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OBSERVATION

Not Quite So Blind: Semantic Processing Despite Inattentional Blindness

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We often fail to detect clearly visible, yet unexpected objects when our attention is otherwise engaged, a phenomenon widely known as inattentional blindness. The potentially devastating consequences and the mediators of such failures of awareness have been studied extensively. Surprisingly, however, hardly anything is known about whether and how we process the objects that go unnoticed during inattentional blindness. In 2 experiments, we demonstrate that the meaning of objects undetected due to inattentional blindness interferes with the classification of attended stimuli. Responses were significantly slower when the semantic content of an undetected stimulus contradicted that of the attended, to-be-judged object. We thus clarify the depth of the "blindness" caused by inattention, as we provide compelling evidence that failing to detect the unexpected does not preclude its processing, even at postperceptual stages. Despite inattentional blindness, our mind obviously still has access to something as refined as meaning.

Keywords: inattentional blindness, semantic processing, attention

We often remain unaware of clearly visible stimuli simply because these appear unexpectedly and outside our attentional focus. Real-world occurrences of such inattentional blindness (Mack & Rock, 1998; Most et al., 2001) can have devastating consequences; for example, when pilots collide with a plane on the runway (Haines, 1991) or radiologists overlook massive anomalies in CT scans (Drew, Võ, & Wolfe, 2013). While we have developed a somewhat comprehensive understanding of the factors that determine whether or not inattentional blindness occurs (see, e.g., Downing, Bray, Rogers, & Childs, 2004; Seegmiller, Watson, & Strayer, 2011), surprisingly little is known about the fate of a stimulus that remains undetected due to inattentional blindness. Even if we fail to detect such a stimulus, we might still process it to a certain degree (Mack & Rock, 1998). Indeed, objects that remain fully undetected during inattentional blindness are presumably processed perceptually (Mack & Rock, 1998; Pitts, Martínez, & Hillyard, 2012). What remains controversial, however, is whether these objects are also processed at higher levels, for example, semantically (Koivisto & Revonsuo, 2007; Lathrop, Bridgeman, & Tseng, 2011; Mack & Rock, 1998). In fact, no direct and reliable evidence in favor of this notion has ever been provided. Therefore, in the present study, we tested whether the semantic content of objects unnoticed due to inattentional blindness is processed. During a simple categorization task, unexpected objects whose content was either congruent or incongruent with the currently to-be-categorized object appeared. We hypothesized that incongruent undetected stimuli should interfere with classification, thus slowing down responses. This would strongly suggest that while we fail to detect unexpected objects or events, the mind still has access to something as refined as their meaning.

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Experiment 1

Method

Experiment 1 was registered on the Open Science Framework prior to data collection. Hypotheses, procedure, sample size, exclusion criteria, data preparation, and analyses were specified in advance and are available online along with the data https://osf.io/x6qkb.

Participants. On the basis of pilot testing ($N = 45$), we expected a small-to-medium effect for the difference between incongruent and congruent/neutral trials ($d_z = 0.4$). Using the software G*Power 3.1.6 (Faul, Erdfelder, Lang, & Buchner, 2007), we ascertained that a sample of 80 participants would yield a power $(1 - \beta) > .97$ for an effect of this size. Assuming that several participants would have to be excluded from analysis (which is typically necessary in inattentional blindness studies), this sample size guaranteed that a power $> .92$ would be achieved even if up to 25% of all participants would have to be excluded. Eighty participants were recruited for the experiment and partly excluded from analysis on the basis of predefined criteria: technical error (1), impaired vision (1), suspicions regarding the aim of the study (1), noticing the unexpected objects in the experimental trials (5), or inadequate performance—less than 80% correct responses—in the control trials (11). The remaining sample comprised 61 participants ($M_{age} = 23.3$ years, $SD_{age} = 5.5$; 49 female).

Materials and procedure. Participants gave written informed consent and were seated at a distance of approximately 50 cm in front of a 23-inch display. All instructions were presented onscreen. Upon completion of the task, participants filled out a questionnaire collecting demographics, anticipation of the unexpected object, and general knowledge about inattentional blindness. Finally, participants were debriefed.

The task was loosely based on paradigms previously introduced by Pitts et al. (2012) and Dehaene and colleagues (1998). Each trial consisted of three phases: the waiting phase, the cueing phase, and the target phase. Throughout the entire trial, participants continuously fixated on a small red cross centered on the display. This cross was surrounded by 118 black characters that were arranged as a rectangle (width: 6.6° visual angle; height: 5°) consisting of seven rows with 17 characters each. The red cross occupied the centermost position of this rectangular character array. Surrounding the rectangular array, eight black hash symbols (#) were arranged equally spaced on an imaginary circle with a diameter of 11°. In the *waiting phase* (random duration between 1,000 and 3,000 ms), each character of the array was chosen at random to be a W, an X, or a Y. In the subsequent *cueing phase*, one of the peripheral hashes, selected at random, turned red for 300 ms. Simultaneously, each character of the array was newly filled at random with a W, an X, or a Y. In the final *target phase* (see Figure 1a), the hash that had previously turned red was now replaced by a black numeral (randomly drawn from 1, 2, 3, 4, 6, 7, 8, 9). Simultaneously, the characters of the array were again drawn randomly for each of the 118 positions. Crucially, in some trials, some of the characters were not drawn randomly in the target phase, but systematically filled with numerals instead of letters (see below). In the target phase, the display turned blank after 300 ms. After 2,000 ms (from the beginning of the target phase) or upon participants' response, the trial was terminated and the next commenced with the waiting phase.

Participants categorized the target numeral (i.e., the numeral replacing one of the hashes in the target phase) as smaller than 5 (left hand) or greater than 5 (right hand) by button press. They were instructed that the red hash cued the location of the target numeral with a validity of 100% and that they should respond as quickly, but also as accurately as possible. Also, they were informed that the character array surrounding the red cross always contained letters that were irrelevant to the task at hand.

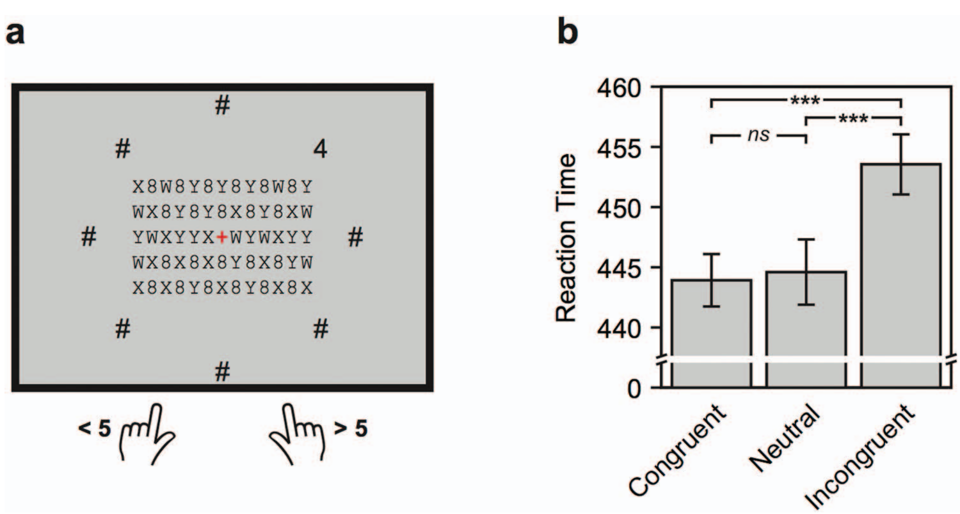

Figure 1. Overview of the experimental task and the results of Experiment 1. (a) Schematic illustration of the critical moment during each trial. Participants categorized the single peripheral numeral as smaller or greater than 5 as quickly as possible. Crucially, the seemingly irrelevant central distractor array contained only letters (neutral condition); multiple instances of a numeral matching the category of the peripheral, to-be-judged numeral (congruent condition); or multiple instances of a numeral pertaining to the opposite category (incongruent condition). The latter condition is displayed above. Note that the image is for illustration purposes only; details have been simplified and are not drawn to scale. The distractor field contained seven rows of 17 characters each. (b) Mean median reaction times for the three experimental conditions in Experiment 1. Error bars depict the 95% Cousineau–Morey confidence interval for repeated measures (Cousineau, 2005; Morey, 2008). *** $p \leq .001$; *ns* = not significant. See the online article for the color version of this figure.

Participants first completed a block of 20 practice trials, after which they received feedback (percentage of correct responses and average response time). If they failed to categorize at least 17 target numerals correctly, they had to repeat this block. Subsequently, participants performed a total of 150 experimental trials. In neutral trials (50), the character array surrounding the fixation cross contained only letters (all W, X, or Y). In congruent and incongruent trials (50 each), during the target phase of the trial, 38 positions within the character array were unexpectedly filled with the same numeral. In congruent trials, the unexpected numeral matched the category of the target numeral (smaller vs. greater than 5). In half of these cases, the unexpected numeral was identical to the target numeral, whereas in the other half, they merely pertained to the same category. In incongruent trials, the unexpected numeral always pertained to the category opposing the target numeral. Trials from the three conditions were presented in randomized order.

Upon completion of the experimental trials, participants were asked whether they had noticed anything other than Ws, Xs, and Ys in the character array during any of the trials. If they answered in the affirmative, they were asked to describe what they had seen in detail and to indicate in how many trials they had seen it. Participants who indicated that they had noticed something other than letters within the character array and, in the open follow-up questions, reported seeing numerals (at least once during the experiment) were excluded from all further analyses.

A final set of 20 control trials (full-attention trials) was identical to the experimental trials, except that numerals appeared among the letters of the character array in each trial. Participants did not have to categorize the peripheral numerals any more. They were instructed to continuously fixate on the middle of the screen just as before, but to openly attend to the whole display. After each trial, they were asked to enter the exact numeral that had been presented within the central character array. We excluded participants from analysis if they answered incorrectly in more than 3 of the 20 control trials. If someone does not detect the additional stimulation under conditions of full attention (i.e., when attention is not diverted to another task), they might have basal visual problems or might not have followed task instructions. Thus, if someone does not spot the clearly visible, attended numerals in the control trials, they cannot be interpreted as being inattentionally blind to these numerals when they were unexpected during the experimental trials.

Data analysis. For analyses of variance (ANOVAs), generalized eta-squared (η^2_G) is reported as a measure of effect size (Bakeman, 2005; Olejnik & Algina, 2003). For *t* tests, we computed effect size d_z (Equation 8 in the work of Morris & DeShon, 2002). In case of directed hypotheses for pairwise comparisons, one-tailed *p* values are reported. The 95% confidence intervals of the mean for repeated measures were computed according to Cousineau (2005) and Morey (2008) using R code provided by Baguley (2012).

Results and Discussion

First, it is noteworthy that a large proportion of participants did not notice the unexpected numerals spontaneously (92%), even though these were presented 100 times. This robustness of inattentional blindness in the present paradigm corroborates the assertion that observers are particularly likely to miss unexpected events that occur in an area that is currently actively inhibited (Mack & Rock, 1998; Thakral & Slotnick, 2010).

A repeated-measures ANOVA with median reaction time (RT) in correct trials as dependent variable and condition (congruent vs. neutral vs. incongruent) as independent variable revealed a significant main effect, $F(2, 120) = 8.69$, $p < .001$, $\eta^2_G = .01$ (see Figure 1b). As hypothesized, RT was significantly higher in the incongruent condition than in the congruent condition, $t(60) = 4.16$, $p < .001$, $d_z = 0.54$, and the neutral condition, $t(60) = 3.15$, $p = .001$, $d_z = 0.43$. No difference was observed between the congruent and the neutral conditions, $t(60) = 0.27$, $p = .791$, $d_z = 0.04$. Furthermore, there was no significant difference between congruent trials in which the unexpected numeral was identical to the target numeral and those in which it only matched its category, $t(60) = 0.69$, $p = .496$, $d_z = 0.09$. Response accuracy was at a high level ($>$ 90% overall) and did not vary with condition ($p = .384$). Thus, there was no speed–accuracy trade-off.

The results of Experiment 1 confirmed our expectation that stimuli that remained undetected due to inattentional blindness would affect responses to simultaneously occurring attended objects. We did not find evidence that this effect was based on perceptual incongruency: If the interference caused by an unexpected numeral from the incongruent category was merely due to its perceptual deviance from the target, then unexpected stimuli that are congruent in terms of category, yet perceptually different from the attended stimuli should likewise slow categorizations. However, responses were equally fast when the unexpected numerals were identical to the target (perceptual congruency) or only matched its category (perceptual incongruency). Thus, our findings presumably reflect the influence of higher-level, postperceptual features of the undetected stimuli.

The observed effect might, however, be based on sensorimotor associations, rather than on the content of the unseen stimuli (Damian, 2001; Kouider & Dehaene, 2009). Because of repeated responses to the numerals in the course of the experiment, specific percepts (e.g., all numerals below 5) could be directly coupled with a specific response (e.g., left hand), bypassing any semantic analysis. Thus, interference effects could rely upon the conflict of incompatible motor activations induced by perceptual cues of the attended (peripheral) and unexpected (central) numerals. To scrutinize this alternative explanation, we tested whether the incongruency effect was still observed when sensorimotor associations between the unexpected numerals and the manual responses could not develop. Participants categorized words indicating numbers (e.g., "EIGHT"), while unexpected numerals appeared simultaneously.

Experiment 2

Method

An independent sample of 80 participants was run. Three participants were excluded due to anticipation, four noticed the unexpected objects in the experimental trials, and 15 did not perform adequately in the control trials, yielding a remaining sample of 58 participants ($M_{age} = 23.3$ years, $SD_{age} = 3.5$; 46 female). The experimental protocol of Experiment 2 was identical to that of Experiment 1 except that in the experimental trials, number words in capital letters were presented as peripheral targets (see Figure 2a). Also, we slightly increased the number of trials to 64 per condition and counterbalanced the assignment of responses to hands across participants.

Results and Discussion

Again, the proportion of participants who were inattentionally blind to the critical numerals was very high (94%). Importantly, we observed a significant main effect of condition on median RT, $F(2, 114) = 4.37$, $p = .015$, $\eta^2_G = .01$ (see Figure 2b). This effect was not further modulated by response mapping ($p = .891$). As hypothesized, RT was significantly higher in the incongruent condition as compared to the congruent condition, $t(57) = 2.53$, $p = .007$, $d_z = 0.33$, and the neutral condition, $t(57) = 2.68$, $p = .005$, $d_z = 0.36$. No difference was observed between the congruent and the neutral conditions, $t(57) = 0.41$, $p = .686$, $d_z = 0.06$. Response accuracy (> 90% overall) did not vary with condition ($p = .087$). Notably, there was a trend toward less accurate responses in incongruent trials. Thus, there was no speed–accuracy trade-off.

In Experiment 2, we replicated the exact pattern of results obtained in Experiment 1, although the effect was slightly smaller. Crucially, as the unexpected numerals were never shown as attended targets and never consciously perceived, participants could not develop associations between these unexpected stimuli and the manual responses. Thus, the observed modulation of response speed could not have relied on sensorimotor associations (Naccache & Dehaene, 2001).

General Discussion

We show that the speed of categorizations was affected by simultaneously occurring, unexpected objects that remained undetected when participants' attentional focus was shifted elsewhere. Although the observed effect was small in size, it was robust and replicable. Moreover, it was not solely carried by sensorimotor associations, but rather based on the semantic mismatch between currently attended and unnoticed stimuli. This finding can only be explained by assuming that the mental representation of objects missed during inattentional blindness goes beyond perceptual analysis and extends to the level of meaning.

Classification of numerals (Experiment 1) and number words (Experiment 2) was slower when they were incongruent with unexpected stimuli, while congruent information did not speed up responses. We predicted this precise pattern, as it is straightforward that competing stimulation creates interference, while congruent stimulation provides only redundant evidence of the target's evident category. Importantly, the unexpected stimuli did not precede the targets, such that congruent numerals could not preactivate the correct response, which might have accelerated participants' reactions. And even if congruent stimulation precedes numeric categorizations, this does not necessarily speed up responses (Naccache & Dehaene, 2001).

The present findings are in keeping with previous studies indicating that semantic processing is neither contingent upon awareness (e.g., Dehaene et al., 1998; Lin & Murray, 2014) nor upon attention (e.g., Rolke, Heil, Streb, & Hennighausen, 2001). However, they constitute a novel contribution to our understanding of the prerequisites of higher-level representations, as we clarify that ecologically valid failures of awareness, induced by distraction and unexpectedness, do not preclude advanced, semantic processing. This extension of the literature is particularly valuable as different occurrences of unconsciousness need not necessarily entail the same principles of processing (Kiefer et al., 2011).

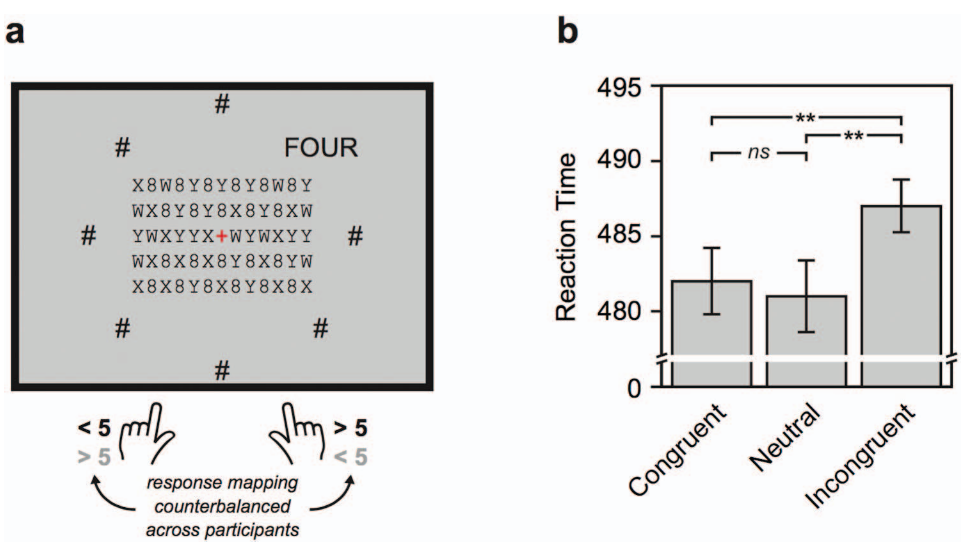

Figure 2. Overview of the experimental task and the results of Experiment 2. (a) Schematic illustration of the critical moment during incongruent trials. In this experiment, participants categorized words as describing numbers smaller or greater than 5. Note that the assignment of responses to hands was now counterbalanced across participants. (b) Mean median reaction times for the three experimental conditions in Experiment 2. Error bars depict the 95% Cousineau–Morey confidence interval for repeated measures (Cousineau, 2005; Morey, 2008). ** $p < .01$; *ns* = not significant. See the online article for the color version of this figure.

Finally, our data advance contemporary theorizing on inattentional blindness, in that we conclusively illuminate the nature of this state. Previous work suggests that inattentional blindness is characterized by the absence of conscious perception accompanied by a low-level extraction of sensory information (Lathrop et al., 2011; Mack & Rock, 1998; Pitts et al., 2012). We do, however, suggest that it is primarily a failure of declarative awareness that does not eliminate advanced cognitive analysis of what remains unseen.

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