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# The effects of perceptual load on semantic processing under inattention

**Mika Koivisto**
*University of Turku, Turku, Finland*

**and**

**Antti Revonsuo**
*University of Turku, Turku, Finland*
*and University of Skövde, Skövde, Sweden*

*Inattentional blindness* refers to a failure to consciously detect an irrelevant object that appears without any expectation when attention is engaged with another task. The perceptual load theory predicts that task-irrelevant stimuli will reach awareness only when the primary task is of low load, which allows processing resources to spill over to processing task-irrelevant stimuli as well. We studied whether perceptual load has an effect on inattentional blindness for a task-irrelevant stimulus whose meaning is or is not relevant to the attentional goals of the observer. In the critical trial, a word appeared without any expectation in the center of a display of attended pictures. The results showed that, under both high and low load, unexpected words belonging to the attended semantic category were detected more often than semantically unrelated words. These results imply that task-irrelevant stimuli, whose meanings are relevant to the observer's task, enter awareness irrespective of perceptual load.

When do task-irrelevant stimuli intrude into awareness? According to early-selection views (Broadbent, 1958), attentional selection for further processing occurs on the basis of early sensory features, and attention can thus prevent irrelevant stimuli from entering awareness. Late-selection views (Deutsch & Deutsch, 1963) argue that attention and awareness occur after stimulus identification: Attention affects late processes after the meaning of the stimulus has been analyzed. According to the perceptual load model (Lavie, 1995, 2005), this long-standing debate can be solved by assuming that attention can prevent irrelevant stimuli from reaching awareness (early selection) when the processing of task-relevant stimuli involves a high level of perceptual load, which consumes all capacity. When the task places lower demands, any unused capacity spills over involuntarily, resulting in awareness of irrelevant stimuli (late selection). However, with few exceptions (Cartwright-Finch & Lavie, 2007), the evidence for the load theory comes from experiments in which awareness was not measured, but the facilitatory or inhibitory effects of irrelevant stimuli on processing task-relevant stimuli were. Here, we focus directly on the relationship between attentional load, the contents of attention, and awareness.

A strong connection between attention and reports of visual awareness is demonstrated by the phenomenon of *inattentional blindness* (Mack & Rock, 1998): Observers with normal vision are often functionally blind to the appearance of an unexpected, task-irrelevant object if they are at the same time performing an attention-demanding task and do not expect anything additional to appear (Becklen & Cervone, 1983; Mack & Rock, 1998). However, not all irrelevant stimuli remain undetected under inattention. Whether or not aware detection of an unexpected stimulus is reported depends on the task-relevant goals of the observer (Most, Scholl, Clifford, & Simons, 2005; Most et al., 2001; Simons, 2000). If the physical features such as the color or shape of the unexpected object are similar to those of the attended objects, the probability of detecting the unexpected object increases (Koivisto & Revonsuo, 2008; Most et al., 2005; Most et al., 2001; Simons & Chabris, 1999). In addition, some stimuli (e.g., the observer's own name, a happy face icon) seem to escape inattentional blindness and are easily detected (Mack, Pappas, Silverman, & Gay, 2002; Mack & Rock, 1998). Mack and Rock suggested that these stimuli capture attention because they have signal value and are meaningful for the observer, implying that their meaning must have been processed before they entered awareness.

Koivisto and Revonsuo (2007b) showed that an unexpected stimulus semantically relevant to the observer's goals is likely to escape inattentional blindness. They manipulated the semantic category that was attended to in such a way that it was either congruent or incongruent with the category of an unexpected stimulus presented in a different format (i.e., picture vs. word). For example, the primary task was to recognize either pictures of animals or pictures of pieces of furniture in each display. In the critical inatten-

**M. Koivisto, mika.koivisto@utu.fi**

 

tion trial, a word presented without any warning in the center of the screen was detected by 91% of the observers when it was semantically congruent with the attended category and by 41% when it was incongruent. Thus, the unexpected stimulus was detected more often when its semantic category was represented in the observer's attentional set.

The semantic congruency effect (Koivisto & Revonsuo, 2007b) and the fact that some stimuli (the observer's name and a happy face in Mack & Rock, 1998) are easily detected under inattention seem to imply that the meaning of the unexpected stimulus is analyzed preattentively—before the stimulus draws attention and is detected. This implication is consistent with the findings of priming effects produced by undetected stimuli (Mack & Rock, 1998), supporting the view that selection of the irrelevant stimulus occurs at late processing stages under inattention. According to the perceptual load model (Lavie, 2005), such late selection should occur only under low perceptual load as the capacity left over from a less demanding task spills over to the processing of irrelevant stimuli. In line with this view, Cartwright-Finch and Lavie (2007) showed that detection of an irrelevant stimulus under inattention is more likely to occur under low than under high perceptual load.

We studied whether perceptual load has an influence on awareness of a task-irrelevant stimulus whose meaning is or is not relevant to the goals of the observer. The perceptual load model (Lavie, 1995) predicts that by increasing perceptual load, the effect of semantic relevance on detection of the irrelevant stimulus (Koivisto & Revonsuo, 2007b) should be decreased, because there is less capacity to spill over to processing the meaning of the stimulus; there should be less or no semantic processing of the stimulus. The alternative hypothesis of genuine automatic processing of the meaning, by contrast, assumes that there is no need for the spilling over of capacity from the task-relevant stimuli to semantic processing of the unexpected stimulus. Therefore, the meaning of a semantically relevant stimulus will capture attention, and it will more likely be detected than a semantically irrelevant stimulus independent of the level of perceptual load. These two opposing hypotheses were tested by varying the perceptual load (number of stimuli) in the primary task, which required the observers to recognize pictures from the prespecified, attended category and by varying the semantic congruency of the irrelevant, unexpected word stimulus in relation to the attended category.

## METHOD

### Participants

The participants in the main experiment were 149 students (mean age = 23.3 years, range = 19–43 years; 49 male) with normal or corrected-to-normal vision. They participated as part of a course in neuroscience at the Medical School of the University of Turku. They were tested in subgroups of 6–10 persons.

### Apparatus and Stimuli

The stimuli were presented on a screen by a video projector (Epson EMP82) with a 60-Hz refresh rate and 1,024 × 768-pixel resolution. The participants were seated about 3 m from the screen.

Each stimulus display consisted of 2–6 pictures of objects (on average 2.7º × 2.7º; Snodgrass & Vanderwart, 1980), presented in black on a round, white viewing area (12.2º in diameter). The pictures could appear in six possible locations centered on an imaginary circle about 3.7º from the central fixation cross (see Figures 1A and 1B). In trials involving fewer than six pictures, the remaining locations were filled by black "X" letters. In the third and fourth trials, the critical unexpected stimulus word was presented in the center of the area. The unexpected word *kissa* ("cat") subtended a visual angle of 2.6º × 0.7º; the size of the word *sohva* ("couch") was 3.2º × 0.7º. In the critical trials, 76 of the participants attended to animals (for 36 of them, the unexpected word stimulus was congruent with the attended category), and 73 participants attended to pieces of furniture (for 40 of them, the unexpected word stimulus was congruent with the attended category).

### Procedure

Each trial began with the presentation of the text box (6.5º × 2.6º) for 1 sec, with the name of the to-be-attended category written in it, followed by the fixation cross for 1 sec, followed by the stimulus display for 1 sec, and then by the empty box for 1 sec. The participants were told that their task was to recognize pictures belonging to prespecified categories. They were asked to attend to the category indicated in the text box at the beginning of each trial and to write down the names of pictures from the attended category on an answer sheet after the trial. After a demonstration trial, two noncritical trials followed. In the first trial, the attended category was *carpenter's tool* and the semantically

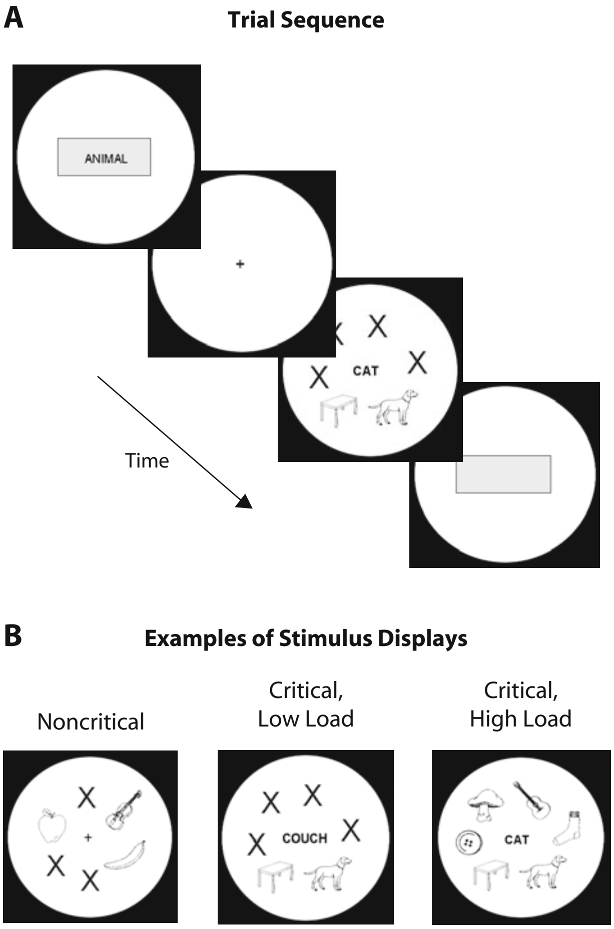


**Figure 1. (A) An example of a semantically congruent trial. Each trial began with a text box indicating the category to attend (1 sec), followed by the fixation cross (1 sec), the stimulus display (1 sec), and the empty box (1 sec). (B) Examples of different stimulus displays.**

related picture was of a saw. In the second trial, the category was *fruit* and the related pictures were of a banana and an apple. For about half of the observers, the first trial included five nontarget pictures (six pictures in total) and the second trial included one nontarget (three pictures in total), whereas, for the other half, the first trial included two nontargets (three pictures in total) and the second trial included four nontargets (six pictures in total). Pictures of a ball, a bow, an eye, a key, a shoe, and a violin were the nontarget pictures in these trials. In the more demanding second trial, which involved two target pictures, we expected that the perceptual load manipulation (three vs. six pictures) would have an effect on the recognition of the targets, which would confirm that the manipulation of load was effective.

The third trial was the critical *inattention trial*, in which the unexpected stimulus (the word for "cat" or that for "couch," semantically congruent or incongruent with the attended category) appeared on the center of the display for 1 sec at the same time as the pictures did. In this trial, 76 participants attended to animals and 73 to pieces of furniture. Depending on the attended category, the semantically related target picture was of a dog or of a table. About two seconds after this trial (i.e., the time taken for writing down the answer to the primary task), the participants were asked, "Did you notice anything new or additional that was not present in the previous trials?" and, "If you did, what and where?"

The inattention trial was followed by the fourth, the *full-attention trial*. It was physically identical to the previous trial, but now, the only task was to try to detect whether anything new was presented. It was stressed to the participants that they should not attend to the pictures anymore but that something completely different might appear. The same questions concerning the additional stimulus as those in the inattention trial were repeated after the full-attention trial. The purpose of the full-attention trial was to control that the observers could detect the unexpected stimulus when attentional resources were fully directed to the detection task.

In order to manipulate perceptual load, for 75 participants, the stimulus display in the inattention and full-attention trials included two pictures (a dog and a table; low-load condition), whereas, for 74 participants, the display in these trials included six pictures (a dog, a table, a guitar, a sock, a button, and a mushroom; high-load condition).

We conducted a response time experiment with 10 independent observers (mean age = 24.7 years, 3 male) to confirm that the manipulation of perceptual load was successful. The stimuli were presented on a CRT screen with the same angular size and using the same procedure as in the main experiment. Three low-load (two pictures) and three high-load (six pictures) trials, each including one target picture (a dog, a table, or a saw) from the attended category, were presented in random order with eight filler trials (four low-load and four-high load trials, which included two targets or no targets at all). The task was to decide as quickly and accurately as possible whether the display contained one, two, or no items from the attended category. Since the critical inattention trial in the main experiment contained one target, only the trials including one target were analyzed. Accuracy did not differ between the load conditions (93% in both conditions), but response times were 1,181 msec to the low-load displays and 1,611 msec to the high-load displays [$t(9) = 3.50$, $p < .01$], showing a strong effect (457 msec) of load and confirming that the manipulation was effective.

## RESULTS

The primary task (recognizing the pictures in the attended category) was performed correctly by 97% of the participants in the first trial and by 99% in the third trial. Perceptual load did not have any effect on performances in the primary task in these trials, which contained only one target picture. In the second trial, which included two target pictures, both targets were recognized correctly more often when the stimulus display contained three pictures (94%) than when it contained six pictures (76%) [$\chi^2(1,149) = 8.66$, $p < .01$], confirming that the manipulation of perceptual load was successful even when it was less strong (three vs. six pictures) than in the critical trials (two vs. six pictures).

In the critical inattention trial and in the full-attention trial, the observer was scored as having detected the unexpected stimulus if he or she reported having noticed a word or letters in the center of the viewing area. In addition, if the observer could identify what the stimulus was ("cat" or "couch"), he or she was scored as having recognized it. The participants who failed to detect anything new in both the inattention and the full-attention trials were excluded from further analyses ($n = 24$, 16% of the participants). The data were distributed similarly to those in the high and low perceptual load conditions [$\chi^2(1,149) = 1.51$]. The participants who also failed in the full-attention trial often reported something related to the pictures (e.g., "a new category was represented in one of the pictures"), revealing that they may have continued to attend to the pictures, although they were explicitly asked not to do so.

Figure 2 displays the detection results for the inattention trial ($n = 125$).Under low load, 31% of the participants detected the semantically incongruent stimulus (78% of these participants could also recognize it), whereas the semantically congruent stimulus was detected by 91% of the participants (97% of these observers also recognized it). Thus, the semantically congruent stimulus was detected more often than the incongruent one in the low-load condition [$\chi^2(1,64) = 25.13$, $p < .001$]. In the high-load condition, only 7% of the participants detected the semantically incongruent stimulus (100% of these participants could also recognize it), whereas the semantically congruent stimulus was detected by 82% of the participants (93% of them also recognized it). Thus, against the prediction derived from the load theory, there was also a highly significant congruency effect in the high-load condition [$\chi^2(1,61) = 33.87$, $p < .001$]. The interaction between load and congruency in detection of the unexpected stimulus, as tested with a logit loglinear analysis, was not significant [$Z(1,125) = 0.81$, $p = .442$], although the congruency effect was numerically larger in the high-load condition (75%) than in the low-load condition (60%). Note that this numerical difference is toward the opposite direction from that predicted by the hypothesis that, under high load, attentional selection occurs at early levels.

The semantically incongruent stimulus was detected more easily under low load (31%) than under high load (7%) [$\chi^2(1,57) = 5.22$, $p < .025$]. For the semantically congruent condition, the detection rate did not differ significantly between the low- (91%) and the high- (82%) load conditions [$\chi^2(1,68) = 1.37$].

We were interested in testing whether the unexpected stimulus draws attention when its semantic category is represented in the observer's attentional set. It remains possible that the semantic congruency effect is due to priming elicited by the attended picture from the same semantic category as the unexpected word. For example, when participants at-

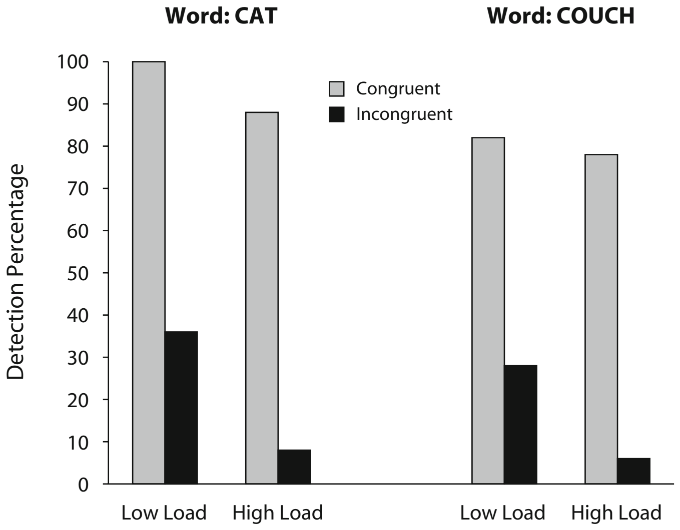


**Figure 2. Percentage of participants who detected the irrelevant unexpected word as a function of perceptual load and whether the category of the word was semantically congruent with the category of attended stimuli. Results are shown separately for the stimulus words for "cat" and "couch."**

tend to animals, recognizing the picture of a cat might prime representations of other animals, which would facilitate the detection of the unexpected word ("dog"). To rule out this interpretation, 29 new participants (mean age = 22.4 years, range = 19–42; 9 male) were tested in the high-load condition by using displays that did not contain any picture from the attended category in the critical trial (the pictures of the dog and of the couch were replaced with unrelated fillers). The results from the inattention trial showed that, when the unexpected word was semantically incongruent with the attended category, 0 of the 14 participants detected the word, whereas, in the congruent condition, 14 (93%) of the 15 participants detected and recognized it [$\chi^2(1,29) = 25.26$, $p < .001$]. This semantic congruency effect cannot be due to priming from semantically related pictures, because such pictures were not presented.

## DISCUSSION

The results replicate our earlier finding (Koivisto & Revonsuo, 2007b) showing that an unexpected stimulus belonging to the attended category but not sharing physical features with the attended stimuli is easier to detect than a semantically incongruent stimulus. This congruency effect implies a powerful role for the semantic contents of the observer's attentional set in the detection of unexpected stimuli. Here, we could rule out an alternative explanation for the congruency effect: It is not generated, because the picture from the attended category in the display would prime the processing of the unexpected word from the attended category.

The main aim was to test whether an unexpected stimulus that is semantically congruent with the attended category is detected more easily than an incongruent one under high perceptual load. The load theory of attention predicts that late selection would occur only under low load—that is, when additional processing capacity can spill over to processing irrelevant stimuli (Lavie, 1995, 2005). The main finding of the present study was the robustness of the semantic congruency effect: Perceptual load did not decrease it. In fact, this effect was numerically stronger in the high-load condition, which goes against the assumption that late selection occurs only when the primary task is of low load. On the other hand, the finding that increasing perceptual load almost completely eliminated the detection of semantically incongruent stimuli is exactly as expected from the previous perceptual load experiments, in which neutral stimuli were used (Cartwright-Finch & Lavie, 2007).

An exception to the pattern that irrelevant stimuli are processed only under low load has been reported for processing irrelevant faces, which produced an interference effect that was unaffected by load (Lavie, Ro, & Russel, 2003), suggesting that faces, as biologically and socially important stimuli, are processed automatically. These and the present findings suggest that the perceptual load theory does not apply to all stimuli: Biologically or socially important stimuli, as well as word meaning, may be processed irrespective of load. However, there are many potentially important differences between the present study and typical previous studies on perceptual load (e.g., Lavie, 1995; Lavie & Cox, 1997). We measured *aware detection* of an *unexpected* stimulus that was presented only *once*, whereas previous researchers have measured the effects of *expected distractors* on *response times* to the *primary task*. Therefore, it remains to be tested whether the present findings are restricted to awareness under inattention or whether they generalize to other conditions.

The finding that conscious attention enhanced awareness of task-irrelevant stimuli may be based on a preactivation mechanism. In this view, attention to a semantic category preactivates the representations of its category members, lowering their detection thresholds and thus facilitating their entrance to awareness. This is consistent with recent neurophysiological (Koivisto & Revonsuo, 2007a; Koivisto, Revonsuo, & Salminen, 2005) and behavioral (Fabre, Lemaire, & Grainger, 2007; Koivisto & Revonsuo, 2004; Naccache, Blandin, & Dehaene, 2002) findings, indicating that conscious attention modulates the processing of subliminal stimuli. This explanation is also in line with Treisman's (1960) filter-attenuation theory, which assumes that an early filter only attenuates the information available in an unattended channel and that highly activated information in a mental dictionary needs fewer resources to break through the filter. The combination of the attenuating early filter and the activation of mental representations allows for selection at different levels of processing.

An alternative explanation to the preactivation view would follow late selection theories (e.g., Deutsch & Deutsch, 1963) and assume that all stimuli are processed automatically or without a high level of attention, but only those stimuli that are congruent with the attentional set of the observer will capture attention and be consciously reportable. For example, if attentional filters use semantic parameters, semantically congruent words are semantically relevant, although not necessarily task-relevant in a task requiring recognition of pictures from a specific category, and they pass through the same filters as the task-relevant target pictures.

The critical stimulus was presented at fixation. Inattentional blindness is stronger for stimuli at fixation than in the periphery (Mack & Rock, 1998), which may be attributed to higher task demands of the primary task between the conditions (Cartwright-Finch & Lavie, 2005). Because we used placeholders (Xs) as nonstimuli in the low-load condition, and the target location was unpredictable, our manipulation affected perceptual load, as well as search difficulty (e.g., Lavie & Cox, 1997). Therefore, we cannot be certain that our effects were due to perceptual load per se. Fortunately, since both perceptual load and search difficulty reflect attentional demands, the same predictions that were made for perceptual load should also hold for attentional demands of search. According to another counterargument, the high-load condition may have involved a greater tendency for eye movements than the low-load condition, causing blur on the retina and making stimuli less visible. However, such eye movements would explain only a general effect of load on the detection of unexpected words, not the similar semantic congruency effects in the load conditions.

In conclusion, the present results demonstrate that the semantic contents of observers' attentional set strongly determine whether a task-irrelevant stimulus enters visual awareness. The fact that this effect resisted perceptual load suggests that it is generated automatically once the attentional settings have been turned to relevant meanings.

## AUTHOR NOTE

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