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Object-based attention overrides perceptual load to modulate visual distraction

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Abstract

The ability to ignore task-irrelevant information and overcome distraction is central to our ability to efficiently carry out a number of tasks. One factor shown to strongly influence distraction is the perceptual load of the task being performed; as the perceptual load of task-relevant information processing increases, the likelihood that task-irrelevant information will be processed and interfere with task performance decreases. However, it has also been demonstrated that other attentional factors play an important role in whether or not distracting information affects performance. Specifically, object-based attention can modulate the extent of distractor processing, leaving open the possibility that object-based attention mechanisms may directly modulate the way in which perceptual load affects distractor processing. Here, we show that object-based attention dominates perceptual load to determine the extent of task-irrelevant information processing, with distractors affecting performance only when they are contained within the same object as the task-relevant search display. These results suggest that object-based attention effects play a central role in selective attention regardless of the perceptual load of the task being performed.

Keywords

Selective Attention; Perceptual Load; Object-based Attention; Visual Attention; Perception; Perceptual Grouping

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Selective attention allows us to process task-relevant information while effectively ignoring task-irrelevant information and minimizing distraction. For example, our ability to read a newspaper in a crowded coffeehouse depends on our ability focus on the words on the page while simultaneously ignoring the conversations around us. Lavie and colleagues have proposed that the *perceptual load* of a task determines the likelihood that task-irrelevant information will be processed and cause distraction, a proposal formalized in Lavie's "Load Theory" of selective attention (Lavie, 1995; Lavie et al., 2004). Specifically, Load Theory proposes that perceptual-level attention is a finite resource - when perceptual load is high and processing capacity is exhausted, the processing of task-irrelevant distractors is attenuated early and distracting information does not influence task performance. Furthermore, load theory proposes that processing capacity is filled in a mandatory manner, such that when perceptual load is low, attentional resources obligatorily "spill over" to task-irrelevant distractors, causing them to interfere with task performance. Given its parsimonious resolution to debates regarding the locus of selection (e.g., Deutsch & Deutsch, 1963; Treisman, 1969), load theory has been an influential theory of attentional selection in both cognitive psychology and neuroscience, and has received support from

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numerous behavioral and neurophysiological studies (e.g., Lavie & Cox, 1997; Cosman & Vecera, 2009; 2010; Rees et al., 1997; Bahrami et al., 2007).

At the same time, factors other than perceptual load have been shown to affect the extent of task-irrelevant information processing. For example, using a modified flanker task, Kramer and Jacobson (1991) demonstrated that the amount of interference caused by a task-irrelevant flanker varied as a function of whether or not it was part of the same perceptual group as the task-irrelevant target, using good continuation and connectedness as cues (see also Baylis & Driver, 1992; Chen, 2003; Richard, Lee, & Vecera, 2008). When a central target was physically connected to two task-irrelevant flanking distractors and created one object, flankers influenced reaction times to the target; however, the flankers had little or no effect when they were physically separated from the target (Kramer & Jacobson, 1991; Richard et al., 2008).

Taken together, the studies outlined above suggest that in addition to perceptual load, other factors such as perceptual grouping or object-based attention may play a crucial role in determining the level of distractor processing. Given that object-based attention mechanisms control the allocation and spread of attentional resources (e.g., Vecera, 1994; Vecera & Farah, 1994; Richard et al., 2008; Hollingworth, Maxcey-Richard, & Vecera, in press), it is plausible that these mechanisms may directly influence the operation of selective attention regardless of perceptual load. For example, all features of task-relevant objects may be obligatorily processed under high-load conditions even when some of these features are task-irrelevant, and features of objects that are irrelevant to task performance may be effectively ignored even under low-load conditions (O'Craven, Downing, & Kanwisher, 1999; Richard et al., 2008; Wuhr & Frings, 2008). In other words, it is possible that object-based attention mechanisms can trump perceptual load to determine whether task-irrelevant information receives processing resources.

In the standard perceptual load task, a task-relevant search array and task-irrelevant distractor appear as parts of different perceptual groups (e.g., Lavie & Cox, 1997; see also Beck & Lavie, 2005). Under these conditions, larger flanker congruency effects are observed when the search task is low, as opposed to high, in perceptual load. In the current study, we were interested in examining whether this effect of load on distractor processing could be modulated by simple object cues placed strategically in these displays. Specifically, we included a superordinate object structure that encompassed both the search array and one of two possible distractor locations (Figure 1). As a result, on each trial the task-irrelevant flanker was either a part of the same or different object as the task-relevant search array, giving us the ability to measure object-based effects on distractor processing under varying conditions of perceptual load. If object-based attention mechanisms arising from our object manipulation act as a primary determinant of whether task-irrelevant information is processed and allowed to affect behavior, we would expect to see flanker congruency effects emerge when the flanker is contained within the same object as the search array, but not when it appears in a different object than the search array, regardless of perceptual load. In contrast, if perceptual load predominates to determine the extent of distractor processing, we would expect to see flanker congruency effects emerge when the search task is low in perceptual load, but not when it is high in perceptual load, regardless of which object contains the flanker (i.e., a typical perceptual load effect). This would indicate that the superordinate object structure and corresponding object-based attention effects were sufficient to override the effect of load on distractor processing, and would point to a central role for object-based attention mechanisms in determining the extent to which task-irrelevant information is processed.

Method

Participants

Eighteen University of Iowa undergraduates participated for course credit. All participants had normal or corrected to normal vision.

Stimuli & Procedure

A Macintosh mini computer displayed stimuli on a 17-inch CRT and recorded responses and response latencies. The experiment was controlled using MATLAB and the Psychophysics toolbox (Brainard, 1997). Participants sat 65 cm from the screen in a dimly lit room, and performed a basic search task like that depicted in Figure 1.

Following the presentation of a fixation point for 1000ms, the search displays were presented for 100ms. The search arrays themselves always appeared as part of the same object and consisted of letters presented around fixation following the arc of an imaginary circle (radius 2.0°), and were either high load displays containing a target letter (E or H) among five heterogeneous distractor letters (D, J, K, B, T each measuring 0.9° × 1.4°), or low load displays consisting of the target letter and five small placeholder circles (each 0.25° radius), with load being blocked (see Lavie & Cox, 1997). The objects on which the search array and flanker appeared consisted of two gray 3D rendered objects presented on a white background, one large (12° × 10°) and one small (3° × 10°). The large object always contained the task-relevant search array, and on half of the trials also contained a single, task-irrelevant flanker letter (same-object flanker condition). On the other half of trials, the flanker letter appeared in the smaller object (different-object flanker condition). The flanker appeared equidistant from the search array in both object conditions with a distance of approximately 2.2° from the edge of the search array to the edge of the flanker, with the relative location of each object (left vs. right side of display) and the congruency of the flanker letter being equiprobable and pseudorandomly determined on each trial.

Participants were instructed to maintain central fixation and to search the circular arrays for the target while ignoring the task-irrelevant flankers and objects. Participants performed three high-load and three low-load blocks of 96 trials each for total of 576 trials, with load blocks alternated and starting order counterbalanced across subjects.[1]

Results

Reaction times faster than 200ms or longer than 3000ms were excluded from the analyses. Removal of these outliers excluded less than 2% of the RT data. Additionally, the data from 2 participants were excluded because overall accuracy was greater than 3 SDs below the mean, leaving data from sixteen participants in the analyses below. We performed an omnibus three-way ANOVA with flanker object (same vs. different) display load (high vs. low), and flanker congruency (congruent vs. incongruent) on both correct mean RTs (Figure 2) and percent errors. For RTs, we observed a main effect of congruency, $F(1, 15) = 33.5$, $p < .0001$, with faster RTs to congruent trials (587 ms) than to incongruent trials (609 ms), as well as a main effect of load, $F(1, 15) = 83.6$, $p < .0001$, with faster RTs on low load trials (526 ms) than high load trials (671 ms). We also found a significant interaction between

[1]Ten observers performed a basic version of our load task to ensure that our stimuli generate a typical load effect. This task consisted of 192 trials of high and low load search arrays (blocked) presented on a gray background, identical to the search arrays used in the primary experiment. An ANOVA performed on RTs in this task revealed a significant main effect of load $F(1, 9) = 29.0$, $p < .001$., with response times in high-load trials (638 ms) being overall slower than responses in low-load trials (497 ms), and a significant load by congruency interaction, $F(1, 9) = 4.96$, $p = .05$. Thus, the current displays generate what would be considered typical load effects in the absence of the object structure imposed in the experiment of interest.

flanker object and congruency $F(1, 15) = 11.0$, $p < .01$. No other main effects or interactions were significant, $Fs < 3.5$, $ps > .08$.

Secondary two-way ANOVAs were conducted on RTs from high and low load conditions to examine the root of the flanker object by congruency interaction. A significant main effect of congruency was observed in both the low load, $F(1, 15) = 18.5$, $p < .001$, and high load, $F(1, 15) = 15.4$, $p < .001$, conditions. Importantly, significant two-way interactions between flanker object and congruency were observed in both the low load, $F(1, 15) = 4.5$, $p = .05$, and high load, $F(1, 15) = 7.6$, $p = .01$, conditions, with flanker effects being significantly larger when the flanker appeared in the same object as the target, regardless of load. Moreover, we observed no three-way interaction, $F(1, 15) < 1$, *n.s.*, indicating that our object manipulation eliminated the interaction between perceptual load and flanker congruency typically observed in this task (e.g., Lavie & Cox, 1997; Lavie, 2005; Lavie et al., 2004), and providing evidence that object-based attention effects can override the effect of perceptual load to determine whether task-irrelevant information affects performance during search.

The error rates generally paralleled the RTs. Most important, error rates showed larger flanker effects in the same object condition than in the different object condition for both low and high load displays, although these differences were not significant: We observed a main effect of congruency $F(1, 15) = 4.5$, $p = .05$, but no other main effects or interactions were significant, $Fs < 2.1$, $ps > .17$.

Discussion

Our results show that object-based attention strongly determines the extent of task-irrelevant information processing, modulating selective attention based on whether the task-relevant and irrelevant information are part of the same or a different object. Furthermore, this effect was observed regardless of the perceptual load of the search task. During high-load search, where attentional capacity should have been exhausted and attentional filtering very effective (Lavie, 1995; Lavie et al., 2004), task-irrelevant flanker letters still exerted an interference effect if targets and flankers appear in the same object. Conversely, during low-load search, filtering efficiency was increased when the to-be-ignored letter did not group with the search array. Thus, adding a superordinate object structure that encompassed the search display led to increased processing of distracting information located within the object boundary and an attenuation of processing for distracting information located outside of the object boundary. Such a finding is at odds with load theory, which posits that resource demands on perceptual-level attention are the sole factor driving selective attention mechanisms. The fact that the relationship between the object containing the search array and that containing the distractor directly determined the extent of distractor processing in the face of our perceptual load manipulation suggests that perceptual load is not the sole determinant of attentional selection.

Instead, these results are in line with studies that propose a key role for objects in modulating the extent of task-irrelevant information processing. Specifically, our results are predicted by spreading enhancement accounts of object-based attention, in which attentional resources spread within an object, enhancing the representations of features contained in those objects (Richard et al., 2008; Hollingworth et al., in press; Mozer, 2002; Valdez-Sosa, Bobes, Rodriguez, & Pinilla, 1998; Han, Dosher, & Lu, 2003). The increased magnitude of flanker effects when the task-irrelevant flanker appeared in the same object as the search array is presumably due to such a spreading mechanism – when the flanker appeared in the same object as the search array, it is likely that attention spread throughout the object and led to an enhanced representation of both task-relevant and task-irrelevant items, generating increased interference when task-irrelevant distractors appeared in the object containing the search array. Given this direct modulation of perceptual load effects and distractor interference by object-based attention mechanisms, it appears that object boundaries and the attentional effects they produce can act as a primary determinant of what information is processed and allowed to affect behavior.

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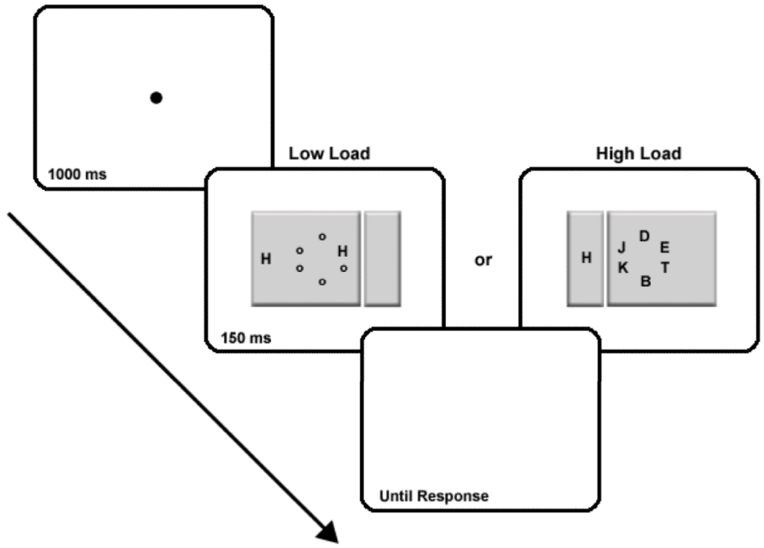

Figure 1.
Task diagram showing examples of low-load different object (left) and high-load same object trials (right).

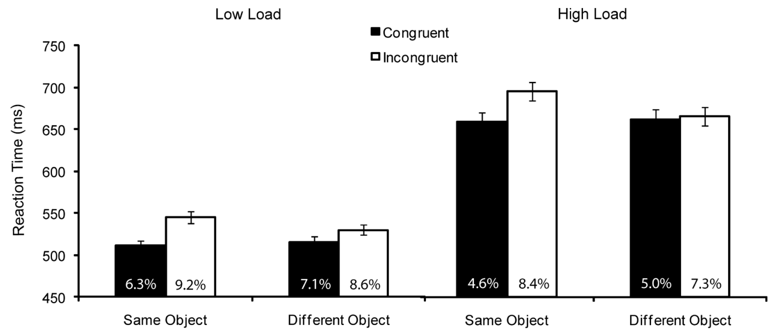

Figure 2.
Reaction Times and error rates (at base of the bar) for each condition in the experiment. Error bars represent 95% confidence intervals (Loftus & Masson 1994, Cousineau 2005)