when finding an additional target was more likely. This was observed both within participants (with a main effect of number of targets found), and between groups (with an interaction between condition and number of targets found), suggesting that people adapt and optimize their search strategies to match the complex statistics of the environment. This has broad implications for search, suggesting that artificially modifying target distribution statistics, such as priming baggage screeners with daily training runs of multiple-target bags (cf. Wolfe et al., 2007), may be an effective way to enhance sensitivity in critical multiple-target visual searches.

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Perceptual grouping determines the locus of attentional selection

Joshua D. Cosman and Shaun P. Vecera

Departments of Neuroscience and Psychology, University of Iowa, Iowa City, IA, USA

Selective attention allows us to process task-relevant information while effectively ignoring task-irrelevant information. For example, our ability to

Please address all correspondence to Joshua Cosman, Departments of Neuroscience and Psychology, E305 Seashore Hall, University of Iowa, Iowa City, IA 52242-1407, USA. E-mail: joshua-cosman@uiowa.edu

read a newspaper in a noisy, crowded coffeehouse depends on our ability focus on the words on the page while simultaneously ignoring the conversations and sounds around us. Although much is known about the effects of attentional selection, the locus of processing at which such selection occurs (i.e., early vs. late in processing) is long debated (Duncan, 1980; Lachter, Forster, & Ruthruff, 2004; Treisman, 1969). As a resolution, Lavie and colleagues have proposed that the locus of attentional selection is flexible, being determined by the demands, or *perceptual load*, of task-relevant information processing (Lavie, 1995; Lavie, Hirst, de Fockert, & Viding, 2004). Specifically, perceptual level attention is viewed as a finite resource—when perceptual load is high and processing capacity is exhausted, early selection is induced and the processing of task-irrelevant distractors is attenuated at an early level of processing. Conversely, when perceptual load is low, there are sufficient attentional resources left to "spill over" and process task-irrelevant distractors. Given its parsimonious resolution to the debate regarding the locus of selection, load theory has been an influential theory of attentional selection in both cognitive psychology and neuroscience, being supported by numerous behavioural and neurophysiological studies.

In the current experiment, we tested whether the locus of selection, as measured by perceptual load effects, can be modulated by perceptual grouping. Given that perceptual grouping serves up objects that control the allocation and spread of attentional resources (e.g., Richard, Lee, & Vecera, 2008; Vecera & Farah, 1994), it is plausible that perceptual grouping might directly influence the level at which selective attention exerts its effects. For example, features of task-relevant objects may be obligatorily processed under high-load conditions even when the features themselves are task irrelevant, and features of task-irrelevant objects may be effectively ignored under low-load conditions. In support of this possibility, there is evidence that perceptual grouping can modulate the processing of task-irrelevant information under some conditions (e.g., Baylis & Driver, 1992; see also Chen, 2003).

We addressed this possibility by having observers perform a search task in which we varied both perceptual load and the position of task-irrelevant distractors relative to the search arrays—specifically, the task-irrelevant flanker letter could appear either in the same object as the search array or in a different object. With this design it was possible to examine the effect of perceptual grouping on processing under different conditions of load. If perceptual grouping modulates the locus of attentional selection, we would expect to see interference 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 other words, it is possible that perceptual grouping, not perceptual load, may determine of the locus of attentional selection.

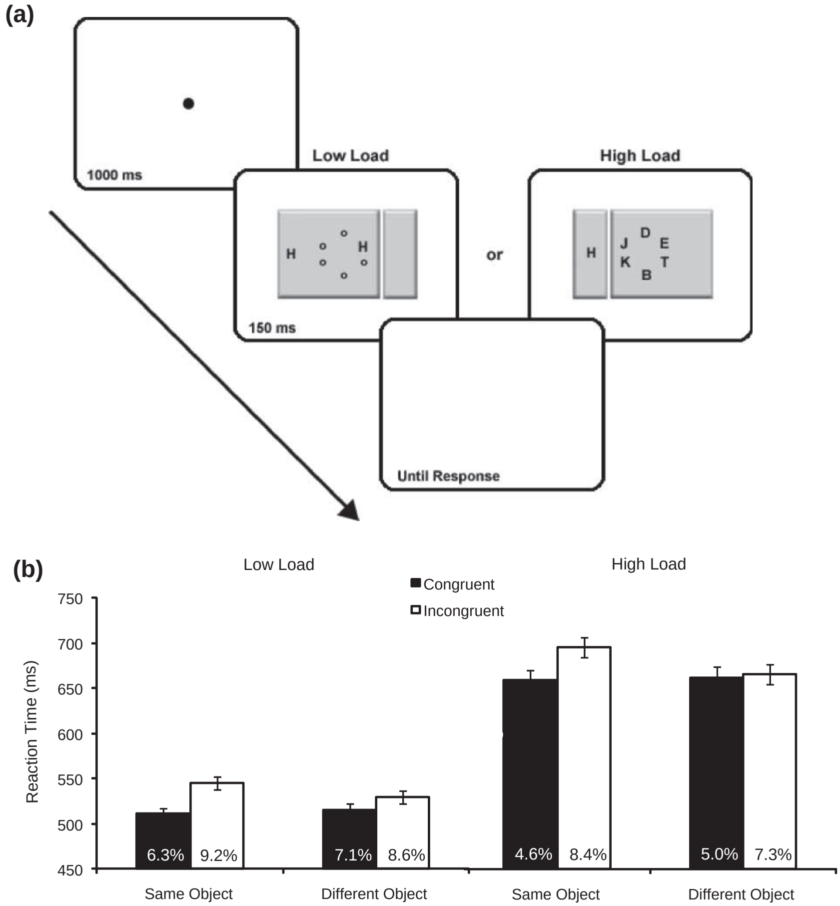

Figure 1. (a) The trial sequence, giving example of low-load different object (left) and high-load same object trials (right). (b) Reaction times and error rates for each condition in the experiment. Error bars represent 95% confidence intervals (Loftus & Masson 1994).

METHOD

Sixteen University of Iowa undergraduates performed a basic search task (Figure 1). Following the presentation of a fixation point for 1000 ms, a search display was presented for 100 ms. The displays consisted of two grey 3-D rendered objects on a white background, one large ($12^\circ \times 10^\circ$) and one small ($4^\circ \times 10^\circ$). 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 relative location of each object (left vs. right side of display) was randomly determined on a given trial, with the task-irrelevant flanker letter being either congruent or incongruent on a given trial. The search arrays were either high-load displays containing a target letter (E or H) among five heterogeneous distractor letters (D, J, K, B, and T, each measuring $0.9^\circ \times 1.4^\circ$), or low-load displays consisting of the target letter and five small placeholder circles (0.5° diameter), with load being blocked (cf. Lavie & Cox, 1997). Participants were told to maintain central fixation, and search the circular arrays for the target while ignoring the task-irrelevant flankers and objects. Participants performed three high- and three low-load blocks of 96 trials each, with load blocks alternated and order counterbalanced across subjects.

RESULTS

An omnibus ANOVA with flanker object (same vs. different) display load (high vs. low), and flanker congruency (congruent vs. incongruent) was performed on correct RTs. We observed main effects of congruency, $F(1, 15) = 33.5$, $p < .0001$, and load, $F(1, 15) = 83.6$, $p < .0001$, as well as a significant interaction between 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 individually to examine the root of the flanker object by congruency interaction. Importantly, significant two-way interactions between flanker object and congruency were observed in both the high-load, $F(1, 15) = 7.7$, $p = .01$, and low-load, $F(1, 15) = 4.9$, $p = .04$, conditions, indicating that flanker effects were significantly *larger* when the flanker appeared in the same object as the target, regardless of load.

DISCUSSION

Our results show for the first time that perceptual grouping is a major determinant of the locus of attentional selection, flexibly increasing or decreasing filtering efficiency based on whether the task-relevant and irrelevant information are part of the same perceptual group. During high-load search, where attentional capacity should be exhausted and attentional filtering very effective (Lavie, 1995; Lavie et al., 2004), task-irrelevant flanker letters still exert an interference effect so long as they group with the task-relevant search array. Conversely, during low-load search, filtering efficiency is increased when the to-be-ignored letter does not group with the search array. Given this direct modulation of perceptual load effects by grouping, it appears that perceptual grouping, rather than perceptual load, is the primary determinant of what information is processed and allowed to affect behaviour.

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Unitary vs. multiple attentional loci reflect space-based vs. object-based modes of attention

Lisa N. Jefferies and Steven Yantis

Johns Hopkins University, Baltimore, MD

Visual stimuli are processed faster and more accurately when they appear at attended locations. Theories of spatial attention tend to appeal either (1) to the idea of a single unitary focus of attention that expands and contracts to optimize performance on the task at hand (e.g., Eriksen & Yeh, 1985), or (b) to multiple foci deployed to different locations simultaneously (e.g., Awh &

Please address all correspondence to Lisa N. Jefferies, Department of Psychological and Brain Sciences, Johns Hopkins University, 136 Ames Hall, 3400 North Charles Street, Baltimore, MD 21218, USA. E-mail: ljefferi@gmail.com