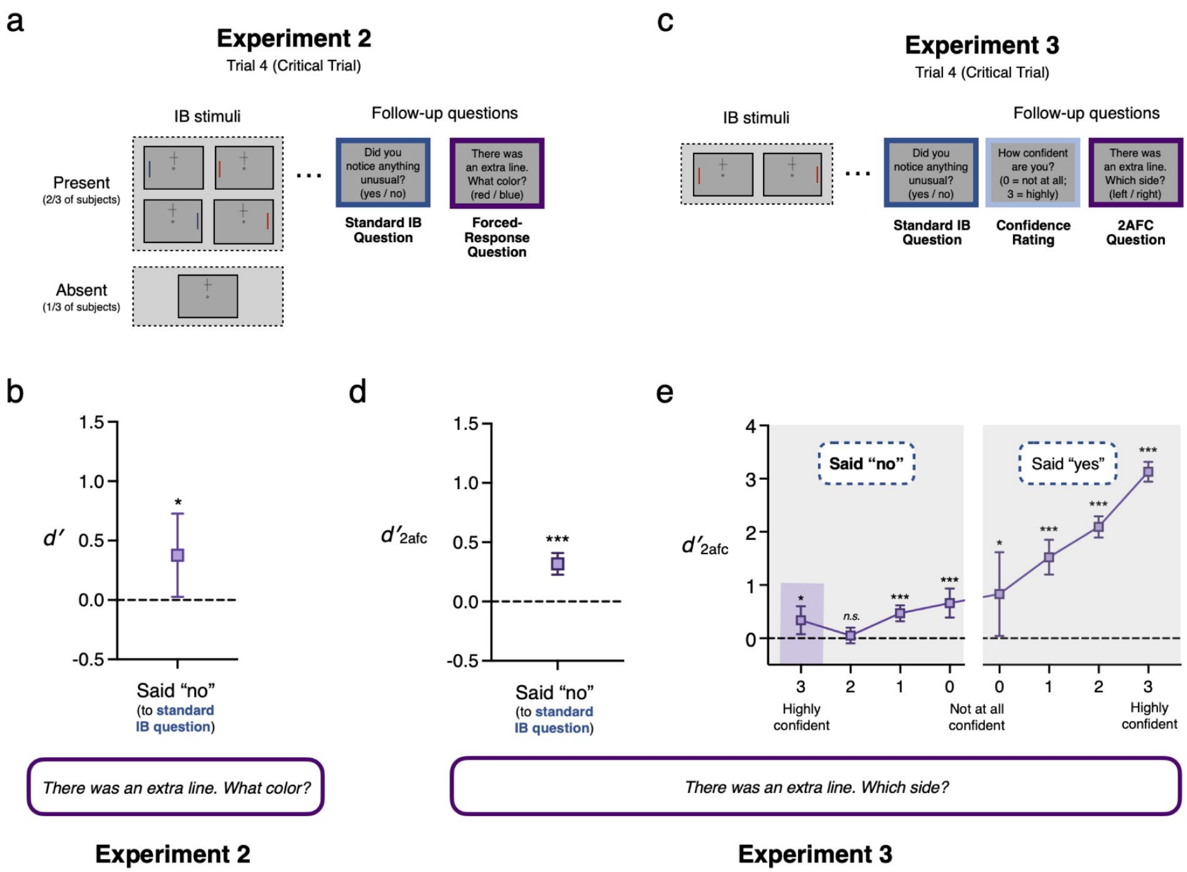


Figure 3.

Stimuli, procedure and results for Experiments 2 and 3.

a Schematic trial sequence for Experiment 2. On trials 1-3 subjects were presented with a cross above or below fixation for 200 msec and judged which arm was longer. On trial 4, for 2/3rds of subjects, an unexpected line appeared in the periphery simultaneous with the cross. This line could be either blue or red and one the left or right. For 1/3 of subjects no additional line was shown. After reporting which cross-arm was longer, all subjects were asked, “Did you notice anything unusual on the last trial that wasn’t there on previous trials?” (yes/no), followed by a one-interval forced-response question concerning the color of the line (red/blue). **b** Performance on the one-interval forced-response question about the unexpected line’s color amongst subjects who were shown a line and who reported not noticing anything unusual (27.73% of subjects). Subjects who answered “no” demonstrated sensitivity to the color of the stimulus they had just claimed not to have noticed. **c** Schematic trial sequence for Experiment 3. Trials 1-4 were identical to Experiment 1, except subjects were asked additional questions about their confidence following both yes/no and 2afc questions. **d** Performance on the 2afc question in Experiment 3, considering only subjects who reported not noticing anything unusual (30.85% of subjects). Replicating the finding of Experiment 1, subjects who answered “no” demonstrated sensitivity to the location of the stimulus they had just claimed not to have noticed. **e** Performance on the 2afc question in Experiment 3 for all subjects, broken down by confidence in their response to the yes/no question whether they had noticed anything unusual. Remarkably, even subjects who were highly confident that they had not noticed anything unusual were significantly above chance. Error bars are 95% CIs.

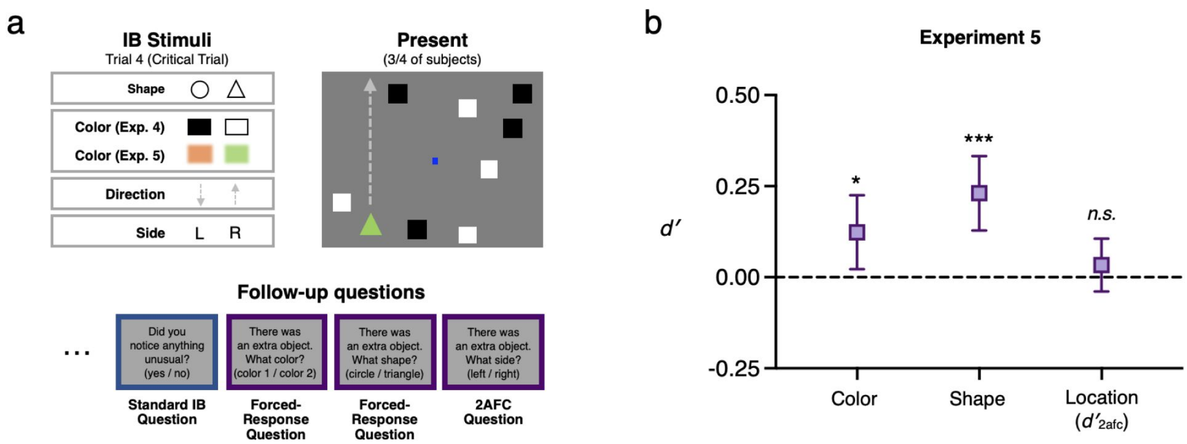


Figure 4.

Stimuli, procedure and results for Experiment 5.

a Stimulus parameters and a schematic critical trial for Experiment 5, in which an unexpected object moved across the display for several seconds while subjects counted the number of times the white squares bounced off the display's 'walls' (task adapted from Wood & Simons, 2017). The unexpected object varied in its shape, color, direction of motion, and side of the display. As in Experiment 4, subjects were then asked follow-questions about this stimulus's color, shape and location. **b** Subjects who reported not noticing the unexpected stimulus still showed above-chance sensitivity to its color and shape (though not to its location), a pattern predicted in our pre-registration. Thus, sensitivity to IB stimuli arises even when the stimuli are visible for a sustained period (rather than appearing only briefly, as in Experiment 1-3). Error bars are 95% CIs.

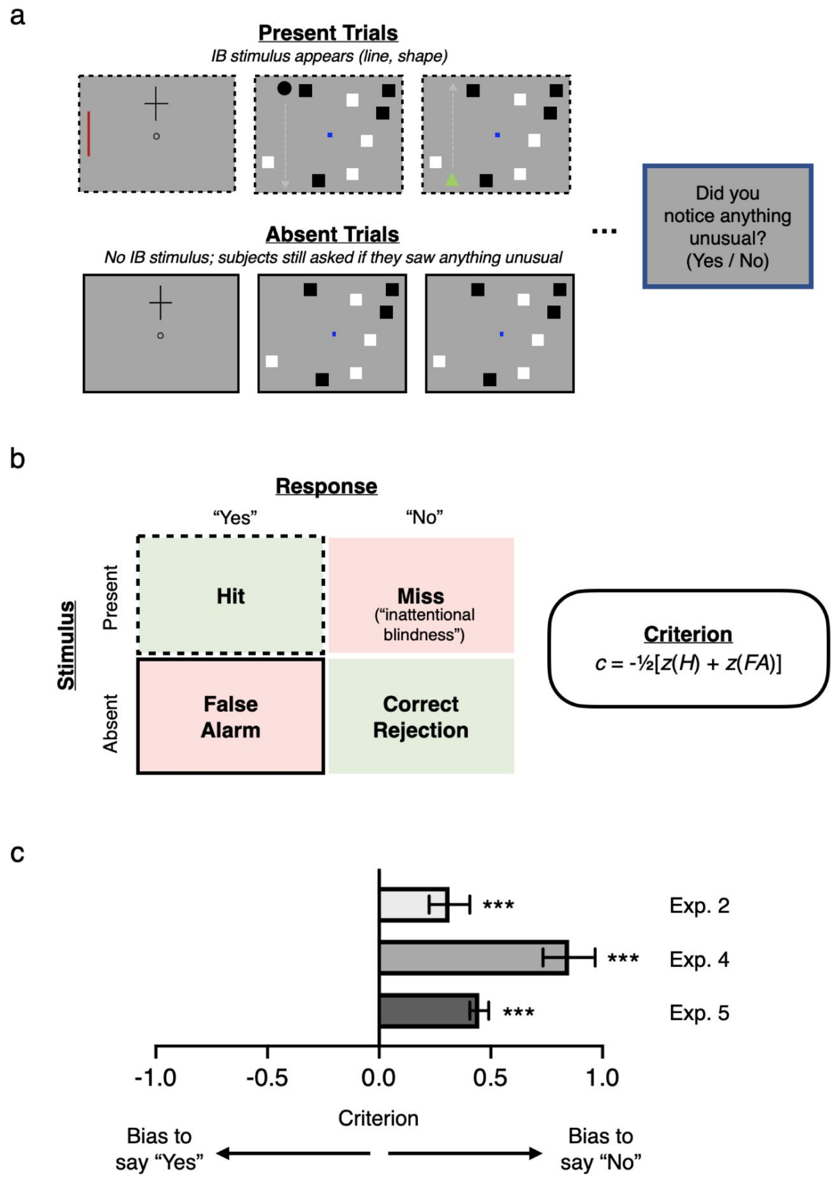


Figure 5.

Conservative criteria in Experiments 2, 4 and 5.

a Critical trials from Experiments 2, 4 and 5, showing present trials in which an IB stimulus was presented to subjects (2/3rds subjects in Experiment 2, 3/4 in Experiments 4 and 5), and absent trials in which no IB stimulus was presented (1/3rd subjects in Experiment 2, 1/4 in Experiments 4 and 5). On all trials, subjects were asked, "Did you notice anything unusual on the last trial that wasn't there on previous trials?" (yes/no). **b** Left: Decision matrix for this yes/no question, indicating the four possible stimulus/response pairings: hits corresponding to 'yes' responses on present trials; false alarms corresponding to 'yes' responses on absent trials; misses corresponding to 'no' responses on present trials (i.e. inattentional blindness); and correct rejections corresponding to 'no' responses on absent trials. Right: Formula for calculating criterion or response bias from hit rate (H), i.e. proportion of present trials in which subjects responded 'yes', and false alarm rate (FA), i.e. proportion of absent trials in which subjects responded 'no'. **c** Criteria for Experiments 2, 4 and 5, showing that in each case subjects exhibited a significantly conservative bias, i.e. a tendency to say 'no' when asked if they noticed anything unusual, independent of the actual presence of a stimulus. This suggests that subjects in inattentional blindness experiments may systematically underreport their awareness of unexpected stimuli across different paradigms.

Just as in Experiment 2, subjects underreported their awareness of the IB stimulus on the traditional yes/no question, employing a decision criterion that was even more conservative than that measured in Experiment 2 (c = 0.85, 95% CI = [0.73, 0.97]; d' = 1.33, 95% CI = [1.10, 1.57]; again, note that statistics here are for all subjects). The fact that subjects were more reluctant to report their awareness of the IB stimulus in this experiment compared with Experiment 2 is surprising given that subjects had 5 full seconds to build confidence that there was a stimulus. However, given that the colors of the squares in the primary task were the same as the colors used for the IB stimuli, it is possible that estimates of criterion and color sensitivity in Experiment 4 were affected by an interaction effect due to enhancement of color-congruent stimuli and suppression of color-incongruent stimuli (cf. Wood and Simons, 2017). Specifically, the IB rate for color-incongruent stimuli was substantially higher than for color-congruent stimuli (86.57% vs. 28.71%), suggesting suppression occurred. That is, a subject shown an unexpected black stimulus while attending to black squares was more likely to report noticing than a subject shown an unexpected white stimulus. This in turn may have inflated our estimate of color sensitivity if subjects correctly assumed that they would have been more likely to notice a color-congruent stimulus and biased their responses towards the incongruent color.

To address this, Experiment 5 repeated the design of Experiment 4, with two key differences: (1) Every subject was assigned to attend to the white squares in the primary task, (2) the IB stimuli were either orange or green—two colors that as a pair produced equal IB rates in pilot testing. Moreover, by selecting such highly salient colors (which differ dramatically from any other stimulus on the display), these parameters served as an especially strong test of our broader hypothesis. Remarkably, even under these conditions (and with the concern about color congruency effects mitigated), the pattern of results matched that of Experiment 4: Subjects performed above-chance in discriminations of both color (d' = 0.12, 95% CI = [0.02, 0.23]) and shape (d' = 0.23, 95% CI = [0.13, 0.33]), but not location (d'_{2afc} = 0.03, 95% CI = [-0.04, 0.11]). Sensitivity to the color of the IB stimulus was lower than in Experiment 4, consistent with our prediction that color sensitivity in that experiment was inflated by a color-congruence bias; however, it was still significantly above chance, indicating that color-congruence does not fully account for the pattern of results. That subjects could still correctly report the color and shape of the IB stimulus despite the attentionally demanding primary task is compelling evidence that perception of IB stimuli is not abolished by inattention. Further, we again found that subjects were biased to respond "no" to the traditional yes/no IB question (c = 0.45, 95% CI = [0.41, 0.49]; d' = 2.01, 95% CI = [1.94, 2.09]; statistics here are for all subjects). Thus, even when an unexpected stimulus remains on screen for many seconds, subjects are hesitant to report noticing anything unusual.

Box 1: Signal Detection Theory and Inattentional Blindness

In Signal Detection Theory (SDT; Green and Swets, 1966; Macmillan and Creelman, 2005), perceptual decisions are based on statistically variable sensory evidence ($S + N$) due to a stimulus or signal (S), if any, together with omnipresent noise (N). Deciding whether a stimulus was present or not (yes/no detection) involves deciding whether the evidence received is a sample from $S + N$ or from N alone. To make this decision, an observer must set a *criterion*, a level of sensory evidence sufficient for a positive response. This criterion is flexible and can be adjusted in accord with the payoffs associated with different outcomes such as hits (saying "yes" when a stimulus is present) and false alarms (saying "yes" when no stimulus is present).

SDT uses observed hit and false alarm rates to distinguish two distinct aspects of an observer's performance: their *sensitivity* and *bias*. In simple models, N and $S + N$ distributions are treated as equal variance Gaussians. The *sensitivity* of an observer is then measured as the standardized distance between the means of the N and $S + N$ distributions. Intuitively, if the two distributions entirely overlap, an observer is entirely insensitive to the presence of a stimulus, whereas the greater the separation, the greater the sensitivity. To calculate this measure of sensitivity, we

subtract the *z*-transform of the false alarm rate from the *z*-transform of the hit rate: $d' = z(H) - z(FA)$. Critically, this measure is independent of the location of a subject's criterion and so offers an objective, bias-free measure of their sensitivity.

The *bias* of an observer is their tendency to prefer a particular response independent of the actual presence of a stimulus. This can be measured by the location of their criterion with respect to the midpoint of the *N* and *S* + *N* distributions. Intuitively, a criterion at the midpoint shows no preference for "yes" responses over "no" responses independent of the actual presence of a stimulus, whereas a *conservative* criterion reflects a preference for "no" responses, and a *liberal* criterion a preference for "yes" responses. We can calculate a standardized measure of bias, as follows: $c = -\frac{1}{2}[z(H) + z(FA)]$.

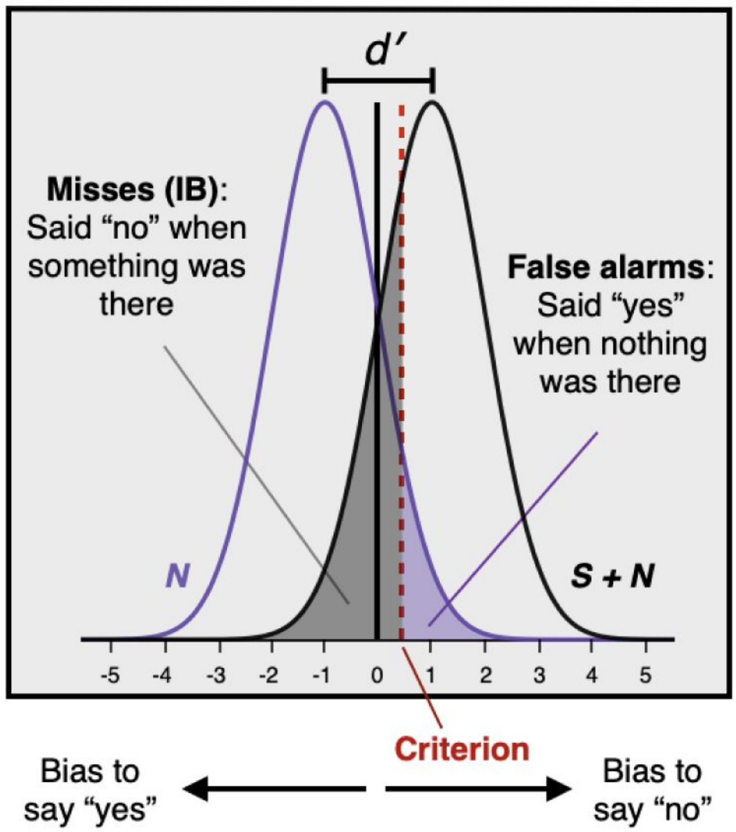
The traditional question in IB studies—"Did you notice anything unusual on the last trial that wasn't there on previous trials?"—can be treated as a yes/no detection question. By including absent trials, where no stimulus was presented and yet we ask this question anyway, we determined hit and false alarm rates across critical trials after applying the Hautus (1995) correction of adding 0.5 to every cell in the decision matrix to avoid infinite values which would arise if any cell were zero. For example, in our Exp. 5, 7.2% of subjects who were shown no IB stimulus nonetheless responded "yes"—yielding a corrected false alarm rate of 0.073. On the other hand, 71% of subjects who were shown a stimulus responded "yes"—yielding a corrected hit rate of 0.71. Using the calculations described, we could separate the sensitivity of the corresponding super-subject from their bias. This revealed a significant *conservative* bias ($c = 0.45$), indicating a preference to deny noticing an unexpected stimulus, independent of its actual presence.

"Did you notice anything unusual?"

	"Yes"	"No"
Present	5730	2339
Absent	200	2561

$$\textbf{Corrected hit rate} \text{ (say "Yes" when Present)} = \frac{5730 + 0.5}{(5730 + 0.5) + (2339 + 0.5)} = 0.71$$

$$\textbf{Corrected false alarm rate} \text{ (say "Yes" when Absent)} = \frac{200 + 0.5}{(200 + 0.5) + (2561 + 0.5)} = 0.073$$



General Discussion

Inattentional blindness captures both scholarly interest and popular imagination because of its striking and counterintuitive implication that we may fail to see what is right before our eyes, simply because our attention is otherwise engaged. Its influence is both wide and deep: It apparently provides a dramatic demonstration of the limits of visual perception, serves as a tool to reveal the neural correlates of consciousness, and even motivates theories of consciousness holding that awareness requires attention. These and still other implications arise from the "consensus" interpretation of IB, according to which inattention completely abolishes perception

of the unexpected stimulus: “one can have one’s eyes focused on an object or event … without seeing it *at all*” (Carruthers, 2015, emphasis added). Yet this interpretation rests on a crucial and untested assumption: that observers who say they didn’t notice a stimulus (i.e., answer “no” under traditional yes/no questioning) in fact didn’t see it.

The present work puts this crucial assumption to the test, yielding results that point to a very different pattern than the consensus interpretation: Across 5 pre-registered experiments totaling over 25,000 subjects, we found that observers could successfully report a variety of features of unattended stimuli, even when they claimed not to have noticed those stimuli. Furthermore, our approach revealed that subjects are conservatively biased in reporting their awareness, in ways that not only explain our results (i.e., provide an account of how and why subjects who claim not to have seen something could still report its features) but also recast the large and influential body of literature that has taken answers to yes/no questions in IB paradigms at face value.

Design and analytical approach

Our experiments all employed designs and protocols closely modeled on canonical IB studies. In Experiments 1-3, we studied IB using a cross task closely modeled on Mack and Rock’s classic studies (Mack & Rock, 1998). In Experiments 4-5, we studied IB using a dynamic task closely modeled on Wood & Simons (2017) (itself adapted from influential work by Most et al., 2001; Most et al., 2005; Ward & Scholl, 2015). In all cases, we used the standard yes/no question from previous experiments to determine IB rates. These choices were deliberate: Our aim was to interrogate the canonical interpretation of a large and long-standing tradition of experimental work, and so we sought to cleave as closely as possible to the experiments which inspired and have been subject to this interpretation. Our results do not reflect idiosyncratic design choices but rather speak to the central paradigms in the literature.

To assess objective sensitivity and bias in IB, we adopted a novel analytical approach, applying signal detection models to a “super subject” whose responses are comprised of individual subjects’ responses in their single critical trials. This strategy involves various assumptions which future work should explore. Nonetheless, we believe any violations of such assumptions will not affect our main results or, where they might, lead only to our underestimating residual sensitivity and response bias. First, in calculating d', it is standardly assumed that a subject’s criterion is stable throughout a given experiment. This assumption may be more likely to be violated with respect to a “super subject”. However, its violation will not affect calculations of d' in 2afc tasks which are criterion free (Exps. 1, 3 and location results in Exps. 4 & 5). Moreover, if criterion instability is present, its effect will be to reduce estimated sensitivity in one-interval forced-response tasks (Exp. 2, and shape and color results in Exps. 4 & 5; see, Azzopardi & Cowey, 2001). Our approach can thus be seen as offering a conservative estimate of residual sensitivity. (Indeed, given the essentially retrospective nature of IB judgments, our estimates should in any case be considered conservative since signal available at the time of stimulus presentation may have been lost by the time of judgment.) Second, in calculating d' and c, it is standardly assumed that signal and noise distributions are equal variance Gaussians. There is theoretical reason to think this assumption is robust with respect to 2afc tasks (Macmillan & Creelman, 2005), and in general in relation to the Gaussian nature of the distributions (Green & Swets, 1966; Pastore et al., 2003; Wixted, 2020). However, empirically, equal variance might not hold in one-interval tasks. Violation of this equal variance assumption could lead to under- or over-estimation of d' and c. However, any such under- or over-estimation would be slight and unlikely to affect our main results. For example, if the relative variance of the signal-plus-noise distribution as compared to the noise distribution (σ) is 1.25, then c for the yes/no task in Experiment 5 (illustrated in Box 1) would be 0.443 and d' would be 1.898; whereas, if $\sigma = 0.75$, then c would instead be 0.438 and d' would be 2.118. In either case, our main results are qualitatively unchanged.

Relation to previous work

Previous studies of the related phenomenon of change blindness have investigated whether subjects who fail to detect changes nonetheless perform above chance in discrimination tasks concerning the changed object (Mitroff et al., 2002, 2004; Hollingworth & Henderson, 2002). However, only a handful of prior studies have explored the possibility that inattentionally blind subjects outperform chance in reporting or responding to features of IB stimuli (e.g., Schnuerch et al., 2016; see also Kreitz et al., 2020, Nobre et al., 2020). Moreover, a recent meta-analysis of this literature (Nobre et al., 2022) concluded that such work is problematic along a number of dimensions, including underpowered samples and evidence of publication bias that, when corrected for, eliminates effects revealed by earlier approaches. (These concerns hold in addition to our own worries about biased measures of performance.) The authors of this meta-analysis conclude with the following recommendation for future work: “We suggest that more evidence, particularly from well-powered pre-registered experiments, is needed before solid conclusions can be drawn regarding implicit processing during inattentional blindness” (Nobre et al., 2022). We see the present set of high-powered pre-registered studies as providing precisely this evidence, in ways that advance our understanding of IB considerably.

Our results also shed new light on evidence that inattentionally blind subjects process the unexpected stimuli they deny noticing. For example, in the electrophysiology literature, unexpected line patterns have been found to elicit the same Nd1 ERP component in both noticers and inattentionally blind subjects (Pitts et al., 2012). Similarly, behavioral studies show that unattended stimuli can influence the accuracy and speed of inattentionally blind subjects’ judgments in a primary task (e.g., Moore & Egeth, 1997; replicated in Wood & Simons, 2019; Pugnaghi et al., 2020). Although some researchers have interpreted these results as implying a kind of subliminal processing of IB stimuli, our results point to an alternative (and perhaps more straightforward) explanation: that inattentionally blind subjects consciously perceive these stimuli after all (albeit in a degraded manner)—they show sensitivity to IB stimuli *because they can see them*.

We acknowledge that above-chance performance in our experiments could be taken to reflect unconscious representations in a manner akin to orthodox interpretations of blindsight (Weiskrantz et al., 1974; Kolb & Braun, 1995; though see Phillips, 2021a; Morgan et al., 1997; and for more general skepticism, Newell and Shanks, 2023). However, in our view, explicit voluntary judgments of stimulus features (especially in neurotypical subjects) constitute strong prima facie evidence of conscious processing, and should be interpreted that way unless there is some compelling reason to favor an alternative (Snodgrass, 2002; Balsdon and Azzopardi, 2015; Heeks and Azzopardi, 2015; Phillips, 2021b). As a result, we take our results to be best interpreted in terms of residual conscious vision in IB.

Evidence that inattentionally blind subjects process and are sensitive to the unexpected stimuli they deny noticing has been used to support so-called *inattentional amnesia* accounts of IB—the traditional rival to the orthodox interpretation of IB. On inattentional amnesia accounts, unattended objects and features are consciously perceived but not encoded so as to be available for later explicit report (Wolfe, 1999; Moore, 2001; though see Ward & Scholl, 2015; Hirschhorn et al., 2024). Our results are consistent with some degree of inattentional amnesia, and likewise, with what Block (2001) calls *inattentional inaccessibility*. (For a fuller discussion of these alternative hypotheses and IB more generally, see Wu, 2014.) However, our findings suggest that inattentional amnesia cannot be the whole story, since they reveal that some features of unexpected objects are available for later explicit report even in subjects who deny noticing anything unusual.

Visual awareness as graded

A further upshot of our findings is that they lend support to a more graded perspective on IB (in particular) and visual awareness (in general). This stands in contrast to the two interpretations that have dominated discussion of IB, both of which adopt a binary perspective. On the orthodox interpretation, inattention abolishes all awareness; on the rival inattentional amnesia account, inattention abolishes all explicit encoding. Our data suggest the need to move beyond such binaries (cf. Cohen et al., 2023): Inattention degrades but does not eliminate awareness, and likewise explicit encoding. This more nuanced approach has some kinship with what Simons (2000) calls *inattentional agnosia*. On this account, subjects who report not noticing may have some awareness of the unexpected object but fail to "encode the properties necessary to register that the item was something new, different, or noteworthy" (Most et al., 2005). Though aligned with the spirit of our view, this account still does not fully capture our results, since in our studies non-noticing subjects could explicitly report features which would ordinarily suffice to mark the unexpected object as new or different (e.g., color, shape). Nonetheless, we agree that unattended stimuli are encoded in a partial or degraded way. Here we see a variety of promising options for future work to investigate. One is that unattended stimuli are only encoded as part of ensemble representations or summary scene statistics (Rosenholtz, 2011; Cohen et al., 2016). Another is that only certain basic "low-level" or "preattentive" features (see Wolfe & Utochkin, 2019 for discussion) can enter awareness without attention. A final possibility consistent with the present data is that observers can in principle be aware of individual objects and higher-level features under inattention but that the precision of the corresponding representations is severely reduced. Our central aim here is to provide evidence that awareness in inattentional blindness is not abolished. Further work is needed to characterize the exact nature of that awareness.

Conclusion

Taken together, and after decades of inconclusive findings, the results of our five studies offer the strongest evidence so far of significant residual visual sensitivity across a range of visual features in IB. In other words, the inattentional blind can see after all, enjoying at least some degraded or partial sensitivity to the location, color and shape of stimuli which they report not noticing. Together with our finding that subjects exhibit a systematically conservative bias in reporting their awareness, our results also provide evidence against the orthodox interpretation of IB on which inattention entirely abolishes awareness, suggesting that a major reconceptualization of inattentional blindness is required. Indeed, perhaps ironically, inattentional blindness if anything provides evidence that awareness of certain features *survives* inattention. Our results highlight the critical value of assessing response bias and including objective measures of sensitivity in studying inattentional blindness and visual awareness. They also point to a broader rethinking of consciousness as a graded, rather than binary, phenomenon.

Methods

Open Science Practices

All sample sizes, exclusion criteria, analyses and key experimental parameters reported here have been pre-registered. Data, analyses, stimuli and pre-registrations are publicly available at *https://osf.io/fcrhu/*. Readers can also experience all experiments for themselves at *https://perceptionresearch.org/ib/*.

Experiment 1: Above-chance sensitivity to the location of unnoticed stimuli

Participants

500 adults were recruited from the online platform Prolific (for validation of the reliability of this subject pool, see Peer et al., 2017), with participation limited to US subjects. As described in our pre-registration, we reached this number by running batches of 100 subjects until a target number of 100 non-noticers (i.e., subjects answering "no" to the yes/no question about whether they noticed the unexpected stimulus) was reached. After excluding subjects who incorrectly reported which arm of the cross was longer on any of trials 1-3 and those who failed to provide a complete dataset, or failed a test for color vision (Ishihara color plate; see data archive), 374 subjects were included in the analysis. (All of these exclusion criteria were pre-registered.) This experiment and all others reported here were approved by the Homewood Institutional Review Board of Johns Hopkins University. All subjects provided informed consent and were compensated financially for their participation.

Stimuli and Procedure

As shown in **Figure 2**, Experiment 1 contained four trials, with the fourth trial differing from the first three in several ways. All trials took place in a display with dimensions 600 px x 600 px. Due to the nature of online experiments, we cannot be sure of the exact size or distance of stimuli as subjects actually experienced them (and so we give these figures in pixels); however, any differences in subjects' monitors and/or display setups would have been constant across all trials of the experiment.

On trials 1-3, a fixation circle appeared in the center of the display; subjects pressed the spacebar when they were ready to begin the trial. The keypress was followed by a 1500 msec delay, after which a cross formed by two thin black lines (3 px thickness; 200 px x 140 px dimensions) appeared for 200 msec either 150 px above or below the fixation circle. The location of the cross (above or below), as well as its aspect ratio (vertical-longer or horizontal-longer) was randomly chosen on each of these trials. The cross then disappeared, followed by a 500 msec blank interval. Subjects were then asked which of the cross's arms was longer (horizontal or vertical).

The fourth, critical trial proceeded the same way, except that simultaneous with the cross, a vertical red line (200 px long; 3 px thick; RGB(147,0,0)) appeared on one side of the display (10 px from the boundary of the display), also for 200 msec. Subjects were then asked the same cross arm length question as before.

Following this, two additional questions were asked, in the following order, each on its own display (such that subjects only saw the second question after answering the first).

Question 1

Did you notice anything unusual on the last trial which wasn't there on previous trials? (yes / no)

Question 2

In fact, the last trial you just saw contained one extra element — a vertical red line on either the left or the right side of the box. What side do you think it appeared on? If you don't know, or don't think it appeared on either side, take your best guess. (left / right)

For all forced-choice and forced-response questions asked in all experiments reported here, subjects indicated their answers by clicking a radio button next to the text corresponding to their answer, and then submitted their responses by clicking a separate “Submit” button, a design aimed at eliminating motor-error responses.

Analysis and Results

As reported in the main text, 28.6% (107/374) of subjects responded “no” to Question 1; we refer to these subjects as “non-noticers”. These subjects are those who demonstrate inattentional blindness by conventional standards. However, 63.6% of non-noticers answered Question 2 correctly (the 2afc location task). This proportion was compared to chance responding (50%) with both frequentist and Bayesian null hypothesis tests, using the binom.test and proportionBF functions, respectively, from the BayesFactor package in R (Ihaka et al., 1996; Morey et al., 2015; all arguments used were defaults), which yielded a 95% CI = [0.54, 0.73], and a BF10 = 9.9.

SDT analyses began by calculating the number of hits, false alarms, present trials, and absent trials, and then applying the log-linear correction of adding 0.5 to all cells of the decision matrix (Hautus, 1995; see also Box 1). This is a standard correction to prevent an infinite *d'* in the event that either hits or false alarms are zero (this correction was applied to all experiments, though neither hits nor false alarms were ever zero), and simulations have shown that if anything, this correction *underestimates d'* (Hautus, 1995).

The signal detection theory measure of sensitivity (*d'*) for non-noticers' performance on the 2afc location task was calculated as follows:

$$d'_{2afc} = \frac{1}{\sqrt{2}}\left[z(H) \; - \; z(FA)\right]$$

For our analysis, we (arbitrarily) considered trials where a stimulus was presented on the *left* to be “present” trials, and trials where a stimulus was presented on the *right* to be “absent” trials (*d'* will be identical regardless of which trial type is considered present/absent; *c* will be the same value with the opposite sign). With a hit rate and false alarm rate of 72.64% and 45.54% respectively (after log-linear adjustment), the resulting d'_{2afc}= 0.51. Note that *d'* for this experiment was adjusted downward by a factor of $1/\sqrt{2}$ because 2afc tasks are theoretically easier than yes/no or forced-response tasks (Macmillan and Creelman, 2005). This formula for d'_{2afc}(as well as those for *d'* and *criterion*, described below) assumes equal variance for signal and noise distributions (a standard assumption in SDT), but the analysis code provided allows for the calculation of SDT statistics when the variance of signal and noise distributions is unequal.

Because each subject in the experiment contributes just one trial, the signal detection metrics were calculated at the group level, and the standard error for each SDT calculation was estimated using methods described by Macmillan and Creelman (2005, pgs. 325-328; see also Kadlec, 1999). We estimated the variance for *d'* in this 2afc task using methods first described by Gourevitch and Galanter (1967), and re-described in Macmillan and Creelman (2005), equations 13.5 and 13.7. First, equation 13.5 demonstrates how φ (a function which converts z-scores into probabilities) can be computed for the hit rate and false alarm rates:

$$\phi(H) \;=\; \frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}z(H)^2}$$

$$\phi(FA) \;=\; \frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}z(FA)^2}$$

With φ(H) and φ(FA) computed, we then estimated the variance of *d'* in this 2afc task using equation 13.7:

$$\mathrm{var}(d'_{2afc}) = \frac{H(1-H)}{2N_2[\phi(H)]^2} + \frac{FA(1-FA)}{2N_1[\phi(FA)]^2}$$

where N_2 is the number of present trials, and N_1 is the number of absent trials. (For information about how the variance is affected by sample size using different methods and in different tasks, see Macmillan and Creelman Table 13.2 and 13.3; our sample sizes are more than sufficient to expect this variance estimation to be accurate to the hundredth decimal place).

Finally, we computed a confidence interval around d'_{2afc} using standard methods: The result is 95% CI = [0.16, 0.85], suggesting performance in the non-noticing group was significantly above chance.

Experiment 2: Above-chance sensitivity to the color of unnoticed stimuli

Participants

1700 adults were recruited from Prolific, collected in batches of 100 subjects until a target number of 100 non-noticers was reached. After excluding subjects who incorrectly reported which arm of the cross was longer on any of trials 1-3 and those who failed to provide a complete dataset, or failed a test for color vision, 1261 subjects were included in the analysis.

Stimuli and Procedure

The fourth, critical trial proceeded the same way as Experiment 1, except that the extra vertical line that appeared simultaneous with the cross was either red (RGB(147,0,0)) or blue (RGB(0,0,136)), with the color and location of the line randomized across subjects.

Following the presentation of Trial 4, subjects were asked which cross arm was longer, and then the same traditional IB question as in Experiment 1 (Question 1), followed by:

Question 2

The last trial you just saw contained one extra element — a vertical line on one side of the box. What color was the extra line? If you don't know, or don't think any line appeared, take your best guess. (red / blue)

To reduce uncertainty about what color "red" and "blue" referred to, the text for each color option was printed in the red and blue color used for the IB stimuli in the different conditions (RGB(147,0,0), RGB(0,0,136)).

Analyses and Results

As reported in the main text, 27.7% of subjects shown an additional stimulus responded "no" to Question 1 (i.e., demonstrated inattentional blindness by conventional standards). However, 58.5% of these non-noticers answered correctly on Question 2 (95% CI = [51.95%, 64.93%]; BF10 = 4.54).

In Experiment 2, the follow-up color discrimination was a two-alternative forced-response design, and so for signal detection analyses, sensitivity was calculated without the 1/sqrt(2) adjustment, such that

$$d' = z(H) - z(FA)$$

resulting in a d' = 0.38. We estimated the variance of d' for this one-interval forced-response task using similar methods to those described for Experiment 1, with one minor change to the variance equation to account for this being a forced-response task (equation 13.4 in Macmillan and Creelman, 2005):

$$\mathrm{var}(d') = \frac{H(1-H)}{N_2[\phi(H)]^2} + \frac{FA(1-FA)}{N_1[\phi(FA)]^2}$$

The only difference between equation 13.4 and equation 13.7 is that the latter includes a factor of 2 in the denominator of both terms, which accounts for 2afc tasks theoretically being easier than yes/no tasks.

The procedure for significance testing comparing d' to chance (d' = 0) was identical to Experiment 1 Methods, and the two-sided frequentist binomial probability test yielded a 95% confidence interval of [0.03, 0.73]. As stated in the main text, subjects demonstrated a significant bias to respond “blue,” which we measured by calculating subjects’ criterion on the red/blue question as,

$$c = -\frac{1}{2}[z(H) + z(FA)]$$

resulting in a positive (conservative) criterion value of c = 0.67. The 95% confidence interval around the criterion estimate is [0.49, 0.84]. Since this interval does not contain zero, this represents a statistically significant bias. For a more intuitive understanding of the bias, 78.42% of subjects shown *no IB stimulus* guessed that the stimulus was blue.

Lastly, an important contribution of this work is the inclusion of absent trials, which enable us to compute response bias (c) for the traditional IB question, “Did you notice anything unusual on the last trial that wasn’t there on previous trials?” As predicted, we found that subjects were conservative in reporting their awareness of the IB stimulus (c = 0.31, 95% CI = [0.22, 0.41]), suggesting that subjects in inattentional blindness experiments may systematically underreport their awareness of unexpected stimuli.

Experiment 3: Above-chance sensitivity even in highly confident non-noticers

Participants

7,000 subjects were recruited from Prolific, and data were collected in batches until we reached 200 non-noticers who reported being “highly confident” in their yes/no response. After excluding duplicate data files, subjects who incorrectly reported which arm of the cross was longer on any of trials 1-3, those who failed to provide a complete dataset, or failed a test for color vision, 5296 subjects were included in the analysis.

Stimuli and Procedure

This experiment explored whether sensitivity to the visual features of an IB stimulus varies as a function of subjects’ confidence in their responses to the traditional IB question (i.e., whether or not they noticed anything unusual on the last trial), and more specifically whether even highly confident non-noticers would show such sensitivity. Experiment 3 was identical to Experiment 1, except that after subjects answered the traditional yes/no question (which was the same as Question 1 in Experiment 1) and the follow-up left/right question (which was the same as Question 2 in Experiment 2), they also rated their confidence in each of those responses:

Question 1

Did you notice anything unusual on the last trial which wasn't there on previous trials? (yes / no)

Question 2 (Confidence rating for Question 1)

How confident are you in your answer? (Four-point scale: 0 = Not at all confident – 3 = Highly confident)

Question 3

The last trial you just saw contained one extra element - a vertical red line on either the left or the right side of the box. What side do you think it appeared on? If you don't know, or don't think it appeared on either side, just take your best guess. (left / right)

Question 4 (confidence rating for Question 3; not shown in **Figure 3**)

How confident are you in your answer? (Four-point scale: 0 = Not at all confident – 3 = Highly confident)

Analyses and Results

As reported in the main text, 30.85% of subjects shown an additional stimulus responded "no" to Question 1 (i.e., demonstrated inattentional blindness by conventional standards)

As with Experiments 1 and 2, we were interested in whether subjects who responded "no" to the traditional IB question would nevertheless perform above-chance on subsequent discrimination questions about the IB stimulus. Beyond our general interest in all subjects who answered "no," we were most interested in whether the non-noticers who reported high confidence in their answer still performed above-chance on the 2afc question. We compared the performance of those observers to chance ($d' = 0$) using the methods described above, and found that even the most confident non-noticers—i.e., those who reported being "highly confident" that they did not notice anything unusual, rating their confidence at 3 on a scale from 0 to 3—demonstrated significantly above-chance sensitivity to the location of the IB stimulus: $d'_{2afc} = 0.34$; 95% CI = [0.08, 0.60]. Importantly, this group of subjects is minimally powered, with just 204 subjects, adding force to the argument that there is meaningful sensitivity in highly confident non-noticers. The bin of second-most interest is that of the moderately confident non-noticers (those responding with a confidence rating of 2 on a scale from 0 to 3). Sensitivity in this group was above zero ($d'_{2afc} =$ 0.05), but not significantly so (95% CI = [-0.10, 0.20]). **Figure 3e** depicts the uncorrected results of null hypothesis significance tests comparing the d'_{2afc} estimate for each confidence rating bin to chance ($d'_{2afc} = 0$), but essentially the same pattern of significant results is obtained when the Holm-Bonferroni correction for multiple comparisons is applied ($p = .034$ for the No-3 bin, and $p =$ 0.09 for the Yes-0 bin–though note this bin only contains 25 subjects). roni correction for multiple comparisons is applied (p = .034 for the No-3 bin, and p = 0.09 for the Yes-0 bin–though note this bin only contains 25 subjects).

Experiment 4: Above-chance sensitivity in a sustained inattentional blindness task

Participants

1500 subjects were recruited from Prolific, and data were collected in batches until we reached 100 non-noticers who answered the color discrimination question first, 100 non-noticers who answered the shape discrimination question first, and 100 non-noticers who answered the location discrimination question first (more on these three discrimination questions below).

After exclusions, 1278 subjects including 417 non-noticers remained in the analysis for Experiment 4. The pre-registered exclusion criteria for this experiment were the same as those reported by Wood & Simons (2017). Subjects were excluded if: (i) their reported bounces for either of the first two trials erred by more than 50% in either direction from the true number of bounces of their attended objects on that trial, (ii) they failed to contribute a complete dataset, (iii) they reported problems with experimental playback, such as stuttering, freezing or another issue specified in a free-response, or (iv) an observer managed to submit or run the study twice (evidenced by two files sharing the same Prolific ID), in which case we excluded their second run from the analysis.

Stimuli and Procedure

In Experiment 4, subjects participated in a sustained inattentional blindness task modified slightly from experimental code published by Wood & Simons (2017). All subjects completed three trials of a dynamic, multiple object tracking task containing black squares and white squares. At the beginning of the experiment, each subject was told whether they should attend to the black or white squares. At the beginning of each trial, subjects were instructed to fixate on a small blue square (11 px x 11 px; RGB(0,0,255)) in the center of a gray (RGB(127,127,127)) rectangle (666 px x 546 px), and were told that their task was to count the number of times the squares of their attended color bounced off of the walls of the gray rectangle. Each trial lasted approximately 17 seconds, and each subset of black/white squares bounced an average of 28 times. After the trial ended, subjects were asked to report how many times the squares of their attended color bounced off of the walls of the rectangle. Of the 222 excluded subjects, 185 were excluded for bounce reports that erred by more than 50% in either direction of the actual number of bounces.

The critical trial was Trial 3. In this trial, 3/4 of subjects (Present condition) were shown an unexpected shape (a circle or a triangle, which was either black or white). This unexpected object entered the display on either the left or the right 5 seconds after the trial began, and moved either upward or downward until it exited the other side of the display (thus, there were 2 color x 2 shape x 2 side x 2 motion direction options for IB stimuli, randomly chosen for each subject). For 1/4 of subjects, no additional object was shown on Trial 3 (Absent condition).

Regardless of condition, at the end of the critical trial, subjects were again asked to report the number of bounces, followed by four additional questions:

Question 1

Did you notice something on the last trial that did not appear on previous trials? (yes/no)

After answering Question 1 (the standard IB question), subjects were told (again regardless of condition): *An extra object may have appeared on that last trial. If you saw it, please tell us its color, shape, and whether it appeared on the left or the right side of this gray box. If you didn't see the extra object, please guess. We'll ask about* [whichever discrimination question was randomly chosen to be asked first] *first*.

Questions 1-3 (presented in random order for each subject)

The new object was… (black/white)

The new object was a… (circle/triangle)

The new object was on the… (left/right)

Note that Question 1 (the traditional IB question) differs slightly in Experiments 4 and 5 from the question wording in Experiments 1-3 because we aimed to cleave as closely as possible to Wood & Simons (2017) and other inattentional blindness experiments using similar paradigms.

Analyses and Results

As reported in the main text, 57.32% of subjects shown an additional stimulus on the critical trial answered "no" to the traditional IB question (Question 1). For absent trials, 6.31% of subjects answered "yes" to the traditional IB question when no additional stimulus appeared; this is the false alarm rate, which can be used (along with the hit rate) to estimate subjects' bias in responding to the traditional IB question. In Experiment 4, as in Experiment 2, we found that subjects answered the traditional IB question using a conservative criterion (c = 0.85, 95% CI = [0.73, 0.97]), suggesting they may be underreporting their awareness of IB stimuli.

Experiment 4 asked subjects to perform 3 discrimination tasks following their response to Question 1, with the order randomized for each subject. The color and shape discriminations are one-interval forced response tasks, and so d' was calculated for these two questions without the 2afc correction. We found that non-noticers performed significantly above chance on both the color (d' = 0.82, 95% CI = [0.61, 1.04]) and shape (d' = 0.21, 95% CI = [0.005, 0.42]) discriminations. In addition to the issue identified below, the fact that this result was marginal further motivated Experiment 5, in which we substantially increased the number of subjects recruited in order to reduce the size of the confidence intervals around d' estimates of discrimination sensitivity by 50%. For the location discrimination (left/right), the 2afc correction to d' was applied, and non-noticers' performance was trending but was not above-chance (d'_{2afc} = 0.07, 95% CI = [-0.08, 0.22]).

Because the order of the discrimination questions varied by subject, we pre-registered an analysis specifying that we would also derive sensitivity and bias for subjects who answered a given discrimination question first. With these subsets of non-noticers (roughly one-third the original sample size), confidence intervals are much larger, and although color discrimination remained significantly above-chance (d' = 0.78, 95% CI = [0.41, 1.16]; N = 189), shape discrimination was no longer significant (d' = 0.15, 95% CI = [-0.20, 0.50]; N = 195) and location (d'_{2afc} = -0.17, 95% CI = [-0.44, 0.10]; N = 176) was again not significant.

Finally, in a pre-registered analysis breaking down the inattentional blindness rate by the color of the attended stimuli, we found that subjects were roughly 3x more likely to report noticing a color-congruent than a color-incongruent IB stimulus (86.57% vs. 28.71%). This interacted with subjects' responses on the color discrimination task, with subjects shown an IB stimulus demonstrating a significant bias to say that the stimulus that appeared was the opposite color to the colored squares they attended (84.25% of subjects who attended to white squares answered black; 75.09% of subjects who attended to black squares answered white). In order to get a better estimate of sensitivity to color in this task, we pilot tested a new pair of IB stimulus colors in Experiment 5 to equate the guessing rate on absent trials.

Experiment 5: Replicating above-chance sensitivity in a sustained inattentional blindness task

Participants

To ensure a large enough sample without overlap with previous experiments using this paradigm, Experiment 5 recruited Prolific subjects not only from the USA but also from Canada, the United Kingdom, and Australia. In order to reduce the size of the confidence intervals around the sensitivity estimates relative to Experiment 4, we collected data until we reached at least 2,200 subjects who reported not noticing the unexpected stimulus. Exclusion criteria were identical to

Experiment 4. After exclusions, 10,830 subjects in total, including 2,339 non-noticers, were included in the analysis. (To our knowledge, this made Experiment 5 the largest single inattentional blindness sample ever collected.)

Stimuli and Procedure

Experiment 5 repeated the design of Experiment 4, with two key differences: (1) Every subject was assigned to attend to the white squares in the primary task, (2) the IB stimuli were either orange or green—two colors that as a pair produced equal IB rates in pilot testing. Again, subjects were asked the traditional IB question (yes/no) followed by three discrimination questions (color, shape, and location) in random order for each subject. The change to the colors of the IB stimuli of course meant that the color question and options were changed to read:

The new object was… (color 1/color 2; with the text printed in the given color)

Analyses and Results

As reported in the main text, with the congruency effects mitigated and despite the highly salient color of the orange/green IB stimuli, the pattern of results matched that of Experiment 4: Analysis of responses to the traditional yes/no question once again revealed that subjects were biased to respond “no” (c = 0.45, 95% CI = [0.41, 0.49]), with the hit rate (subjects in the Present condition who responded “yes”) being 71.01% (100% - the IB rate) and the false alarm rate (subjects in the Absent condition who responded “yes”) being 7.24% (see a more detailed breakdown of the SDT analysis for this experiment in Box 1). Thus, even when a highly salient, moving stimulus entered the display suddenly and remained on screen for multiple seconds, subjects were hesitant to report noticing anything unusual.

Non-noticers’ performance on the three discrimination questions was also consistent with the pattern of results in Experiment 4, with non-noticers performing significantly above-chance in discriminating both color (d' = 0.12, 95% CI = [0.02, 0.23]) and shape (d' = 0.23, 95% CI = [0.13, 0.33]), but not location (d'_{2afc} = 0.03, 95% CI = [-0.04, 0.11]). Biases in the discrimination question responses among subjects shown no IB stimulus on the critical trial (the Absent condition) were minimal, confirming that the congruency effect (interaction between the IB rate and subjects’ choices on the color discrimination question) was mitigated in Experiment 5: For subjects shown no unexpected stimulus on the critical trial (the Absent condition), 52.95% guessed that the extra object had been orange, and 47.05% guessed that it had been green. On the shape question, 51.43% of subjects guessed that the extra object had been a triangle, and 48.57% guessed that it had been a circle. Finally, on the location question, 54.87% of subjects guessed that the extra object had been on the left side of the display, and 45.13% guessed that it had been on the right side of the display.

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Reviewer #1 (Public review):

Summary:

In the abstract and throughout the paper, the authors boldly claim that their evidence, from the largest set of data ever collected on inattentional blindness, supports the views that "inattentionally blind participants can successfully report the location, color, and shape of stimuli they deny noticing", "subjects retain awareness of stimuli they fail to report", and "these data...cast doubt on claims that awareness requires attention." If their results were to support these claims, this study would overturn 25+ years of research on inattentional blindness, resolve the rich vs. sparse debate in consciousness research, and critically

challenge the current majority view in cognitive science that attention is necessary for awareness.

Unfortunately, these extraordinary claims are not supported by extraordinary (or even moderately convincing) evidence. At best, the results support the more modest conclusion: If sub-optimal methods are used to collect retrospective reports, inattentional blindness rates will be overestimated by up to ~8% (details provided below in comment #1). This evidence-based conclusion means that the phenomenon of inattentional blindness is alive and well as it is even robust to experiments that were specifically aimed at falsifying it. Thankfully, improved methods already exist for correcting the ~8% overestimation of IB rates that this study successfully identified.

Comments:

(1) In experiment 1, data from 374 subjects were included in the analysis. As shown in figure 2b, 267 subjects reported noticing the critical stimulus and 107 subjects reported not noticing it. This translates to a 29% IB rate, if we were to only consider the "did you notice anything unusual Y/N" question. As reported in the results text (and figure 2c), when asked to report the location of the critical stimulus (left/right), 63.6% of the "non-noticer" group answered correctly. In other words, 68 subjects were correct about the location while 39 subjects were incorrect. Importantly, because the location judgment was a 2-alternative-forced-choice, the assumption was that if 50% (or at least not statistically different than 50%) of the subjects answered the location question correctly, everyone was purely guessing. Therefore, we can estimate that ~39 of the subjects who answered correctly were simply guessing (because 39 guessed incorrectly), leaving 29 subjects from the non-noticer group who may have indeed actually seen the location of the stimulus. If these 29 subjects are moved to the noticer group, the corrected rate of IB for experiment 1 is 21% instead of 29%. In other words, relying only on the "Y/N did you notice anything" question leads to an overestimate of IB rates by 8%. This modest level of inaccuracy in estimating IB rates is insufficient for concluding that "subjects retain awareness of stimuli they fail to report", i.e. that inattentional blindness does not exist.

In addition, this 8% inaccuracy in IB rates only considers one side of the story. Given the data reported for experiment 1, one can also calculate the number of subjects who answered "yes, I did notice something unusual" but then reported the incorrect location of the critical stimulus. This turned out to be 8 subjects (or 3% of the "noticer" group). Some would argue that it's reasonable to consider these subjects as inattentionally blind, since they couldn't even report where the critical stimulus they apparently noticed was located. If we move these 8 subjects to the non-noticer group, the 8% overestimation of IB rates is reduced to 6%.

The same exercise can and should be carried out on the other 4 experiments, however, the authors do not report the subject numbers for any of the other experiments, i.e., how many subjects answered Y/N to the noticing question and how many in each group correctly answered the stimulus feature question. From the limited data reported (only total subject numbers and d' values), the effect sizes in experiments 2-5 were all smaller than in experiment 1 (d' for the non-noticer group was lower in all of these follow-up experiments), so it can be safely assumed that the ~6-8% overestimation of IB rates was smaller in these other four experiments. In a revision, the authors should consider reporting these subject numbers for all 5 experiments.

(2) Because classic IB paradigms involve only one critical trial per subject, the authors used a "super subject" approach to estimate sensitivity (d') and response criterion (c) according to signal detection theory (SDT). Some readers may have issues with this super subject approach, but my main concern is with the lack of precision used by the authors when interpreting the results from this super subject analysis.

Only the super subject had above-chance sensitivity (and it was quite modest, with d' values between 0.07 and 0.51), but the authors over-interpret these results as applying to every subject. The methods and analyses cannot determine if any individual subject could report the features above-chance. Therefore, the following list of quotes should be revised for accuracy or removed from the paper as they are misleading and are not supported by the super subject analysis:

"Altogether this approach reveals that subjects can report above-chance the features of stimuli (color, shape, and location) that they had claimed not to notice under traditional yes/no questioning" (p.6)

"In other words, nearly two-thirds of subjects who had just claimed not to have noticed any additional stimulus were then able to correctly report its location." (p.6)

"Even subjects who answer "no" under traditional questioning can still correctly report various features of the stimulus they just reported not having noticed, suggesting that they were at least partially aware of it after all." (p.8)

"Why, if subjects could succeed at our forced-response questions, did they claim not to have noticed anything?" (p.8)

"we found that observers could successfully report a variety of features of unattended stimuli, even when they claimed not to have noticed these stimuli." (p.14)

"our results point to an alternative (and perhaps more straightforward) explanation: that inattentionally blind subjects consciously perceive these stimuli after all... they show sensitivity to IB stimuli because they can see them." (p.16)

"In other words, the inattentionally blind can see after all." (p.17)

(3) In addition to the d' values for the super subject being slightly above zero, the authors attempted an analysis of response bias to further question the existence of IB. By including in some of their experiments critical trials in which no critical stimulus was presented, but asking subjects the standard Y/N IB question anyway, the authors obtained false alarm and correct rejection rates. When these FA/CR rates are taken into account along with hit/miss rates when critical stimuli were presented, the authors could calculate c (response criterion) for the super subject. Here, the authors report that response criteria are biased towards saying "no, I didn't notice anything". However, the validity of applying SDT to classic Y/N IB questioning is questionable.

For example, with the subject numbers provided in Box 1 (the 2x2 table of hits/misses/FA/CR), one can ask, 'how many subjects would have needed to answer "yes, I noticed something unusual" when nothing was presented on the screen in order to obtain a non-biased criterion estimate, i.e., c = 0?' The answer turns out to be 800 subjects (out of the 2761 total subjects in the stimulus-absent condition), or 29% of subjects in this condition.

In the context of these IB paradigms, it is difficult to imagine 29% of subjects claiming to have seen something unusual when nothing was presented. Here, it seems that we may have reached the limits of extending SDT to IB paradigms, which are very different than what SDT was designed for. For example, in classic psychophysical paradigms, the subject is asked to report Y/N as to whether they think a threshold-level stimulus was presented on the screen, i.e., to detect a faint signal in the noise. Subjects complete many trials and know in advance that there will often be stimuli presented and the stimuli will be very difficult to see. In those cases, it seems more reasonable to incorrectly answer "yes" 29% of the time, as you are trying to detect something very subtle that is out there in the world of noise. In IB paradigms, the stimuli are intentionally designed to be highly salient (and unusual), such that with a tiny bit

of attention they can be easily seen. When no stimulus is presented and subjects are asked about their own noticing (especially of something unusual), it seems highly unlikely that 29% of them would answer "yes", which is the rate of FAs that would be needed to support the null hypothesis here, i.e., of a non-biased criterion. For these reasons, the analysis of response bias in the current context is questionable and the results claiming to demonstrate a biased criterion do not provide convincing evidence against IB.

(4) One of the strongest pieces of evidence presented in the entire paper is the single data point in Figure 3e showing that in Experiment 3, even the super subject group that rated their non-noticing as "highly confident" had a d' score significantly above zero. Asking for confidence ratings is certainly an improvement over simple Y/N questions about noticing, and if this result were to hold, it could provide a key challenge to IB. However, this result hinges on a single data point, it was not replicated in any of the other 4 experiments, and it can be explained by methodological limitations. I strongly encourage the authors (and other readers) to follow up on this result, in an in-person experiment, with improved questioning procedures.

In the current Experiment 3, the authors asked the standard Y/N IB question, and then asked how confident subjects were in their answer. Asking back-to-back questions, the second one with a scale that pertains to the first one (including a tricky inversion, e.g., "yes, I am confident in my answer of no"), may be asking too much of some subjects, especially subjects paying half-attention in online experiments. This procedure is likely to introduce a sizeable degree of measurement error.

An easy fix in a follow-up study would be to ask subjects to rate their confidence in having noticed something with a single question using an unambiguous scale:

On the last trial, did you notice anything besides the cross?

(1) I am highly confident I didn't notice anything else
(2) I am confident I didn't notice anything else
(3) I am somewhat confident I didn't notice anything else
(4) I am unsure whether I noticed anything else
(5) I am somewhat confident I noticed something else
(6) I am confident I noticed something else
(7) I am highly confident I noticed something else

If we were to re-run this same experiment, in the lab where we can better control the stimuli and the questioning procedure, we would most likely find a d' of zero for subjects who were confident or highly confident (1-2 on the improved scale above) that they didn't notice anything. From there on, the d' values would gradually increase, tracking along with the confidence scale (from 3-7 on the scale). In other words, we would likely find a data pattern similar to that plotted in Figure 3e, but with the first data point on the left moving down to zero d'. In the current online study with the successive (and potentially confusing) retrospective questioning, a handful of subjects could have easily misinterpreted the confidence scale (e.g., inverting the scale) which would lead to a mixture of genuine high-confidence ratings and mistaken ratings, which would result in a super subject d' that falls between zero and the other extreme of the scale (which is exactly what the data in Fig 3e shows).

One way to check on this potential measurement error using the existing dataset would be to conduct additional analyses that incorporate the confidence ratings from the 2AFC location judgment task. For example, were there any subjects who reported being confident or highly confident that they didn't see anything, but then reported being confident or highly confident in judging the location of the thing they didn't see? If so, how many? In other words, how internally (in)consistent were subjects' confidence ratings across the IB and location

questions? Such an analysis could help screen-out subjects who made a mistake on the first question and corrected themselves on the second, as well as subjects who weren't reading the questions carefully enough. As far as I could tell, the confidence rating data from the 2AFC location task were not reported anywhere in the main paper or supplement.

(5) In most (if not all) IB experiments in the literature, a partial attention and/or full attention trial (or set of trials) is administered after the critical trial. These control trials are very important for validating IB on the critical trial, as they must show that, when attended, the critical stimuli are very easy to see. If a subject cannot detect the critical stimulus on the control trial, one cannot conclude that they were inattentionally blind on the critical trial, e.g., perhaps the stimulus was just too difficult to see (e.g., too weak, too brief, too far in the periphery, too crowded by distractor stimuli, etc.), or perhaps they weren't paying enough attention overall or failed to follow instructions. In the aggregate data, rates of noticing the stimuli should increase substantially from the critical trial to the control trials. If noticing rates are equivalent on the critical and control trials one cannot conclude that attention was manipulated.

It is puzzling why the authors decided not to include any control trials with partial or full attention in their five experiments, especially given their online data collection procedures where stimulus size, intensity, eccentricity, etc. were uncontrolled and variable across subjects. Including such trials could have actually helped them achieve their goal of challenging the IB hypothesis, e.g., excluding subjects who failed to see the stimulus on the control trials might have reduced the inattentional blindness rates further. This design decision should at least be acknowledged and justified (or noted as a limitation) in a revision of this paper.

(6) In the discussion section, the authors devote a short paragraph to considering an alternative explanation of their non-zero d' results in their super subject analyses: perhaps the critical stimuli were processed unconsciously and left a trace such that when later forced to guess a feature of the stimuli, subjects were able to draw upon this unconscious trace to guide their 2AFC decision. In the subsequent paragraph, the authors relate these results to above-chance forced-choice guessing in blindsight subjects, but reject the analogy based on claims of parsimony.

First, the authors dismiss the comparison of IB and blindsight too quickly. In particular, the results from experiment 3, in which some subjects adamantly (confidently) deny seeing the critical stimulus but guess a feature at above-chance levels (at least at the super subject level and assuming the online subjects interpreted and used the confidence scale correctly), seem highly analogous to blindsight. Importantly, the analogy is strengthened if the subjects who were confident in not seeing anything also reported not being confident in their forced-choice judgments, but as mentioned above this data was not reported.

Second, the authors fail to mention an even more straightforward explanation of these results, which is that ~8% of subjects misinterpreted the "unusual" part of the standard IB question used in experiments 1-3. After all, colored lines and shapes are pretty "usual" for psychology experiments and were present in the distractor stimuli everyone attended to. It seems quite reasonable that some subjects answered this first question, "no, I didn't see anything unusual", but then when told that there was a critical stimulus and asked to judge one of its features, adjusted their response by reconsidering, "oh, ok, if that's the unusual thing you were asking about, of course I saw that extra line flash on the left of the screen". This seems like a more parsimonious alternative compared to either of the two interpretations considered by the authors: (1) IB does not exist, (2) super-subject d' is driven by unconscious processing. Why not also consider: (3) a small percentage of subjects misinterpreted the Y/N question about noticing something unusual. In experiments 4-5, they dropped the term "unusual" but do not analyze whether this made a difference nor do they

report enough of the data (subject numbers for the Y/N question and 2AFC) for readers to determine if this helped reduce the ~8% overestimate of IB rates.

(7) The authors use sub-optimal questioning procedures to challenge the existence of the phenomenon this questioning is intended to demonstrate. A more neutral interpretation of this study is that it is a critique on methods in IB research, not a critique on IB as a manipulation or phenomenon. The authors neglect to mention the dozens of modern IB experiments that have improved upon the simple Y/N IB questioning methods. For example, in Michael Cohen's IB experiments (e.g., Cohen et al., 2011; Cohen et al., 2020; Cohen et al., 2021), he uses a carefully crafted set of probing questions to conservatively ensure that subjects who happened to notice the critical stimuli have every possible opportunity to report seeing them. In other experiments (e.g., Hirschhorn et al., 2024; Pitts et al., 2012), researchers not only ask the Y/N question but then follow this up by presenting examples of the critical stimuli so subjects can see exactly what they are being asked about (recognition-style instead of free recall, which is more sensitive). These follow-up questions include foil stimuli that were never presented (similar to the stimulus-absent trials here), and ask for confidence ratings of all stimuli. Conservative, pre-defined exclusion criteria are employed to improve the accuracy of their IB-rate estimates. In these and other studies, researchers are very cautious about trusting what subjects report seeing, and in all cases, still find substantial IB rates, even to highly salient stimuli. The authors should consider at least mentioning these improved methods, and perhaps consider using some of them in their future experiments.

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Reviewer #2 (Public review):

In this study, Nartker et al. examine how much observers are conscious of using variations of classic inattentional blindness studies. The key idea is that rather than simply asking observers if they noticed a critical object with one yes/no question, the authors also ask follow-up questions to determine if observers are aware of more than the yes/no questions suggest. Specifically, by having observers make forced choice guesses about the critical object, the authors find that many observers who initially said "no" they did not see the object can still "guess" above chance about the critical object's location, color, etc. Thus, the authors claim, that prior claims of inattentional blindness are mistaken and that using such simple methods has led numerous researchers to overestimate how little observers see in the world. To quote the authors themselves, these results imply that "inattentionally blind subjects consciously perceive these stimuli after all... they show sensitivity to IB stimuli because they can see them."

Before getting to a few issues I have with the paper, I do want to make sure to explicitly compliment the researchers for many aspects of their work. Getting massive amounts of data, using signal detection measures, and the novel use of a "super subject" are all important contributions to the literature that I hope are employed more in the future.

Main point 1: My primary issue with this work is that I believe the authors are misrepresenting the way people often perform inattentional blindness studies. In effect, the authors are saying, "People do the studies 'incorrectly' and report that people see very little. We perform the studies 'correctly' and report that people see much more than previously thought." But the way previous studies are conducted is not accurately described in this paper. The authors describe previous studies as follows on page 3:

"Crucially, however, this interpretation of IB and the many implications that follow from it rest on a measure that psychophysics has long recognized to be problematic: simply asking participants whether they noticed anything unusual. In IB studies, awareness of the unexpected stimulus (the novel shape, the parading gorilla, etc.) is retroactively probed with

a yes/no question, standardly, "Did you notice anything unusual on the last trial which wasn't there on previous trials?". Any subject who answers "no" is assumed not to have any awareness of the unexpected stimulus.

If this quote were true, the authors would have a point. Unfortunately, I do not believe it is true. This is simply not how many inattentional blindness studies are run. Some of the most famous studies in the inattentional blindness literature do not simply as observes a yes/no question (e.g., the invisible gorilla (Simons et al. 1999), the classic door study where the person changes (Simons and Levin, 1998), the study where observers do not notice a fight happening a few feet from them (Chabris et al., 2011). Instead, these papers consistently ask a series of follow-up questions and even tell the observers what just occurred to confirm that observers did not notice that critical event (e.g., "If I were to tell you we just did XYZ, did you notice that?"). In fact, after a brief search on Google Scholar, I was able to relatively quickly find over a dozen papers that do not just use a yes/no procedure, and instead as a series of multiple questions to determine if someone is inattentionally blind. In no particular order some papers (full disclosure: including my own):

(1) Most et al. (2005) Psych Review
(2) Drew et al. (2013) Psych Science
(3) Drew et al. (2016) Journal of Vision
(4) Simons et al. (1999) Perception
(5) Simons and Levin (1998) Perception
(6) Chabris et al. (2011) iPerception
(7) Ward & Scholl (2015) Psych Bulletin and Review
(8) Most et al. (2001) Psych Science
(9) Todd & Marois (2005) Psych Science
(10) Fougnie & Marois (2007) Psych Bulletin and Review
(11) New and German (2015) Evolution and Human Behaviour
(12) Jackson-Nielsen (2017) Consciousness and cognition
(13) Mack et al. (2016) Consciousness and cognition
(14) Devue et al. (2009) Perception
(15) Memmert (2014) Cognitive Development
(16) Moore & Egeth (1997) JEP:HPP
(17) Cohen et al. (2020) Proc Natl Acad Sci
(18). Cohen et al. (2011) Psych Science

This is a critical point. The authors' key idea is that when you ask more than just a simple yes/no question, you find that other studies have overestimated the effects of inattentional blindness. But none of the studies listed above only asked simple yes/no questions. Thus, I believe the authors are mis-representing the field. Moreover, many of the studies that do much more than ask a simple yes/no question are cited by the authors themselves! Furthermore, as far as I can tell, the authors believe that if researchers do these extra steps and ask more follow-ups, then the results are valid. But since so many of these prior studies do those extra steps, I am not exactly sure what is being criticized.

To make sure this point is clear, I'd like to use a paper of mine as an example. In this study (Cohen et al., 2020, Proc Natl Acad Sci USA) we used gaze-contingent virtual reality to examine how much color people see in the world. On the critical trial, the part of the scene they fixated on was in color, but the periphery was entirely in black and white. As soon as the trial ended, we asked participants a series of questions to determine what they noticed. The list of questions included:

(1) "Did you notice anything strange or different about that last trial?"
(2) "If I were to tell you that we did something odd on the last trial, would you have a guess as to what we did?"
(3) "If I were to tell you we did something different in the second half of the last trial, would

you have a guess as to what we did?"
(4) "Did you notice anything different about the colors in the last scene?"
(5) We then showed observers the previous trial again and drew their attention to the effect and confirmed that they did not notice that previously.
In a situation like this, when the observers are asked so many questions, do the authors believe that "the inattentionally blind can see after all?" I believe they would not say that and the reason they would not say that is because of the follow-up questions after the initial yes/no question. But since so many previous studies use similar follow-up questions, I do not think you can state that the field is broadly overestimating inattentional blindness. This is why it seems to me to be a bit of a straw-man: most people do not just use the yes/no method.

Main point 2: Let's imagine for a second that every study did just ask a yes/no question and then would stop. So, the criticism the authors are bringing up is valid (even though I believe it is not). I am not entirely sure that above chance performance on a forced choice task proves that the inattentionally blind can see after all. Could it just be a form of subliminal priming? Could there be a significant number of participants who basically would say something like, "No I did not see anything, and I feel like I am just guessing, but if you want me to say whether the thing was to the left or right, I will just 100% guess"? I know the literature on priming from things like change and inattentional blindness is a bit unclear, but this seems like maybe what is going on. In fact, maybe the authors are getting some of the best priming from inattentional blindness because of their large sample size, which previous studies do not use.
I'm curious how the authors would relate their studies to masked priming. In masked priming studies, observers say the did not see the target (like in this study) but still are above chance when forced to guess (like in this study). Do the researchers here think that that is evidence of "masked stimuli are truly seen" even if a participant openly says they are guessing?

Main point 3: My last question is about how the authors interpret a variety of inattentional blindness findings. Previous work has found that observers fail to notice a gorilla in a CT scan (Drew et al., 2013), a fight occurring right in front of them (Chabris et al., 2011), a plane on a runway that pilots crash into (Haines, 1991), and so forth. In a situation like this, do the authors believe that many participants are truly aware of these items but simply failed to answer a yes/no question correctly? For example, imagine the researchers made participants choose if the gorilla was in the left or right lung and some participants who initially said they did not notice the gorilla were still able to correctly say if it was in the left or right lung. Would the authors claim "that participant actually did see the gorilla in the lung"? I ask because it is difficult to understand what it means to be aware of something as salient as a gorilla in a CT scan, but say "no" you didn't notice it when asked a yes/no question. What does it mean to be aware of such important, ecologically relevant stimuli, but not act in response to them and openly say "no" you did not notice them?

Overall: I believe there are many aspects of this set of studies that are innovative and I hope the methods will be used more broadly in the literature. However, I believe the authors misrepresent the field and overstate what can be interpreted from their results. While I am sure there are cases where more nuanced questions might reveal inattentional blindness is somewhat overestimated, claims like "the inattentionally blind can see after all" or "Inattentionally blind subjects consciously perceive thest stimuli after all" seem to be incorrect (or at least not at all proven by this data).

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Reviewer #3 (Public review):

Summary:

Authors try to challenge the mainstream scientific as well as popularly held view that Inattentional Blindness (IB) signifies subjects having no conscious awareness of what they report not seeing (after being exposed to unexpected stimuli). They show that even when subjects indicate NOT having seen the unexpected stimulus, they are at above chance level for reporting features such as location, color or movement of these stimuli. Also, they show that 'not seen' responses are in part due to a conservative bias of subjects, i.e. they tend to say no more than yes, regardless of actual visibility. Their conclusion is that IB may not (always) be blindness, but possibly amnesia, uncertainty etc.

Strengths:

A huge pool of (25.000) subjects is used. They perform several versions of the IB experiments, both with briefly presented stimuli (as the classic Mack and Rock paradigm), as well as with prolonged stimuli moving over the screen for 5 seconds (a bit like the famous gorilla version), and all these versions show similar results, pointing in the same direction: above chance detection of unseen features, as well as conservative bias towards saying not seen.

Weaknesses:

Results are all significant but effects are not very strong, typically a bit above chance. Also, it is unclear what to compare these effects to, as there are no control experiments showing what performance would have been in a dual task version where subjects have to also report features etc for stimuli that they know will appear in some trials

There are quite some studies showing that during IB, neural processing of visual stimuli continues up to high visual levels, for example, Vandenbroucke et al 2014 doi:10.1162/jocn_a_00530 showed preserved processing of perceptual inference (i.e. seeing a kanizsa illusion) during IB. Scholte et al 2006 doi: 10.1016/j.brainres.2005.10.051 showed preserved scene segmentation signals during IB. Compared to the strength of these neural signatures, the reported effects may be considered not all that surprising, or even weak.

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