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Author(s): Lavie, Nilli; Lin, Zhicheng; Zokaei, Nahid; Thoma, Volker.

Article Title: The Role of Perceptual Load in Object Recognition

Year of publication: 2009

Citation: Lavie, N. et al. (2009) 'The Role of Perceptual Load in Object Recognition', Journal of Experimental Psychology: Human Perception and Performance 35 (5) 1346-1358.

Link to published version: <http://dx.doi.org/10.1037/a0016454>

DOI: 10.1037/a0016454.

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The Role of Perceptual Load in Object Recognition

Nilli Lavie
University College London

Zhicheng Lin
University of Minnesota

Nahid Zokaei
University College London

Volker Thoma
University of East London

Predictions from perceptual load theory (Lavie, 1995, 2005) regarding object recognition across the same or different viewpoints were tested. Results showed that high perceptual load reduces distracter recognition levels despite always presenting distracter objects from the same view. They also showed that the levels of distracter recognition were unaffected by a change in the distracter object view under conditions of low perceptual load. These results were found both with repetition priming measures of distracter recognition and with performance on a surprise recognition memory test. The results support load theory proposals that distracter recognition critically depends on the level of perceptual load. The implications for the role of attention in object recognition theories are discussed.

Keywords: attention, object recognition, perceptual load, distraction, visual perception

The role of attention in object recognition has been debated among attention researchers ever since the start of attention research. In Broadbent's (1958) pioneering model of attention perceptual processes leading to object recognition require focused attention. Attentional selection occurs early on, following only rudimentary processes of sensory registration (see also Treisman, 1969). Numerous reports of failures to recognize unattended objects provided support for this model (e.g., Neisser & Becklen, 1975; Rock & Guttmann, 1981; Treisman & Geffen, 1967).

The opposing late selection view, in which object recognition is an automatic preattentive process (e.g., Deutsch & Deutsch, 1963; Tipper, 1985) has also received much empirical support. Various studies have demonstrated that unattended objects are in fact recognized as shown by effects such as response competition and negative priming (e.g., Gatti & Egeth, 1978; Driver & Tipper, 1989). The accumulation of evidence for both of these conflicting early and late selection views of attention, sometimes within the very same task (e.g., compare Farnoloni & Egeth, 1980 with Driver & Tipper, 1989), has fueled an ongoing debate over four decades of research.

The Perceptual Load Theory

A resolution to this debate has been offered within a hybrid perceptual load model (Lavie, 1995, 2000; Lavie, Hirst, De Fockert, & Viding, 2004). According to this model, object perception and recognition depend on the allocation of attention but several of the previous assumptions about attention and perception have to be reconsidered. First, both of the early selection and late selection views were framed within a structural approach to information processing. In this approach, attentional limits are conceived in terms of a rather rigid "bottleneck" that is placed either early or late in a fixed information processing sequence. The Perceptual Load model has applied a capacity approach (e.g., Kahneman, 1973; Navon, 1984) to the debate. In this approach, capacity limits cannot be described as an all-or-none bottleneck that can only allow for the recognition of one object at a time (c.f., Broadbent, 1958). Rather, several objects can be recognized before perception gets overloaded. Capacity limits can thus be reached either early or late in the processing, depending on the level of perceptual load in the task.

Second, attention should not be confused with intention: the instruction to ignore task-irrelevant distracter objects may not always be sufficient to render these objects unattended. According to the load model, the allocation of attention is an automatic process in the sense that it cannot be simply withheld at will because of the instruction to ignore task-irrelevant objects.

Therefore, it follows that the level of perceptual load in any given task determines whether task-irrelevant objects can be successfully ignored. In tasks that involve only low perceptual load, spare capacity from task-relevant processing will unintentionally spill over to the perception of task-irrelevant objects (producing late selection). Task-irrelevant objects will not be recognized, however, when the current task requires full perceptual capacity in situations of high perceptual load, leaving no capacity available to spill over to task-irrelevant processing (producing early selection).

Nilli Lavie, Institute of Cognitive Neuroscience, University College London; Zhicheng Lin, Department of Psychology, University of Minnesota; Nahid Zokaei, Division of Psychology and Language, University College London; Volker Thoma, School of Psychology, University of East London.

This research was supported by grants from the MRC and the Wellcome Trust to N. L. We thank Isobel Gauthier and Todd Kelley for their valuable comments on an earlier version of this manuscript.

Correspondence concerning this article should be addressed to Nilli Lavie, Institute of Cognitive Neuroscience University College London, 17 Queen Square, London, WC1N 3AR, UK. E-mail: n.lavie@ucl.ac.uk

Although currently there is no agreement on a mathematical formula that can offer precise quantification of information load, there are clear and well-established operational definitions for perceptual load. Perceptual load has been operationally defined either in terms of the number of different items in a perceptual recognition task (a greater number of items involves a higher perceptual load) or in terms of the number and complexity of perceptual operations that the task involves (e.g., a feature detection task involves less perceptual load than a feature conjunction discrimination task, e.g., Bahrami, Carmel, Walsh, Rees, & Lavie, 2008; Lavie, 1995; Schwartz et al., 2005; see also Lavie, 1995; Lavie & Tsal, 1994, for a more detailed discussion, and Lavie & De Fockert, 2003, for distinguishing perceptual load from manipulations of general task difficulty).

Support for the perceptual load model has been provided in numerous studies that have used either type of load manipulation (see Lavie, 2005, 2006; Macdonald & Lavie, 2008, for recent reviews). These have found that increasing the level of perceptual load in task-relevant processing significantly reduces the extent to which task-irrelevant stimuli are perceived, either consciously (e.g., Carmel, Rees, & Lavie, 2007; Cartwright-Finch & Lavie, 2006; Lavie, 2006; Macdonald & Lavie, 2008), or even unconsciously (e.g., Bahrami et al., 2008). They have also shown that increased perceptual load reduces the extent to which task-irrelevant stimuli produce behavioral interference effects (e.g., Lavie, 1995; Lavie & Cox, 1997; Lavie & Fox, 2000; see also Forster & Lavie, 2007, 2008, for generalization of these effects across both different types of distracters and individual differences in distractibility).

Imaging studies have also provided support for the load theory in showing that the level of perceptual load determines the level of visual cortex activity related to the presence of various task-irrelevant stimuli. Such stimuli include meaningless checkerboards patterns, moving dots, meaningful pictures of objects (O'Connor, Fukui, Pinski, & Kastner, 2002; Pinski, Doniger, & Kastner, 2003; Rees, Frith, & Lavie, 1997; Schwartz et al., 2005; Yi et al., 2004) and even invisible images (e.g., Bahrami, Rees, & Lavie, 2007).

This behavioral and imaging research convincingly demonstrates the role of perceptual load in determining distracter processing, from early unconscious processing (mediated by retinotopic processing in primary visual cortex) to distracter interference on performance and intrusions into conscious awareness. This line of research thus provides much evidence for the resolution of the early and selection debate offered by the perceptual load theory.

With respect to the role of attention in object recognition, the question at the heart of this debate, load theory suggests that distracter object recognition should depend on the level of perceptual load in the attended task. Some of the previous studies have generalized the effects of perceptual load to measures of behavioral interference effects and brain activity related to meaningful distracter objects (e.g., Forster & Lavie, 2008; Lavie, Ro, & Russell, 2003; Lavie, 2006; Pinski et al, 2003; Yi et al., 2004). However, these studies have used a small set of distracter objects that were repeated many times throughout the experiment. Such a procedure cannot reveal whether a meaningful distracter object could be recognized upon its first presentation. In addition, the previous research did not yet directly relate load theory to object recognition theory. This was the overall aim of the present study.

Relating Perceptual Load Theory to Object Recognition

Research in object recognition (see e.g., Biederman, 2001; Logothetis & Sheinberg, 1996; Peissig & Tarr, 2007) is traditionally concerned with the nature of the object representations that are formed. Specifically, this research investigates whether the representation is 2D view dependent (e.g., representation of a car just as seen from its back) or 3D view invariant, allowing one to recognize an object independent of its presentation view (e.g., recognition of an object as a car regardless of whether it is seen from the front or the back). Previous research has not yet considered how these important principles of object recognition are affected by the level of perceptual load.

Thus, in the present study, we examined the effects of perceptual load on object recognition while considering the nature of the distracter object representations (specifically whether these are view dependent or view independent). Recall that perceptual load theory adopts a capacity approach, in which all perceptual processing (not just advanced stages, e.g., those that allow for explicit representations) has limited capacity. High perceptual load can significantly modulate very basic perceptual processing (such as detection sensitivity for a light flicker; Carmel et al., 2007) or for stimulus presence (vs. absence; Macdonald & Lavie, 2008), as well as the associated activity in primary visual cortex, and under some conditions even the lateral geniculate nucleus (O'Connor, et al., 2002). This capacity approach and supportive findings led us to predict that high perceptual load would reduce recognition levels even when the distracter objects were always presented in the same view. Although object repetition in the same view allows for recognition based on more rudimentary, view-dependent representations the previous findings suggest that perceptual load can reduce the extent to which such rudimentary representations are formed. On the other hand, in conditions of low perceptual load we predicted that distracter objects would be recognized even when presented in different views. "Spill-over" of attentional capacity in tasks of low perceptual load should result in view-invariant representations of the distracter objects.

Interestingly, somewhat different predictions can be derived from one of the most detailed object recognition models, the hybrid object recognition model (Hummel, 2001; Hummel & Stankiewicz, 1996), which considers the role of attention in object recognition but suggests that it has a more restricted role. Hummel and colleagues suggest that attention is only needed to form "analytic" object representations that involve structural, view-invariant description of the spatial relations of object parts. View-dependent, "holistic" representations, however, are preattentive. In contrast with the perceptual load theory, the hybrid object recognition model implies that distracter object recognition would remain unaffected by the level of perceptual load in the task when the distracter objects are always repeated in the same view. We tested these contrasting predictions both for short-term recognition (over a period of a few seconds, Experiments 1–3) and for long-term recognition (over a period of several minutes, Experiment 5).

In addition, in Experiments 4 through 5b we also tested the prediction derived from load theory that the spillover of attention in conditions of low perceptual load would allow for full representations of the irrelevant distracter objects, including their 3D structural descriptions. This would result in distracter object rec-

ognition being viewpoint-independent in tasks with low perceptual load.

These predictions appear to contrast with the overall claim of the hybrid object recognition model that structural descriptions cannot be formed for unattended objects. The object recognition model does not distinguish between unattended processing under conditions of low or high perceptual load. However, according to the load theory of attention, supposedly unattended distracter objects are only truly unattended in conditions of high perceptual load.

So far, the role proposed for attention in object recognition in the hybrid object recognition model received empirical support in studies measuring object recognition with an object-naming repetition-priming paradigm in which attention was manipulated through spatial cuing (Stankiewicz, Hummel, & Cooper, 1998; Thoma & Davidoff, 2004). We discuss these studies in greater detail later on (in the Results & Discussion of Experiment 4a); for now we just briefly mention that these studies have not varied the level of perceptual load and so neither body of previous studies (those that have addressed perceptual load or those that have addressed the role of attention in object recognition) have examined the effects of perceptual load on explicit object recognition across the same or different viewpoints. This was the purpose of the present study. In Experiments 1 through 4, we measured recognition using a repetition-priming paradigm. In Experiment 5, we measured recognition with a surprise recognition memory test that followed exposure to distracter objects during performance of an attentional task in which we varied the level of perceptual load.

Experiment 1

An object-naming repetition priming task was used. Subjects were asked to name familiar target objects presented in pairs of

prime and probe displays. Object recognition was measured through the facilitation effects in naming of the probe target when this was presented in the prime. A wide range of familiar objects from the Snodgrass and Vanderwart (1980) list was used. Each object was presented only once as a target.

This task was modified so that the level of perceptual load in the prime displays could be varied. Whereas the probe target objects always appeared at fixation the prime task involved visual search. Subjects were required to search for the target object in the prime display in one of three central positions: at fixation, and above or below fixation. Perceptual load was manipulated in the prime search task by varying the relevant search set size (e.g., Lavie, 1995; Lavie & Cox, 1997).

In the low perceptual load condition, the target object appeared among two place holders (circles). In high perceptual load condition, the target appeared among two meaningless nontarget objects (created by scrambling the features of familiar objects). Figure 1 presents an example high perceptual load trial. Meaningless (rather than meaningful) nontarget objects were used so that increased perceptual load would not also involve increased load on naming. A control experiment established that our scrambling procedure was successful in preventing recognition and naming of the nontarget objects (see the Method section for details).

In addition, each of the prime displays contained a meaningful task-irrelevant distracter object on the left or right that subjects were asked to ignore. The irrelevant distracter object was either repeated as the target of the following probe display (on one third of the trials) or not repeated (on another third of the trials) and on another third of the trials, the prime target object was repeated as the probe target. Whenever an object was repeated, it was repeated in the same view as that presented in the prime.

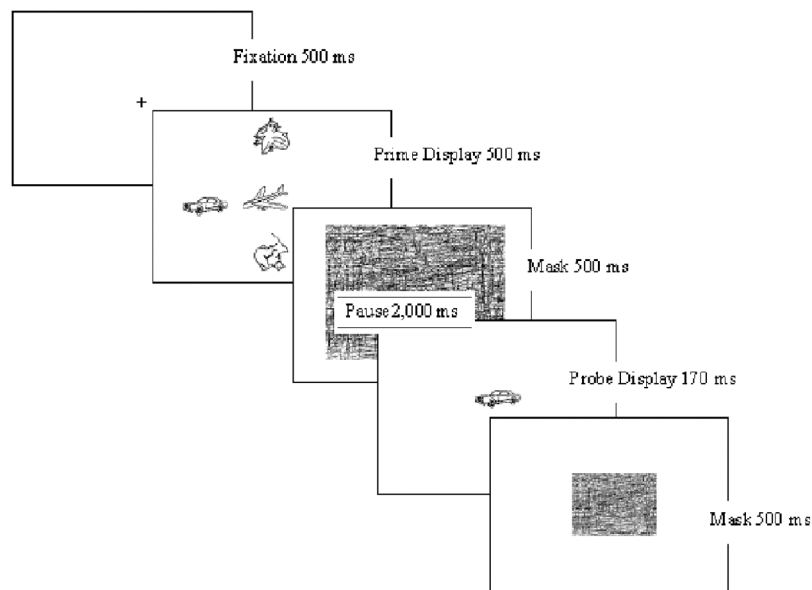


Figure 1. An example of a high-load trial in Experiment 1. Note that the target could appear in any of the three central column positions. In the low-load conditions, the nontarget scrambled objects were replaced with circular place holders.

As we previously discussed, the perceptual load theory predicts that repetition priming effects for the distracter objects should be significantly reduced in the high (compared to the low) perceptual load conditions. By contrast, the hybrid object recognition model (e.g., Hummel, 2001) predicts that repetition priming for ignored distracter objects that are repeated in the same view should remain unaffected by the level of perceptual load in the task (because the more rudimentary, view-based, object representations are preattentive). Repeated target objects, however, should be fully attended under both conditions of load. Thus, both the perceptual load theory and the hybrid object recognition model predict equivalent priming for target objects across conditions of load.

Method

Participants. Twenty-one members of the participant pool of the Department of Psychology, University College London, took part in the experiment. They were paid £3 to participate. All were native English speakers and had normal or fully corrected vision. Three subjects were excluded because of overall error rates of over 33%. The analysis of results was based on the remaining 18 participants (3 male) whose age ranged between 18 and 53 years.

Stimuli. Black and white line drawings of objects from the Snodgrass and Vanderwart (1980) set were displayed on a 15-inch PC monitor. Participants sat approximately 90 cm from the display. All images were standardized in size such that they subtended 1.6° of visual angle (2.5 cm) along their main axis of elongation (i.e., horizontal or vertical). A random-line pattern mask that covered the whole screen (15.6° of visual angle, 24.5 cm) was presented following prime displays and a smaller random-line pattern mask ($4.6^\circ \times 3.45^\circ$, 7.2 cm \times 3.45 cm) was presented at the screen center following probe displays. An outline circle ($0.25^\circ / 0.4$ cm) was presented before each trial. Fixation was indicated with a cross ($0.25^\circ / 0.4$ cm).

A prime display consisted of a target object that appeared either at fixation, above fixation, or below fixation (with its center 1.75° [2.75 cm] from fixation) and nontargets that appeared at the two locations not occupied by the target. The nontarget objects were either scrambled nonobjects (high load) or simple circles (low load) of the same size. An additional distracter object was presented to the left or the right of fixation (with its center 2.25° [3.5 cm] from fixation). The probe display consisted of a single object shown at the center of the screen. The probe object was equally likely to be either the same as the prime-target or the same as the prime-distracter or a new image.

Target location (3) and distracter location (2) were counterbalanced for each of the three repetition condition (target repeated, distracter repeated, or no object repeated). The 18 variations of prime-probe trial-pairs were shown twice in each block resulting in 36 trial-pairs (72 trials in total) in each block. Each of the particular objects appeared only in one prime-probe pair throughout the experiment.

The repeated objects were drawn from six subsets of 12 objects each, which were presented as probes (72 objects for 72 trials). These six subsets were counterbalanced across subjects so that each object appeared in a particular condition (repeated attended, repeated distracter, and unrepeated, for high and low load) equally often as a probe. The unrepeated image (i.e., the image in the prime display that was not displayed as a probe) was randomly

selected from a different set of 96 images. Each of the unrepeated objects appeared in only one trial-pair.

A third set of 60 objects was used to produce scrambled objects for the nontarget objects in the high-load condition. The scrambled objects were created by first rotating an object and then using a filter (PluginCommander 2.0) in Adobe Photoshop 6.0 that divided the image into four quadrants, then “flipped” and reshuffled these quadrants vertically or horizontally. In some cases, this manipulation did not form a coherent object (because not all flipped quadrants appeared connected to each other). These quadrants were then manually moved to form a coherent object. To ensure that the scrambled objects did not afford naming based on their parts, we asked 7 new participants to name the scrambled objects. Even though these objects were now at the center of attention and presented at fixation (rather than unpredictably in one of three locations) and the participants were given 3 s to name these objects, they were only able to name 15% of these objects on average ($SE = 3.85$). In contrast, 97% of the intact objects on average ($SE = 1.1$) were named correctly under these more optimal conditions.

Procedure. The participants were instructed to name the target objects on the prime and probe as quickly and accurately as possible and ignore the distracter object on the prime. Naming latencies for target and probe objects were collected using E-Prime 1.0 (PST) with a dynamic trigger microphone attached to a response box.

An outline circle was presented before each trial. Subjects initiated each trial by pressing the space bar. A fixation cross was then presented at the display center for 500 ms, followed by a blank white screen presented for 30 ms and a prime display shown for 500 ms. The prime display was replaced with a 500-ms mask display, followed by a blank screen displayed for 2,000 ms. Subjects were requested to respond to the prime object as soon as they could recognize it and this procedure provided them 3 s to make their naming response. Following the 2-s blank screen a probe image was shown in the center of the screen for 170 ms, followed by a 500-ms mask. Subjects were also requested to respond to the probe object as soon as they could recognize it and were provided with 3 s to make their probe naming response. After the probe response, or a waiting period of 3,000 ms, the computer displayed the names of the target and the probe object, as well as the probe response time (collected from the onset of the probe display). This marked the end of each trial-pair, at which stage the experimenter used the keyboard to record the participant’s accuracy as well as voice key errors (i.e., when the voice key triggered erroneously). The participant could then initiate the next trial with a key press. Each subject completed one low-load block and one high-load block, each preceded by a block of 16 example trials using a set of objects different from the experimental set. The order of low- and high-load blocks was counterbalanced between subjects. The ordering of trials within a block was randomized for each subject, as was the pairing of target and distracter objects on prime trials.

Results

Trial pairs with a voice key error ($M = 3\%$) were excluded from all analyses.

Prime responses. One-way within-subject analyses of variance (ANOVAs) were conducted on the correct prime RTs and

error rates with the factor of load (low, high). These ANOVAs showed a main effect on the prime RTs, $F(1, 17) = 25.8, p < .001, MSE = 4,792$, and on the prime error rates, $F(1, 17) = 68.8, p < .001, MSE = 4.2$. The mean prime RT was 867 ms under low load (M error rate = 1%) and 985 ms (M error rate = 17%) under high load. Thus, load was effectively manipulated in the target processing of the prime display, with poorer performance under high load.

Probe responses. Only probe responses that followed a correct prime response were entered into analysis in all the experiments reported. For the RT analysis, incorrect probe trials ($M = 5%$) were excluded as well. Thus, 14% of the trial-pairs were removed from the probe RT analysis (Table 1).¹

To examine whether perceptual load of the prime had affected the baseline RTs in the probe we compared the mean baseline RTs in the unrepeated conditions.² The mean baseline RT was 827 ms in the low-load condition and 845 ms in the high-load condition, a nonsignificant difference, $t(17) < 1$. Priming was calculated for each participant by subtracting the participant's mean RT in the repeated conditions (target or distracter) from their mean RT in the baseline conditions in each of the load conditions.

Figure 2 presents the priming results. A two-way within-subject ANOVA on the priming effects as a function of the repetition object (target, distracter) and load (high, low) revealed a main effect for the repetition object, $F(1, 17) = 120.1, p < .001, MSE = 6,264$. The overall level of priming was higher for repeated target objects than for repeated distracter objects. This is expected because of the contribution of response repetition to the priming effects found for the targets (that are repeatedly responded to when primed) but not for the distracters (that are only named when presented as probe targets). There was no main effect for load, $F(1, 17) = 2.1, p > .16, MSE = 23,382$, but, critically, there was an interaction between load and repetition object, $F(1, 17) = 4.8, p < .05, MSE = 4,810$. As can be seen in Figure 2 although priming for repeated targets was unaffected by load ($F < 1$), priming for repeated distracters was significantly reduced by high load, $F(1, 17) = 4.22, p = .05, MSE = 69,301$.

Paired t tests of primed (target or distracter repeated) versus baseline RT in each of the load conditions confirmed that priming by repeated target objects was significant in both the high-load, $t(17) = 10.5, p < .001$ and the low-load, $t(17) = 8.6, p < .001$

Table 1

Experiment 1: Mean Response Time (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of Prime Load and Repetition Conditions

Prime load	Repetition condition		
	TR	DR	NR
Low			
<i>M</i>	588	757	828
<i>SE</i>	15	27	34
Percent error	2	7	5
High			
<i>M</i>	622	862	846
<i>SE</i>	22	28	27
Percent error	5	4	6

Note. TR = target repeated; DR = distracter repeated; NR = not repeated.

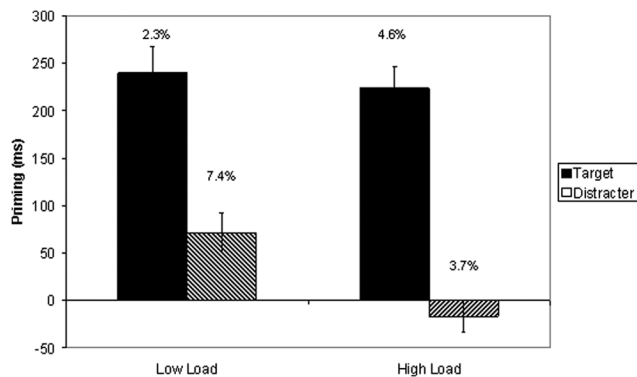


Figure 2. Experiment 1 results. Means and Standard errors for priming (baseline RT minus repeated objects RTs) effects as a function of load and repetition object ($n = 18$).

conditions, whereas priming by repeated distracter objects was only significant in the low-load conditions ($t(17) = 3.4, p < .01$) but not in the high-load condition ($t < 1$).

The probe error rates were low and equivalent analyses to those run on the RT were therefore conducted using nonparametric tests. These showed no significant effects (all $ps > .10$), thus establishing that there was no speed-accuracy tradeoff.

The present results provide initial support for our prediction that increased perceptual load would significantly reduce recognition of distracter objects even when they are repeated in the same view. The reduction, indeed elimination, of distracter repetition priming effects with increased load suggests that engaging attention in a task of high perceptual load reduces the extent to which rudimentary, view-dependent representations of distracter objects are formed, and hence reduces the level of distracter recognition even when the distracter objects are repeated in the same view. Experiment 2 seeks to generalize this finding over a different manipulation of perceptual load.

In addition, the findings that repetition priming effects were reduced with high load only for distracters but not for targets allow us to rule out alternative accounts for the effect of load in terms of a general change in the processing priorities or strategies. A general change in the processing strategy with load (e.g., reverting to a more local part-based processing under conditions of high perceptual load)³ should result in reduced repetition priming effects from both the distracter and the targets. Other alternative accounts that attribute the effects of perceptual load to a higher priority given to targets over distracters with high (vs. low) load

¹ To ensure that the results were not somehow because of the higher number of trials excluded in the high load condition, we ran an additional analysis of the probe RT results with the incorrect prime and probe responses included. This showed the same pattern of results (reduced repetition priming by the distracters under high [vs. low] load) as that shown by the analysis of the RT for the correct responses only.

² We note that the main effect of load on the RTs can only be adequately assessed in the unrepeated baseline conditions. The RTs in the repeated trials are affected by repetition priming effects and as such preclude a clear assessment of the effects of load per se.

³ We thank an anonymous reviewer for suggesting this alternative account.

(e.g., Torralbo & Beck, 2008) are also ruled out. In such accounts target repetition priming effects should be reduced in the low-load conditions where the attentional bias to targets is not as strong.

In contrast, our finding that high perceptual load reduced distracter—but not target—recognition is exactly as we predicted from our claim that distracter recognition depends on the extent to which task-relevant processing leaves any spare capacity. Strategy-based accounts for the effects of perceptual load are further addressed in Experiment 3.

Experiment 2

In Experiment 1, we increased perceptual load by increasing the number of relevant stimuli. As discussed in the General Introduction, perceptual load can also be varied by changing the perceptual processing requirements for the same number of task objects (see Lavie, 2005 for a review). For the sake of generality in Experiment 2, we varied the processing requirements in the task without altering the number of objects.

For this purpose, we manipulated perceptual load in Experiment 2 by presenting the target of the prime display either in a familiar (upright) orientation (low-load condition) or in an unfamiliar (upside-down) orientation (high-load condition). In all other respects, the displays in Experiment 2 were very similar to those used in the low-load conditions of Experiment 1. Note in particular that only the orientation of the target objects in the prime displays was varied, whereas both of the objects presented as the prime distracter and the probe target remained in their upright position across the load conditions. The manipulation of load by flipping the target object around its horizontal axis was inspired by numerous findings of reduced efficiency of object recognition for objects in unfamiliar orientation (e.g., McMullen & Jolicoeur, 1990, 1992; Murray, 1995a, 1995b, 1998, 1999; Murray, Jolicoeur, McMullen, & Ingleton, 1993).

As before, the perceptual load theory and the hybrid object recognition theory lead to contrasting predictions. Repetition priming effects produced by distracter objects that are repeated in the same view are expected to remain unaffected by the level of perceptual load in the task according to the hybrid object recognition model. In contrast, according to the load theory, high perceptual load is expected to reduce even rudimentary view-based distracter representations. Therefore, we predicted that repetition priming effects would be reduced even for distracters that are repeated in the same view.

Method

Participants. Seventeen members from the participant pool of the Department of Psychology, University of London, were recruited for the experiment. They were paid £3 to participate. All were native English speakers and had normal or fully corrected vision. One subject was excluded because of a voice key malfunction. The analysis of results was based on the remaining 16 participants (7 male) whose age ranged between 18 and 32 years.

Stimuli and procedure. The apparatus was the same as in Experiment 1. The stimuli were similar to those of the low perceptual load condition in Experiment 1, except that for the target stimuli only objects from the Snodgrass and Vanderwart (1980) list that had a single familiar upright orientation (e.g., a car) were

used. For example, tools (e.g., a hammer) or some music instruments (e.g., trumpet) were not used as they are familiar in multiple viewpoints (Vannucci & Viggiano, 2000). Target location (3) and distracter location (2) were counterbalanced for each of the two repetition conditions (distracter repeated vs. not repeated). The 12 variations of prime-probe trial-pairs were shown three times in each block producing 36 trial-pairs (72 trials in total) in each block.

As in Experiment 1, an object appeared in only one trial-pair for any given participant. There were 72 objects used as probe-targets and 72 different objects used as prime targets. Probe and target objects were counterbalanced across participants such that each object appeared in each condition equally often. Distracter objects in the unrepeated condition were randomly selected from a set of 36 objects. The procedure of Experiment 2 was the same as Experiment 1 with two exceptions: (1) there were no trials in which targets were repeated, and (2) perceptual load was manipulated by presenting the target object in the prime display either right-way up (low load) or upside-down (high load). Both the prime distracter and the probe target remained in their upright position across the load conditions. The ordering of the 36 trial-pairs in each block and the pairing of repeated and unrepeated objects on prime trials were randomized for each participant.

Results

Trial pairs with a voice key error ($M = 3\%$) were excluded from all analyses in this experiment. One-way within-subject ANOVAs on the correct prime RTs and error rates with the factor of load showed a main effect on the prime RTs, $F(1, 15) = 26.10$, $p < .001$, $MSE = 3,475$, and on the prime errors, $F(1, 15) = 6.57$, $p < .01$, $MSE = 0.59$. The mean prime RT was 949 ms under low load (M error rate = 4.7 %) and 1,056 ms (M error rate = 9.7 %) under high load. Thus, load was again effectively manipulated.

Probe responses. Table 2 shows the results for the probe responses. Incorrect probe trials ($M = 4\%$) were excluded from the RT analyses. Thus, 12.7% of trial-pairs were removed from the RT analysis. As can be seen in Table 2, the mean baseline RT was 823 ms in the low-load condition and 799 ms in the high-load conditions, a nonsignificant difference, $t(15) < 1$.

Table 2
Experiment 2: Mean Response Time (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of Prime Load and Distracter Conditions

Prime load	Distracter condition	
	DR	NR
Low		
<i>M</i>	772	823
<i>SE</i>	22	36
Percent error	5	4
High		
<i>M</i>	809	799
<i>SE</i>	23	20
Percent error	5	3

Note. DR = distracter repeated; NR = not repeated.

A two-way within-subject ANOVA of the RTs with the factors of distracter repetition (repeated vs. unrepeated) and load (high vs. low) revealed no effects of distracter repetition, $F(1, 15) = 1.3$, $MSE = 5,183$, $p > .28$, or load, $F(1, 15) < 1$, $MSE = 6,753$, $p > .75$. Importantly, there was a significant interaction, $F(1, 15) = 5.2$, $MSE = 2,888$, $p < .04$. The pattern revealed by this interaction was as predicted by the load theory: repetition priming from the ignored objects was only found in the low-load condition, $t(15) = 2.1$, $p < .05$, but was eliminated in the high-load condition, $t(15) < 1$. A Friedman ANOVA on the low error frequencies between all four condition was not significant, $\chi^2(3) = 1.28$, $p > .73$, thus establishing that there was no speed-accuracy tradeoff.

These results provide further support for the hypothesis that high perceptual load in the task modulates the extent to which distracter objects can be recognized even when they are repeated in the same view across the prime and probe. In contrast with previous claims that view-dependent object recognition does not require attention (e.g., Stankiewicz et al., 1998), this experiment demonstrates that recognition of distracter objects repeated in the same view does depend on a spill-over of attention (see also Experiments 4 and 5).

Note that in this experiment perceptual load was increased for the same number of objects in the prime display. This manipulation of load allows us to rule out alternative accounts in terms of any specific factor associated with increased number of objects in high load (e.g., specific cross talk in binding parts into objects, e.g., Hummel, 2001) rather than availability of attentional capacity.

Experiment 3

In Experiment 3, we sought to further generalize the effects of load on object recognition over another manipulation of perceptual load that can allow us to rule out any strategy-based alternative accounts for the effects of perceptual load. In this experiment, we manipulated load using a letter-search task. A circle of six letters was presented on each of the prime displays together with a meaningful 3D image of a distracter object at fixation. Subjects were asked to ignore the distracter object at fixation and search the letter circle for either of the target letters X or N. We varied the level of search load through the similarity of the target and nontarget letters and the heterogeneity of the nontarget letters. In the low-load condition, all the nontarget letters were O's. In the high-load condition, the nontarget letters were K, R, V, S, or L. This is a well-established manipulation of visual search load (see Duncan & Humphreys, 1989, for review) that has been used in many of the previous perceptual load studies (see Lavie, 2005, for a review).

As before, after the prime response participants were asked to name the object in a probe display. We measured distracter recognition through the effects of repetition priming. In a change from the previous experiments, we varied the level of perceptual load randomly within the same block. A replication of the load effects with such a design would allow us to rule out any alternative accounts in terms of potential strategy differences in the two conditions of perceptual load. This same approach has been adopted in several previous studies (Brand-D'Abrescia & Lavie, 2007; Cartwright-Finch & Lavie, 2007; Lavie & Cox, 1997; Lavie

& Fox, 2000; Theeuwes, Kramer, & Belopolsky, 2004), each successfully ruling out differential strategies as an alternative explanation of the perceptual load effect. Nevertheless, it seemed desirable to establish that such alternative accounts cannot explain the effect of perceptual load on object recognition found here.

Method

Participants. Twenty-eight participants (9 males) aged between 19 and 42 from the participant pool of the Department of Psychology, University College London took part for £3 or course credits. All were native English speakers and had normal or corrected-to-normal vision.

Stimuli and procedure. The prime display consisted of a circular array of six letters in the center of the screen surrounding a color image of an upright common object. The letters were either one of two targets (X or Z) and five nontargets (five times the letter "O" in low load and letters K, R, V, S, L in high load). The diameter of the circular array was 6 cm, and the distracter object appeared 1 cm from the outer edge of the closest letter. The distracter object was presented at an average size of 4 cm. Participants were placed at a distance of 60 cm from the screen. The stimuli were color images of common objects from the Tarr (<http://www.tarrlab.org/>) image data bank. The procedure was similar to that of Experiment 1 except for the following changes: The prime display appeared only briefly for 195 ms (to prevent eye movements); a neutral letter search task (to find targets X or Z among similar or dissimilar nontargets) instead of an object-naming task was used in the prime display. The participants saw only one object (the distracter) in the prime display while performing the letter search task, in which they were required to press X and Z on a keyboard, and they performed a different task (naming the object) in the probe display. The probe object was either the previous distracter object in the prime display (shown in the same view) or was a new object that was not presented previously. As in the previous experiments, the single probe object appeared in the center of the screen (for 195 ms) and had to be named out loud.

Subjects were acquainted with the experiment by gradually increasing the complexity of the practice trials. Subjects started with four blocks of 16 practice trials each. In the first block of 16 trials, they looked for targets X and Z under low load without a distracter object in the prime display and without a probe display (so that there was no naming task). In the second block, they again only practiced the letter search task but this time under high load only. In the third practice block, they performed the letter search task with low-load and high-load trials intermixed. In the fourth and final practice block, the full trial sequence was presented and they performed the letter search task (prime display) followed immediately by the object naming task (probe display). This was followed by a block of 72 experimental trials. The factors load (high vs. low), repetition (repeated vs. unrepeated), and position of the target letter (6) were fully counterbalanced. The target letters (Z or X) were randomly assigned to each trial with equal probability. The whole experiment lasted about 35 min.

Results

Trial pairs with a voice key error ($M = 9.8\%$) were excluded from all analyses in this experiment. One-way within-subject

ANOVAs were conducted on the correct prime RTs and error rates with the factor of load (low, high). These ANOVAs showed a main effect on the prime RTs, $F(1, 27) = 87$, $MSE = 3,050$, $p < .001$, and on the prime error rates, $F(1, 27) = 30.5$, $MSE = .004$, $p < .001$. The mean prime RT was 729 ms under low load ($SE = 27$; M error rate = 4%) and 867 ms ($SE = 32$; M error rate = 15%) under high load. Thus, again, load was effectively manipulated in the target processing of the prime display, with poorer performance under high load.

Probe responses. Only response times to probe displays that followed a correct response to both the prime and probe display were analyzed. For the RT analysis incorrect probe trials ($M = 5\%$) were excluded as well. Thus, 11.2% of trial-pairs were removed from the RT analysis. As can be seen in Table 3, the mean baseline RT was 1,028 ms in the low-load condition and 1,018 ms in the high-load conditions, a nonsignificant difference, $t(27) < 1$.

A two-way within-subject ANOVA on the probe RTs as a function of repetition (repeated vs. unrepeated) and load (high vs. low) revealed a main effect for repetition, $F(1, 27) = 40.2$, $p < .001$, $MSE = 16,643$, with shorter RTs for repeated objects, and a main effect for load, $F(1, 27) = 5.32$, $p < .05$, $MSE = 6,704$, with shorter RTs in the low-load than in the high-load condition.

These main effects were qualified by a significant interaction between load and repetition, $F(1, 27) = 5.62$, $p < .05$, $MSE = 10,306$. The interaction reflected a greater RT facilitation in the repeated distracter conditions in the low-load compared to the high-load conditions, $t(27) = 2.37$, $p < .05$. This modulation of repetition priming by load is exactly as predicted by the Load Theory. Because the level of perceptual load was now varied randomly within blocks, the present load effects cannot be accounted for in terms of a change in strategy.

A Friedman ANOVA on the low error frequencies in the probe responses revealed no significant difference between the four conditions, $\chi^2(3) = 3.45$, $p > .33$; thus, there was no indication of a speed-accuracy tradeoff.

Experiment 4a

Experiments 1 through 3 demonstrated that high perceptual load in the task eliminates any repetition priming effects produced by distracter objects that are repeated in the same view across dis-

Table 3
Experiment 3: Mean Response Time (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of Perceptual Load and Repetition Conditions

Perceptual load	Repetition condition	
	DR	NR
Low		
<i>M</i>	828	1,028
<i>SE</i>	30	33
Percent error	5	6
High		
<i>M</i>	909	1,018
<i>SE</i>	35	27
Percent error	4	5

Note. DR = distracter repeated; NR = not repeated.

plays. Experiment 4 tested a complimentary prediction regarding object recognition across changes in the object views under conditions of low perceptual load.

As discussed in the beginning of the article, the hybrid object recognition theory suggests that unattended objects would not be recognized if these are repeated in a different viewpoint: view-invariant recognition requires structural description and forming such a representation requires attention. Load Theory concurs with this suggestion as long as recognition is assessed for task-irrelevant objects that are truly unattended. Recall however that on the Load Theory the instruction to direct attention to one object while ignoring another object does not make the to-be-ignored object truly unattended: in tasks of low perceptual load, the to-be-ignored distracter object would still receive attention because of the spillover of any attentional capacity that was left over from the task-relevant processing. Such spillover of attention should therefore allow for a full representation of distracter objects including their structural description, and this should result in view-invariant recognition.

Thus, for situations of low perceptual load, the two theories make contrasting predictions. Based on the general concept of attention adopted in the hybrid object recognition model, this model predicts that the to-be-ignored distracter objects would be recognized only if presented in the same view but not in a different view (because it assumes that when subjects direct their attention to one object, the to-be-ignored distracter object is simply unattended, e.g., Stankiewicz et al., 1998). In contrast, the Perceptual Load Theory predicts that because of spillover of attention in tasks of low perceptual load the distracter objects would be recognized even across different views. To test these contrasting predictions, we presented the distracter objects either in the same-view or in a mirror-reflected view across the prime and probe displays in the low perceptual load condition of Experiment 1.

Method

Participants. Twenty-four members from the participant pool of the Department of Psychology, University of London, were recruited for the experiment. They were paid £3 to participate. All were native English speakers, had normal to fully corrected vision, and were aged between 18 and 37 years.

Stimuli and procedure. The stimuli and procedure in Experiment 4a were the same as in the low-load condition of Experiment 1 except for the following changes. First, black dots (3×3 pixels, instead of circles) were used as place holders. Second, the stimulus set used for prime distracters was modified to include only objects that were asymmetrical along the vertical axis (e.g., objects such as a snowman or a butterfly were excluded).

There were three distracter repetition conditions: distracter repeated in the same view, distracter repeated in a mirror-reflected view, and distracter not repeated. These conditions were randomly intermixed between the trials of each block. The nonrepeated distracter objects were presented facing the same direction in the prime and probe displays (e.g., a distracter car with its front to the left on the prime display, followed by a target ant with its head to the left in the probe display) on half of the trials and the opposite direction on the other half. The direction of facing for all objects was counterbalanced across subjects. Each subject was submitted to 16 example trials followed by two blocks of 36 trials each. The

ordering of the 36 trials in each block (including the pairing of repeated and unrepeated objects, and conditions of view) was randomized for each participant. As in the previous experiments, a particular object appeared in only one trial-pair per participant. Six clusters of 18 objects each were used for the distracters (two clusters for repeated conditions and four clusters used in unrepeated conditions in which distracter and probe objects were different). These six subsets were counterbalanced across subjects so that each object appeared in a particular condition (repeated same view, repeated different view, and unrepeated for same and different facing condition) equally often as a probe. In addition to the distracter/probe objects, four clusters of unrepeated objects were used in prime displays as targets only. Both types of clusters were counterbalanced across participants such that each object appeared in each condition equally often.

Results

Trial pairs with a voice key error ($M = 3\%$) were excluded from all analyses. The mean prime RTs was 908 ms (M error rate = 4.5%). Incorrect probe responses ($M = 6\%$) were excluded from the probe RT analysis. Thus, 9.5% of the total trial-pairs were excluded from analysis. A two-way within-subject ANOVA on the probe RTs as a function of distracter repetition (repeated vs. unrepeated) and view (same vs. mirror) revealed a main effect of repetition: probe target RTs were shorter when the distracter objects were repeated ($M = 794$ ms) than when they were not repeated ($M = 832$ ms), $F(1, 23) = 10.2, p < .01, MSE = 3,389$. There was also a main effect of view: target RTs were shorter when the distracter and target objects were in the same view ($M = 801$ ms) compared to a different view ($M = 825$ ms), $F(1, 23) = 4.4, MSE = 3,065, < .05$. Critically, there was no interaction between the factors of repetition and view, $F < 1$. As can be seen in Table 4, the magnitude of priming was exactly the same for distracter objects repeated in the same view or in a mirror-reflected view. Statistical comparisons of the repeated conditions and their corresponding unrepeated baselines confirmed that the priming effects were significant for both distracter objects in the same-view, $t(23) = 4.09, p < .001$, and in the mirror-reflected view, $t(23) = 2.39, p < .05$. A Friedman ANOVA on error frequencies for all four conditions was not significant, $\chi^2(2) = 5.55, p > .136$, thus establishing no speed-accuracy tradeoff.

As predicted from the load hypothesis, distracter objects produced priming effects regardless of whether they were repeated in the same view or in a different view. This suggests that spillover of attention in conditions of low perceptual load allows for view-invariant recognition of the distracter objects. We note that this result may appear to be in contrast with the results of one previous study that has used spatial cuing to manipulate attention. Using a similar assessment of object recognition through repetition priming effects on object naming as used here Stankiewicz et al. (1998) cued attention to one of two objects presented on the left or right of fixation (each 4° away from fixation) in the prime display. They found that the uncued objects produced repetition priming only when they were repeated in the same view but not when repeated in a mirror-reflected view.

The apparent discrepancy in the results of the two studies may suggest a profound difference between the effects of cuing on attention and that of load. For example, one might claim that

spatial attention (as varied with cuing in Stankiewicz et al.'s study) may specifically affect structural view-invariant representations whereas perceptual load has more general effects extending to both holistic view-dependent representations and structural view-invariant representation. However, the numerous differences in methodological details between our task and theirs (such as the greater visual acuity of our distracter objects than Stankiewicz et al.'s (1998) objects that were presented at more peripheral positions) preclude a direct comparison of the results in the two studies. It is for example possible that the combination of reduced retinal acuity and cuing in Stankiewicz et al.'s study is critical for the elimination of repetition priming from objects in a different view. Future studies that compare the effects of load, cuing and view on object recognition within the same paradigm could shed light on this point.

Experiment 4b

Experiment 4a showed that under low perceptual load, distracter objects produced repetition priming even if presented in mirror-reflected views between the prime and probe displays (c.f., Stankiewicz et al., 1998) [Table 4]. However, invariance across mirror reflection may not indicate full viewpoint invariance. Some view-selective neurons are tuned to both mirror reflection views of an object (Logothetis, Pauls, & Poggio, 1995) and observers often show invariance across mirror reflection (e.g., Biederman & Cooper, 1991; Fiser & Biederman, 2001; Seamon et al., 1997). In contrast, depth rotations typically show costs in recognition performance (e.g., Thoma & Davidoff, 2006). In Experiment 4b, we provided a stronger test for our claim that distracter representations in conditions of low perceptual load include structural descriptions. We presented photo-realistic images of 3D distracter objects from different viewpoints in 3D space (avoiding a mirror-reflection change in view). A view-invariant distracter recognition in this experiment would demonstrate that observers formed structural representations of these distracter objects.

Method

Participants. Eighteen members aged between 18 and 35 years from the participant pool of the Department of Psychology,

Table 4
Experiment 4a: Mean Response Time (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of Target View and Repetition Conditions

View	Repetition condition	
	DR	NR
Same		
<i>M</i>	782	820
<i>SE</i>	21	20
Percent error	8	5
Mirror		
<i>M</i>	806	844
<i>SE</i>	18	22
Percent error	6	5

Note. DR = distracter repeated; NR = not repeated.

University College London, were recruited and paid £3. All were native English speakers and had normal or corrected-to-normal vision.

Stimuli and procedure. The stimuli and procedure were similar to those in the low load condition of Experiment 1 except for the following changes. First, black dots (3×3 pixels) rather than circles were used as place holders. Second, instead of drawings photo-realistic images of 3D objects from different view points in 3D space were used (the Object Databank from Michael Tarr Lab at Brown University, <http://alpha.cog.brown.edu:8200/stimuli/objects/objectdatabank.zip/view>). Specifically, we selected objects in two different views with the difference ranging from 45° to 135° to find the most dissimilar views while preserving the critical parts. We grouped them into view A and view B, with the two different views of each object counter-balanced between subjects so that each view served as the prime distracter and probe target equally often. There were three conditions: the distracter object was either repeated in the same view as the probe target, or it was repeated as the probe target in a substantially different view or it was not repeated. These conditions were randomly intermixed between the trials of each block.

After 16 practice trials, subjects went through two blocks of 27 trials each. Trials in each block and the pairing of prime target and prime distracter in each trial were randomized. For each subject, a particular object appeared only in one trial. There were 72 objects randomly selected from a total set of 108 objects for each subject. Six clusters of 18 objects were used for the prime distracters and probe targets and counterbalanced between subjects so that each object appeared equally often in the three conditions (repeated in the same view, in a different view or not repeated). Four clusters of 18 objects were used for the prime targets, and their selection was counterbalanced between subjects.

Results

Trial pairs with a voice key error ($M = 7\%$) were excluded from all analyses in this experiment. The mean prime object RT was 1,068 ms, and the mean error rate for prime objects was 17%. Subjects incorrectly responded to 7% of probe objects. For the RT analysis, only responses to probe displays that followed a correct response to a prime display were analyzed. Thus, 23% of trial-pairs were removed from the RT analysis.

A one-way within-subject ANOVA of the probe RTs revealed a significant effect of repetition, $F(2, 34) = 17.2$, $MSE = 154,931$, $p < .001$ (Table 5). Planned contrasts showed that RTs in the

unrepeated conditions ($M = 1,050$ ms) was significantly longer than in the repeated same-view condition ($M = 885$ ms) $t(17) = 5.04$, $p < .001$, or in the repeated different-view condition ($M = 896$ ms), $t(17) = 4.48$, $p < .001$. There was no significant difference between the repeated same-view or different-view conditions, $F < 1$. A Friedman ANOVA on the probe error frequencies in the three conditions showed no difference between conditions, $\chi^2(2) < 1$, thus establishing no speed-accuracy tradeoff.

Thus, as in Experiment 4a, a task-irrelevant distracter object produced repetition priming effects irrespective of whether it was repeated in the same view or in a different (here rotated in depth) view, in support of our claim that in low-load tasks automatic spill over of attention allows for recognition of distracter objects across different views.

Experiment 5

In all of the present experiments, we have used selective attention task procedures. The participants were explicitly instructed to ignore the irrelevant distracter, and the distracter object was presented in an irrelevant position that was clearly separated from the target position. However, the repetition priming task used in Experiments 1 through 4 may have unwittingly involved an incentive for the participants to pay attention to the distracters because the distracter objects were repeated as the probe targets. One may then argue that the participants in these experiments treated the task as a divided (rather than selective) attention task. In other words, participants may have ignored the instruction to ignore the irrelevant distracters, attempting to divide their attention between the relevant objects and the distracter objects whenever possible (i.e., under conditions of low but not high perceptual load).

This issue does not influence our present conclusions regarding the role of attention in object recognition. Specifically, our conclusion that object recognition depends on the allocation of limited-capacity attention, even when objects are repeated in the same view, holds irrespective of whether a divided or a selective attention task was used.

However, the resolution to the early versus late selection debate offered in the Load Theory clearly rests on the assumption that the participants always treat selective attention tasks as divided attention tasks, in the sense that they allocate any spare capacity to task-irrelevant stimuli even when there is no incentive to do so (because the spillover of attention to irrelevant distracters is involuntary). Thus, in Experiment 5 we sought to examine whether the effects of perceptual load on object recognition would be found in a selective attention task in which there is no incentive to pay attention to the irrelevant distracters. To that purpose, the participants in Experiment 5 performed a letter search task and were instructed to ignore irrelevant distracter objects as before; but in a change from the previous experiments, the distracters were never repeated as targets during the attention task. We assessed distracter object recognition in a surprise recognition test that followed the selective attention task. In the recognition test, participants were presented with two objects on each trial and had to indicate which of the two was presented in the attention task. In Experiment 5a, we tested the effects of perceptual load on distracter object recognition and in Experiment 5b, we tested the effects of a 3D change in the viewpoint.

Table 5
Experiment 4b: Mean Response Time (ms), Standard Errors, and Percentage Errors for Performance in the Probe Displays as a Function of the Repetition Condition

Variable	Repetition condition		
	Same view	Different view	No Repetition
<i>M</i>	885	896	1,050
<i>SE</i>	34	37	39
Percent error	6	8	7

Method

Participants. Twelve healthy volunteers (8 males) with an average age of 24 years (ranged between 20 and 45) were recruited from the subject pool of the Department of Psychology, University College London. They all had normal or corrected-to-normal vision and were given £3 upon taking part in the study.

Stimuli and procedure. Participants were instructed to perform a letter search task and ignore irrelevant distracter objects that were presented at fixation. The letter search task stimuli and procedure were the same as those used in the prime displays in Experiment 3. Probe displays were no longer included. The distracter objects presented were selected from the same set of objects as that used in Experiments 3 and 4b and had the same dimensions.

Following performance of the attention task, participants were asked to perform a surprise recognition-memory task. Two images of objects (of the same dimensions as those presented during the experiment) were presented 2.25° on the left or right of fixation (measured to the object center), and the participants were asked to indicate which of these was presented as a distracter in the attention task (pressing either '1' to indicate the left object or '2' to indicate the right object). The memory displays remained until the participants made a response. In Experiment 5a, the distracter objects were presented in the same view in both the attention task and memory test. In Experiment 5b, half of the objects were presented in the same view and the other half in 3D rotated view, using the same viewpoint changes as in Experiment 4b. No feedback was given on performance in the memory test.

In Experiment 5a, each participant completed three practice blocks of 18 trials: low load, high load and intermixed. No distracter object was present in these blocks. Practice blocks were then followed by one experimental block of 48 trials (24 low-load trials and 24 high-load trials, intermixed in random). In Experiment 5b, each participant completed one practice block of 18 trials with the search task under low load (but with no distracter object). This was followed by one experimental block of 48 low-load trials. Each experiment was followed by a surprise recognition memory test in which 48 displays were presented (with a distracter object and a foil in each one).

In both experiments, we counterbalanced object identity and conditions such that each object was presented as a distracter in either the low-load or the high-load conditions or as a foil in the recognition test with equal probability across the different participants. Target letter identity (2), position in the attention task (6), as well as object position in the recognition test (left vs. right) were counterbalanced in each of the conditions of load.

Results

Experiment 5a. High load in the search task resulted in longer RT ($M = 857$ ms) and increased error rates ($M = 79\%$ compared to the low-load condition (M RT = 645 ms; M error rate = 94%), $t(11) = 7.87, p < .001$ for the difference in RT; $t(11) = 6.31, p < .001$, for the difference in error rates. This confirmed that perceptual load was successfully manipulated in this search task.

Trials with an incorrect response in the attention task were excluded from the analyses of the recognition test performance in both Experiments 5a and 5b (but inclusion of the incorrect attention trials did not influence the results pattern or their statistical significance). As we predicted, the mean percentage correct rec-

ognition rates in the memory test were significantly higher in the low-load condition ($M = 65\%$, $SE = 3$) compared to the high-load condition ($M = 50\%$, $SE = 3.6$), $t(11) = 3.170, p < .01$.

Experiment 5b. The mean RT in the search task was 650 ms (M error rate = 93%), a level of performance comparable with that in the low-load condition of Experiment 5a. As we predicted, mean percentage correct recognition rates in the memory test did not differ for target objects presented in the same view ($M = 61\%$, $SE = 4.2$) compared to objects presented in a different view ($M = 60\%$, $SE = 3.9$), $t(11) = 0.04, p = .97$. Recognition rates were significantly better than chance both for objects presented in the same view, $t(11) = 2.523, p < .05$ and for objects presented in a different view, $t(11) = 2.806, p < .05$.

General Discussion

The present findings demonstrate that distracter object recognition depends on the level of perceptual load in the task. Distracter objects that subjects are instructed to ignore were nevertheless recognized, irrespective of whether these were repeated in the same or a different view, under conditions of low perceptual load in the task. High perceptual load, on the other hand, significantly reduced distracter recognition rates, bringing them to chance levels (Experiment 5a) and eliminating any repetition priming effects (Experiments 1–3). Importantly, these load effects were established for distracter objects that were repeated in the same view always (Experiments 1–3, 5a).

These findings suggest that high perceptual load that engages full capacity in task-relevant processing significantly reduces the extent to which even view-dependent representations can be formed for task-irrelevant objects, whereas spillover of attention in conditions of low perceptual load allows for full view-invariant representations of the task-irrelevant objects. These findings are the first to establish a critical role for perceptual load in object recognition, as assessed either by overt naming (Experiments 1–4) or by incidental recognition rates (Experiment 5) for a wide range of meaningful objects that are presented in the same view or in a different view to that just stored.

The convergence of the present results with results from other behavioral studies as well as neuroimaging studies on the same conclusion presents a strong case for the important role that perceptual load plays in determining object recognition. Specifically, the load-based modulation observed here of repetition priming effects for distracter objects repeated in the same view is consistent with the fMRI results of Yi et al. (2004). Yi et al. found that high perceptual load reduces the effects of distracter image repetition on fMR adaptation. This imaging finding is supportive of our conclusion that high perceptual load reduces view-dependant representations. This conclusion receives further support from the previous demonstrations that high perceptual load significantly reduces various other measures of early rudimentary object representation. Visual cortex activity related to the presence (vs. absence) of simple 2D stimuli (e.g., black and white checkerboards, O'Connor et al., 2002; Schwartz et al., 2005) is reduced with high perceptual load. The sensitivity of detection either of stimulus presence (vs. absence, Macdonald & Lavie, 2008) or of a mere light flicker (Carmel et al., 2007) is also significantly reduced under high perceptual load. Moreover, the fact that perceptual load can modulate retinotopic representations in primary visual cortex

(and the LGN, e.g., O'Connor et al., 2002) even in cases where these reflect unconscious processing (Bahrami, Rees, & Lavie, 2007) is highly compatible with our conclusion that perceptual load determines the extent to which early view-dependant representations are formed.

With respect to object recognition theory, these findings clearly challenge the claim that attention is only needed for forming view-invariant representations, whereas view-dependent representations are automatic and can be formed in a capacity-free manner (e.g., Hummel & Stankiewicz, 1996). The empirical evidence cited in support of such a claim was based on negative priming and repetition priming paradigms that did not vary the level of perceptual load and involved a rather low level of perceptual load (with just one target object, e.g., Tipper, 1985; Stankiewicz et al., 1998). Lavie and Fox (2000) have since shown that negative priming effects clearly depend on the level of perceptual load in the prime task and the present findings suggest that higher perceptual load in such paradigms would reduce even the view-dependent repetition priming effects that were found for the distracter objects under low load.

In addition, our conclusion that subjects form view-invariant representations for irrelevant distracter objects in tasks with low perceptual load appears to contradict previous claims made by the hybrid object recognition model that such representations are not formed for objects that subjects are instructed to ignore. This contradiction can however be reconciled once the concept of attention in the hybrid object recognition model takes into account the concept of perceptual load. In other words, the present research emphasizes the importance of ensuring that the relevant task involves sufficiently high perceptual load to engage full attention in the attempt to assess the nature of mental representations that are truly unattended.

In this respect, the present findings also highlight the limited effect of instruction and intentions to ignore distracters. Although these did not co-vary with perceptual load, distracter processing clearly did. The findings that subjects could not ignore the distracters as long as the task involved low perceptual load suggest that the mere instruction to ignore distracters cannot prevent their processing. The present results point instead to the need to consider the level of perceptual load in the task in determining both neural and mental representations of distracter objects.

Given the clear demonstration that even view-dependent object recognition is subject to capacity limits, an important challenge for future research would be to clarify the neural and psychological sources of these capacity limits. These may be conceived in terms of temporal limits, so that with a limited exposure duration high perceptual load results in the relevant task processing taking up all of the available time window. Alternatively one may suggest that capacity limits should be conceived in spatial terms, such that high perceptual load results in a narrower spatial extent of perceptual processing. The demonstrations that perceptual load can significantly modulate distracter processing at fixation in Experiments 3 and 5 (see also Beck & Lavie, 2004; Carmel et al., 2007) make this spatial account somewhat unlikely. To explain the effects of high load on processing a distracter at fixation in terms of a narrower spatial extent, one would have to propose that in the high-load condition, the spatial distribution of capacity was in a ring-like shape, accommodating just the letter circle area, to the exclusion of the fixated area. However, the numerous reports of failures to

distribute attention in a ring-like shape (Eimer, 1999, 2000; Eriksen & Yeh, 1985; Heinze et al., 1994; Posner, Snyder, & Davidson, 1980) make it unclear that such distribution of attention is at all possible.

To directly address accounts of the effects of perceptual load in terms of either the spatial extent or processing time, one would need to orthogonally vary perceptual load along with the available processing time (e.g., through the exposure duration) or the spatial extent of perceptual processing in the task (e.g., presenting task-irrelevant stimuli in various distances from the task-relevant stimuli). Such experiments should prove illuminating for the understanding of the sources of capacity limits in perception.

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Received April 10, 2005

Revision received January 7, 2009

Accepted February 6, 2009 ■