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Brief article

Implicit semantic perception in object substitution masking

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ABSTRACT

Decades of research on visual perception has uncovered many phenomena, such as binocular rivalry, backward masking, and the attentional blink, that reflect 'failures of consciousness'. Although stimuli do not reach awareness in these paradigms, there is evidence that they nevertheless undergo semantic processing. Object substitution masking (OSM), however, appears to be the exception to this rule. In OSM, a temporally-trailing four-dot mask interferes with target perception, even though it has different contours from and does not spatially overlap with the target. Previous research suggests that OSM has an early locus, blocking the extraction of semantic information. Here, we refute this claim, showing implicit semantic perception in OSM using a target-mask priming paradigm. We conclude that semantic information suppressed via OSM can nevertheless guide behavior.

1. Introduction

In any given instance, we are only aware of a fraction of the total information available in the environment. To what extent does our visual system represent stimuli that we are not aware of? This is a long-standing and fundamental question for psychology and neuroscience that sheds light on the process of selection and on how information represented outside awareness can implicitly guide behavior (Koch, 2004).

In the laboratory, numerous paradigms reflect failures of consciousness including binocular rivalry, crowding, backward pattern masking, and the attentional blink (Kim & Blake, 2005). In each case, however, the brain extracts semantic meaning from unconscious[1] stimuli (Costello, Jiang, Baartman, McGlennen, & He, 2009; Huckauf, Knops, Nuerk, & Willmes, 2008; Luck, Vogel, & Shapiro, 1996; Shelley-Tremblay & Mack, 1999; van den Bussche, Notebaert, & Reynvoet, 2009). Sharply contrasting with this pattern are results from a recently discovered phenomenon, object substitution masking (OSM), in which a temporally-trailing four-dot mask interferes with target perception, even though the target and mask have dissimilar contours and do not spatially overlap (Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997). Existing evidence suggests only pre-categorical featural information is registered from a non-reported target in OSM. For example, the N2pc, an electrophysiological component that reflects target feature processing (Kiss, Van Velzen, & Eimer, 2008), survives OSM (Woodman & Luck, 2003), whereas the N400 component, a signature of semantic processing (Kutas & Hillyard, 1980), does not (Reiss & Hoffman, 2006). Similarly, Chen and Treisman (2009) obtained implicit priming for a mask judgment from missed targets when the target and mask were related featurally (such as arrows pointing in the same vs. different direction), but not when the target and mask were related semantically (both a consonant/vowel vs. not).

Although the absence of high-level target processing in OSM seems to distinguish it from other methods of manipulating awareness, there are reasons to believe that the fate of missed targets in OSM requires re-examination. First, several findings suggest OSM has a later locus of suppression than binocular rivalry and crowding (Breitmeyer, Koc, Ogmen, & Ziegler, 2008; Chakravarthi & Cavanagh,

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[1] Here we use the terms 'unconscious' and 'implicit' interchangeably to refer to stimuli that are incorrectly identified or go undetected on an objective forced-choice metric of target identity or presence.

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2009), both of which permit semantic analysis of suppressed information. Second, although Reiss and Hoffman (2006) found OSM abolished the N400, they also obtained a semantic congruency effect: accuracy was greater when the context and target words were semantically related. While the authors attributed this congruency effect to a guessing bias, it hints at implicit semantic processing in OSM. Finally, Chen and Treisman (2009) manipulated semantic congruency by varying whether targets and masks were either vowels or consonants – a relatively infrequent semantic categorization that may have blunted congruency effects. In light of these apparent inconsistencies, we investigated whether semantic processing occurs in OSM by employing a priming manipulation based on the Stroop effect, which reflects automatic reading of words (MacLeod, 1991), and an OSM paradigm modelled on Chen and Treisman's (2009) design.

2. Experiment 1

2.1. Method

Targets were words ('BLUE', 'PINK', 'MAIL', or 'HOUR'), or non-word character strings ('JQCG' or 'AWHF'), subtending $\sim 1.53 \times 0.46^\circ$ of visual angle, that occurred equiprobably and were chosen randomly on each trial. The mask consisted of four coloured dots that were randomly selected to be either pink or blue ($\sim 0.31 \times 0.31^\circ$; matched for luminance, 33.40 cd/m^2). On each trial, a target and eight distractor stimuli [hash symbol strings ('####')] were presented at positions defined by a notional 3×3 matrix ($\sim 9.83 \times 9.83^\circ$) against a white background (Fig. 1a). Trials were defined as 'compatible' when the colour of the mask matched the target word (e.g., pink mask, and 'PINK' target), 'neutral' when the target was a non-colour word (e.g., 'MAIL'), and 'incompatible' when the colour of the mask conflicted with the target (e.g., pink mask, and 'BLUE' target).

Trials began with a central fixation cross for 500 ms, followed by a blank screen for 500 ms. The stimulus array was then displayed for 80 ms. On simultaneous offset trials, the stimulus array and mask offset together, whereas on delayed offset trials, the mask offset 200 ms after the stimulus array. Seventeen University of Queensland students gave informed written consent and made speeded responses to the mask colour (blue/pink), followed by an unspeeded lexical decision on the target (word/non-word) by pressing designated keys on a standard keyboard. Both mask-offset and target-mask compatibility trial types were randomly intermixed for a total of 720 trials.[2] Ethical approval was obtained from the School of Psychology Ethics Committee.

2.2. Results and discussion

Data from five participants were excluded: four due to target performance being at ceiling and one for having mean reaction times (RTs) exceeding two seconds. For the remaining participants, RTs shorter than 200 ms or more than two standard deviations above the mean were excluded. Mask identification accuracy averaged 93%: performance was significantly poorer in the delayed relative to the simultaneous mask-offset condition for incompatible target-mask trials, $t(11) = 7.32$, $p < .001$, $\eta_p^2 = .829$, but not for neutral or compatible target-mask trials, (see Table 1).

Target accuracy and RT scores were analysed only on word trials in which the mask was correctly identified. A two-way repeated-measures ANOVA on target accuracy revealed a significant main effect of mask duration ($F[1, 11] = 53.51$, $p < .001$, $\eta_p^2 = .829$, simultaneous = 92.3%, delayed = 74.7%), but no main effect of target-mask compatibility nor an interaction (ps > .229, η_p^2s < .126), demonstrating consistent and significant masking for all conditions. There was also significant masking for non-word targets, such that performance was poorer in delayed mask-offset trials (80%) relative to simultaneous mask-offset trials (89%), ($t[11] = 3.14$, $p = .009$, $\eta_p^2 = .473$). Since the non-words do not have a clearly defined compatibility relationship to the mask and represent the alternative response option to all the word categories, these trials do not form part of the RT priming analysis. To examine semantic processing in OSM, we performed a repeated-measures ANOVA on mask colour judgment RTs from delayed offset trials with target word identification accuracy (correct vs. incorrect) and target-mask compatibility as factors. Significant priming was observed (main effect of target-mask compatibility ($F[2, 22] = 4.33$, $p = .026$, $\eta_p^2 = .282$), however there was no main effect of target identification nor an interaction (ps > .132, η_p^2s < .194; see Fig. 1b). Specifically, RTs were faster in the compatible than incompatible condition, both when the target was correctly identified ($t[11] = 2.98$, $p = .012$, $\eta_p^2 = .447$), and when it was not ($t[11] = 2.71$, $p = .020$, $\eta_p^2 = .401$). This suggests that targets that fail to reach awareness in OSM nevertheless undergo semantic analysis, and that the extent of semantic processing does not vary with the success of target identification.

3. Experiment 2

Experiment 1 clearly shows semantic processing of stimuli that are masked via object substitution. This demonstrates, contrary to previous reports (Chen & Treisman, 2009; Reiss & Hoffman, 2006), that OSM does not prevent semantic analysis of masked target items. However, the results of Experiment 1 are equivocal as to whether the priming on incorrect target trials arose from conscious or unconscious processing. This is because both correct and incorrect target trials (implicit processing condition) showed the same pattern of priming, whereas previous studies have shown qualitatively different patterns of priming for conscious and unconscious stimuli. Specifically, Eimer and Schlaghecken (1998) demonstrated that a briefly presented arrow prime, rendered unconscious by backward pattern masking, slowed a direction judgment about a subsequent target arrow pointing in the same direction (negative compatibility effect; NCE), whereas the opposite pattern was observed for consciously-perceived (unmasked) primes.

[2] This experiment was performed as one block of a larger study. Order of block completion had no effect on performance.

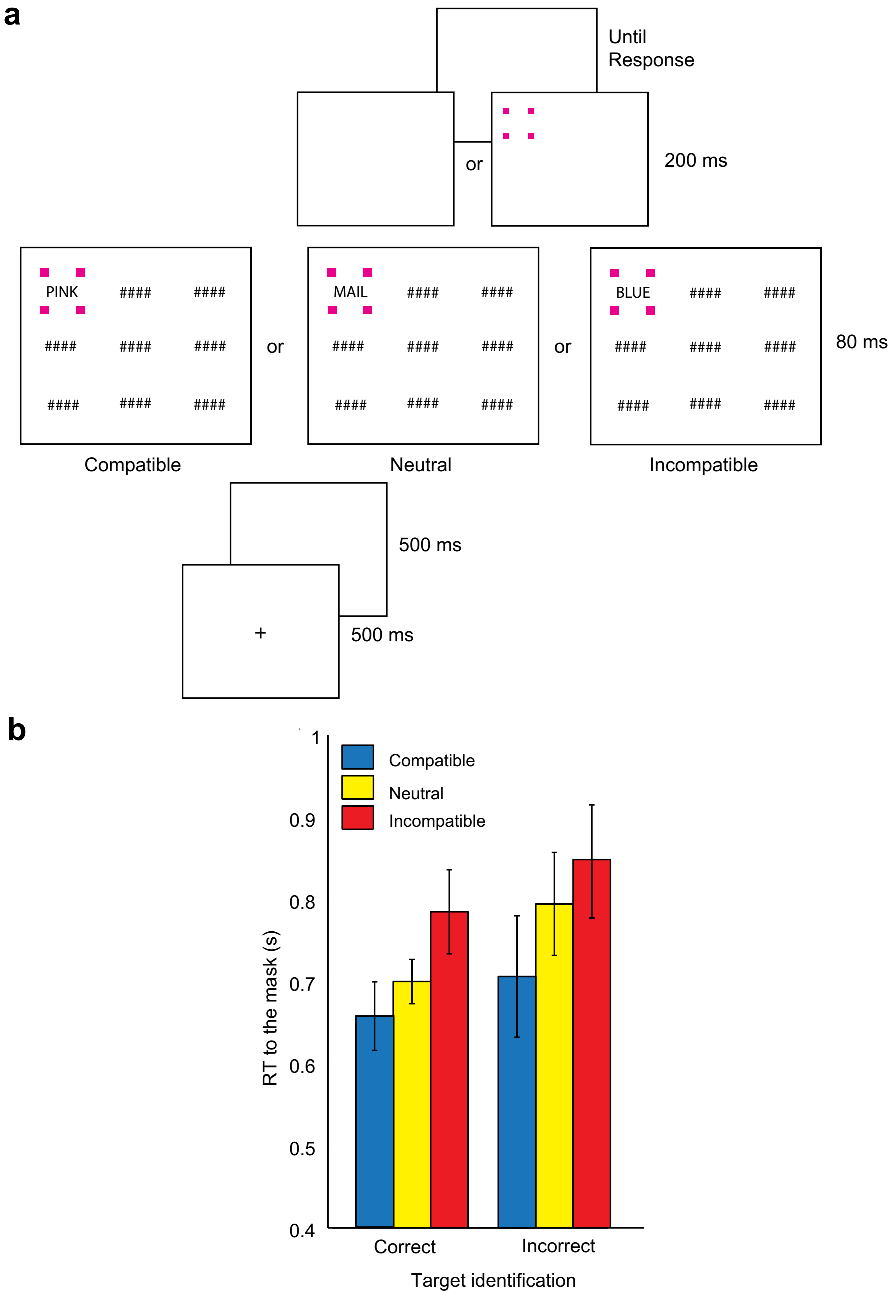

Fig. 1. (a) A schematic illustration of events on a compatible, neutral, and incompatible trial. Here, a pink mask is presented but it was equally likely to be blue. In addition, targets could also be 'HOUR', 'JQCG' or 'AWHF'. (b) Mean RT to the mask (in seconds) for compatible, neutral, and incompatible delayed mask-offset trials when the target either was or was not correctly identified. Error bars represent within participant standard error of the mean.

Table 1
Mask identification accuracy across the conditions from Experiments 1 to 2. Sim = simultaneous mask-offset; Del = delayed mask-offset; Comp = compatible target and mask relationship; Neut = neutral target and mask relationship; Incom = Incompatible target and mask relationship; Targ = Target.

	SimComp (%)	DelComp (%)	SimNeut (%)	DelNeut (%)	SimIncom (%)	DelIncom (%)	SimNon-word/ Targ absent (%)	DelNon-word / Targ absent (%)
Experiment 1	96.68	93.84	91.98	94.22	93.40	86.67	94.98	92.77
Experiment 2	95.03	95.60	95.15	96.03	94.61	94.40	91.25	91.65

To explain this finding, Eimer and Schlaghecken hypothesised that the unperceived prime initially activates its associated response option, but this selection is then suppressed to prevent interference with the target, resulting in facilitation of the response alternative for the unperceived stimulus. Extending this account to the present setup, one might expect that on an incompatible trial, if 'BLUE' is rendered unconscious by a pink mask, the response option of 'blue' should be inhibited leading to facilitation for the 'pink' response (an NCE). In contrast, on a neutral trial, the target (e.g., 'HOUR') is unrelated to either the pink or blue response options for the mask and so any suppression of 'hour'-related activation should not influence the mask judgment.

Why, then, did we not see this pattern of priming for the masked targets that were incorrectly identified in Experiment 1? One obvious possibility is because masked primes were consciously processed. However, this is not the only alternative. It is also possible that we did not find an NCE because the identity of the target was crucial for making the lexical decision judgment, and thus was unlikely to be suppressed. Finally, a third option is that stimuli that fall below a detection threshold tap qualitatively distinct processing mechanisms from those that exceed this threshold. Recall that in Experiment 1, the masking metric was target identification. Thus, error trials could reflect both detection failures and instances where the target's presence was detected, but it could not be identified. It might be the case, therefore, that a more stringent definition of awareness (failure to detection a target; see Chen & Treisman, 2009) must be used in order for an NCE to emerge on error trials. To test this, in Experiment 2 we used a more thorough test of consciousness: a detection task for the target to see if an NCE would emerge under these conditions.

3.1. Method

The stimuli and procedure were identical to Experiment 1, except for the following changes. First, all targets were words printed in grey, with a target present on half the trials. Second, we increased fixation cross exposure duration to 1500 ms to reduce potential inter-trial carryover effects. Finally, in order to increase the number of trials in each target detection condition (hits vs. misses), we decreased the target array presentation duration to 60 ms, reduced the number of distractors to eight (removing the central stimulus, where limited masking should be observed), and reduced stimulus size (targets and distractors each subtended $\sim 0.89 \times 0.38°$ of visual angle, arranged in $17.28 \times 17.28°$ notional square). Sixteen University of Queensland students made speeded responses to the mask colour (blue/pink), followed by an unspeeded target detection response (present/absent). Both mask duration and target-mask compatibility trials were randomly varied for a total of 600 trials.

3.2. Results and discussion

Data from two participants were excluded for failing to follow instructions (pressing an invalid response key on more than 50% of trials in the experiment). Mask identification accuracy averaged 95% and there were no differences between the conditions (see Table 1). A two-way repeated-measures ANOVA on target accuracy revealed a significant main effect of mask duration ($F[1, 13] = 46.22$, $p < .001$, $\eta_p^2 = .780$, simultaneous = 87.53%, delayed = 72.16%), but no main effect of target-mask compatibility nor an interaction ($ps > .150$, η_p^2s $< .136$), demonstrating significant masking for all conditions. To examine semantic processing in OSM, we performed a repeated-measures ANOVA on mean RTs from delayed offset trials with target detection accuracy (hits vs. misses) and target-mask compatibility as factors. There was no main effect of either target detection ($F < 1$) or target-mask compatibility ($F < .124$), however, there was, a significant interaction between these variables ($F[2, 26] = 4.39$, $p = .023$, $\eta_p^2 = .253$; see Fig. 2).

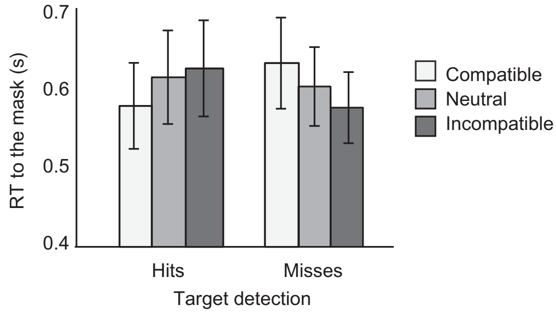

Fig. 2. Mean RT to the mask (in seconds) for compatible, neutral, and incompatible delayed mask-offset trials when the target was either detected (hits) or missed. Error bars represent within participant standard error of the mean.

Follow-up planned comparisons on correct detection trials ("hits") showed a significant priming effect, such that RTs were faster when the target and mask were compatible, relative to when the target and mask were incompatible ($t[13] = 2.21$, $p = .045$, $\eta_p^2 = .274$). More critically, on "miss" trials where the target was not detected due to OSM, there was a significant NCE, such that RTs were faster on incompatible trials than compatible trials ($t[13] = 2.56$, $p = .024$, $\eta_p^2 = .335$). The fact that any systematic priming occurred for undetected targets (i.e., the significant effect of target-mask compatibility on mask RTs on miss trials) unambiguously demonstrates that the targets were processed to the level of semantic meaning. The fact that the priming took the form of an NCE, moreover, is consistent with the previous literature which suggests that stimuli that fail to reach consciousness can produce qualitatively different priming effects to those that are explicitly registered.[3]

4. General discussion

Experiments 1 and 2 demonstrated semantic processing of stimuli masked via object substitution. In Experiment 1, where masking was assessed via a lexical decision task, the

[3] We have also replicated this pattern of results in an identical experiment.

same pattern and magnitude of semantic priming was observed when the targets were correctly identified and when they were misidentified due to OSM. In Experiment 2, using a target detection task, we found positive priming when the target was detected and a significant NCE when it was undetected (see Eimer & Schlaghecken, 1998), indicating implicit semantic processing of the target. We have applied Eimer and Schlaghecken's (1998) active inhibition account to explain the NCE observed here, however, whatever the mechanism responsible for the NCE found in Experiment 2, the results provide strong support for the hypothesis that implicit semantic processing survives OSM. If this is indeed the case, then why did previous studies fail to find evidence for this? As we outlined in the Introduction, Reiss and Hoffman's (2006) behavioral data conflict with their electrophysiological results, rendering their interpretation ambiguous. That is, while they found that the N400 waveform did not survive OSM, their behavioral data showed a significant advantage for compatible vs. incompatible masking trials. Our results, furthermore, suggest that Chen and Treisman's (2009) manipulation of semantic categorization – vowels vs. consonants – was not sufficiently powerful to obtain implicit priming. Indeed, extracting the meaning of a word is a far more practiced and intuitive categorization than deciding whether or not an isolated letter is a vowel or consonant.

A final point for consideration is whether the semantic effects obtained here would generalize to paradigms where the masking dots were task irrelevant and did not require a response. If they did not, it would suggest that the effects of target-mask compatibility obtained here reflect response-level interference, rather than high-level perceptual interference. Although this is an interesting question, for the present purpose, we are agnostic regarding it, as the presence of interference at all is evidence for implicit semantic processing of the target stimulus in OSM. That is, regardless of the level on which it is mediated, the observation of this interference necessitates that the visual system has processed the target to the level of meaning.

5. Conclusion

The present findings demonstrate that despite the profound impairment in consciousness induced by OSM, the visual information-processing system is nevertheless capable of extracting high-level information about the target. This reveals that OSM is not anomalous, but instead, is functionally related to other phenomena where physically present stimuli are not consciously perceived (e.g., binocular rivalry, backward pattern masking, and the attentional blink) but nevertheless undergo semantic analysis (Kim & Blake, 2005).

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