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Concurrent Working Memory Load Can Facilitate Selective Attention: Evidence for Specialized Load

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Load theory predicts that concurrent working memory load impairs selective attention and increases distractor interference (N. Lavie, A. Hirst, J. W. de Fockert, & E. Viding, 2004). Here, the authors present new evidence that the type of concurrent working memory load determines whether load impairs selective attention or not. Working memory load was paired with a same/different matching task that required focusing on targets while ignoring distractors. When working memory items shared the same limited-capacity processing mechanisms with targets in the matching task, distractor interference increased. However, when working memory items shared processing with distractors in the matching task, distractor interference decreased, facilitating target selection. A specialized load account is proposed to describe the dissociable effects of working memory load on selective processing depending on whether the load overlaps with targets or with distractors.

Keywords: attention, working memory, dual-task interference, flanker interference, executive control

People have the remarkable ability to perform more than one task at a time. However, multitasking comes with a cost (Kahneman, 1973; Kahneman, Beatty, & Pollack, 1967; Pashler & Johnston, 1989), and moreover, some tasks are harder to combine than others. Understanding which tasks interfere with each other is important for understanding how to optimize human behavior and also to gain insight into the cognitive architecture of how information is processed in the brain (Pashler, 1984, 1994).

By studying when dual-task interference occurs and when it does not, in the present study we aimed to understand the role of working memory in perception and cognition. Working memory maintains mental representations of a stimulus after the stimulus is no longer present, and this maintenance process can influence concurrent perception and cognition (Baddeley & Hitch, 1974; Courtney, Ungerleider, Keil, & Haxby, 1997; Desimone & Duncan, 1995; Downing, 2000). For example, de Fockert, Rees, Frith, and Lavie (2001) showed that a concurrent working memory load increased distractor interference, making people slower to respond to targets. De Fockert et al. asked participants to categorize famous written names as pop stars or as politicians while trying to ignore task-irrelevant face distractors that were presented behind the written names in the same positions. The faces were either congruent or incongruent in category with the target names, thus eliciting a response conflict during incongruent trials (e.g., trying to categorize "Bill Clinton" as a politician, while his name was superimposed over the face of Mick Jagger, the singer). This selective attention task was paired with one of two working memory load conditions—high load (memorizing a randomly ordered digit sequence) and low load (memorizing a fixed order digit sequence, e.g., 0, 1, 2, 3, 4). Higher working memory load resulted in greater interference from incongruent distractor faces. In addition, higher working memory load increased brain activity in the fusiform face area, a cortical region that processes face information (Kanwisher, 2000; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997) or other stimuli that observers have perceptual expertise in discriminating (Gauthier, Skudlarski, Gore, & Anderson, 2000). De Fockert et al. argued that a high concurrent working memory load consumes the cognitive resources needed to actively maintain stimulus processing priorities, resulting in greater distractor interference in selective attention tasks.

More generally, Lavie, Hirst, de Fockert, & Viding (2004) proposed that the attentional control system can be distinguished between passive, early (posterior) mechanisms and active, late control (anterior) mechanisms. If early processes such as perceptual processes are loaded, for example, by adding multiple distractors to a display or by increasing processing requirements from one feature (e.g., color) to a conjunction of two features (e.g., color and shape), fewer resources become available for distractors, thus resulting in a decrease in distractor interference (Lavie, 1995; Lavie et al., 2004). However, load theory predicts an increase in distractor interference if a load is imposed on active control processes, such as those cognitive processes involved in working

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memory or task switching. The de Fockert et al. (2001) study demonstrated increased distractor interference under concurrent working memory load.

However, there are different types of working memory that might be independent of each other. For example, research that examined the effects of working memory load on visual search found that the efficiency of visual search was impaired when spatial working memory or executive control processes were loaded but not when object working memory was loaded (Han & Kim, 2004; Oh & Kim, 2004; Woodman & Luck, 2004; Woodman, Vogel, & Luck, 2001). Logan (1978, 1979) also demonstrated that maintaining verbal items in working memory did not interfere with visual search efficiency. These results suggest that working memory and visual search do not interfere with each other if the type of attention required for the working memory task, such as maintaining a set of colors or verbal stimuli, draws on separate mechanisms than those required for efficient visual search. Concurrent spatial working memory interfered with visual search because both tasks involve spatial operations (Oh & Kim, 2004; Woodman & Luck, 2004).

These exceptions of dual-task interference suggest that the information processing system is not unitary but has multiple mechanisms that each have their own limited processing capacities, also described as resources (Kahneman, 1973; Logan, 1988; Navon, 1984; Navon & Gopher, 1979; Norman & Bobrow, 1975). Resource theory explains the variability of performance as a function of the amount of internal input invested in each task. Given the limited capacity of attention or mental resources within a cognitive or perceptual mechanism, performance is impaired when the processing resource demand is greater than the capacity of a system. One of the major questions asked about resources is whether there is a central, unitary pool of resources or there are multiple pools of resources. This question is essential for understanding which types of tasks compete with each other and which do not. Unitary-resource theorists suggest that a single, unitary resource pool can account for people's ability to handle multiple tasks (Kahneman, 1973). However, multiple-resource theorists argue that there are multiple resources, each with their own processing-specific, limited-capacity pool. As evidence for multiple resources, dual-task interference between two concurrent tasks was dramatically reduced when response modalities, stimulus modalities, or mental imagery codes used in two tasks did not overlap with each other (Allport, 1980; Allport, Antonis, & Reynolds, 1972; Brooks, 1968; Meyer & Kieras, 1997; Treisman & Davies, 1973; Wickens, 1976, 1980). For example, Brooks (1968) found that vocal responses interfered more with recall of a sentence than did spatial responses, whereas spatial responses interfered more with recall of a line diagram than did vocal responses. In sum, task interference occurred if the tasks' demands required the same type of processing and so had to compete with each other but not when their processing properties did not overlap, supporting the idea of multiple resources. However, the notion of resources can be viewed as vague, so here we aim to be more specific about this concept by referring to capacity limitations in specific processing mechanisms. A major goal of the present study was to identify when dual tasks compete for processing mechanisms and when they are independent.

Several recent neuroimaging studies provide evidence that there are multiple dissociable mechanisms (resources) in the brain. The distinction between verbal and spatial processing is widely supported by neuroimaging studies that show a double dissociation of neural pathways involved in verbal and spatial working memory (Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998; Jonides et al., 1996; Smith, Jonides, & Koeppe, 1996; Wager & Smith, 2003). As evidence for processing overlap between working memory and attentional orienting, an event-related potential and functional MRI (fMRI) study observed functional interactions between spatial working memory and spatial attention (Awh & Jonides, 2001).

The evidence for different types of working memory and multiple-resource theory constrains the general claim that working memory load should always impair cognitive control (de Fockert et al., 2001; Lavie et al., 2004). De Fockert et al. observed increased interference from faces when the name categorization task was combined with a verbal working memory task of memorizing digits. One thing to point out here is that the verbal working memory task and the name categorization task may have recruited similar processing mechanisms.[1] If so, then loading verbal working memory should consume limited-capacity mechanisms needed to process the name targets, resulting in loss of control for prioritizing targets and suppressing the irrelevant distractors. But what if the working memory task required memorizing faces instead of digits in the de Fockert et al. task? A working memory load of faces should not consume processing resources required for the verbal name targets; rather, it would consume processing resources needed to process the face distractors. Would distractor interference still increase with face working memory load? In its current form, load theory predicts that distractor interference should increase with any type of working memory load.

We tested whether the specific type of working memory load had different effects on the ability to focus on targets and to ignore distractors. To do so, we used two categories of stimuli—one for the target and one for the distractor—and we varied whether the concurrent working memory load stimuli matched the target category or the distractor category. Load theory predicts that the type of working memory load should not matter. Multiple-resource theory predicts that different types of working memory load will have different effects on the task.

We used two ecologically important visual object categories: faces and houses. Numerous fMRI investigations have shown that processing for these two visual categories is neurally represented in clearly dissociable areas of the brain. Face perception involves activation in the fusiform face area (FFA; Kanwisher et al., 1997; McCarthy et al., 1997), and house stimuli elicit mechanisms important for scene perception that specifically involve activation in the parahippocampal place area (PPA; Aguirre, Detre, Alsop, & D'Esposito, 1996; Epstein & Kanwisher, 1998). This neural evidence encourages our prediction that these two visual categories of faces and houses are processed fairly independently of each other.

To measure distractor interference in a selective attention task, we modified the Eriksen flanker paradigm (B. A. Eriksen & Eriksen, 1974; C. W. Eriksen, 1995). In the original Eriksen flanker task, participants discriminated a target letter that was always presented in the middle of multiple adjacent noise letters that could elicit responses that were either congruent or incongru-

[1] This is a hypothetical assumption. It is also possible that verbal working memory and name categorization do not share processing mechanisms, and we consider this possibility in the General Discussion.

ent to the target response. Response time to discriminate a target as one of the two possible targets was significantly longer when noise letters were incongruent, suggesting a response conflict between target and noise letters (B. A. Eriksen & Eriksen, 1974; C. W. Eriksen, 1995). To induce a response conflict between faces and scenes, we created displays as shown in Figure 1. Faces were superimposed over the center of house stimuli, forming composite face–house images, and two of these face–house images were presented adjacent to each other for the matching task (same/different judgment). Participants were required to attend to either the faces or the houses as targets and to determine whether the target images were the same or different while ignoring the non-target category. The target images could be same or different, whereas the distractors could also be same or different, making them either congruent or incongruent with the target response. For example, in the face-matching task, participants responded regarding whether the two adjacent faces were the same or different from each other while ignoring whether the distractor scenes were same or different.

To examine the effects of working memory load on selective attention, we combined this matching task with a concurrent working memory task. At the start of each trial, two working memory items were presented, followed by the same/different matching task. After participants responded same or different to the matching task, a memory probe was presented, and participants responded as to whether the probe was one of the memory items.

Our central manipulation was to vary the type of working memory load while participants performed the matching task. In different blocks of trials, participants had to maintain either face memory, house memory, or no memory. We predicted that items from the same category, such as two different faces, would compete for the same limited-capacity mechanisms (resources), as suggested by evidence for functional specialization in the brain (Epstein & Kanwisher, 1998; Kanwisher et al., 1997). Note that the working memory images and the matching task images simply shared the same categories and were always different from the specific image exemplars used in the matching task.

When the face-matching task is combined with face working memory load, target processing overlaps with the working memory load type, so we call this the *target load* condition. When the face-matching task is combined with house working memory load, distractor processing overlaps with the working memory load, so we call this the *distractor load* condition. In a third, *no load* condition, participants were not required to hold any items in working memory while they performed the matching task. The magnitude of the incongruence effect in this no load condition provides a baseline from which to assess how different types of working memory load modulate distractor interference in the matching task. The same logic applies when participants perform the house-matching task.

Intuitively, one would predict that distractor interference would increase in both face and house memory conditions compared with the no memory condition. This is what Lavie's load theory predicts as well (Lavie et al., 2004). However, if there are separate mechanisms for the different types of working memory—each with its own, independent processing capacity—then the predictions depend on how working memory load and target processing overlap. We refer to such dependencies as *specialized load effects*. If there are specialized load effects, when the working memory items do not compete for the same processing mechanisms as target processing (e.g., house working memory load while performing the face-matching task), distractor interference might be similar to when there is no working memory load (Han & Kim, 2004; Oh & Kim, 2004; Woodman et al., 2001). A more counterintuitive prediction from our specialized load account (multiple-resource theory) is that concurrent distractor-related working memory load may actually reduce distractor interference in the matching task.

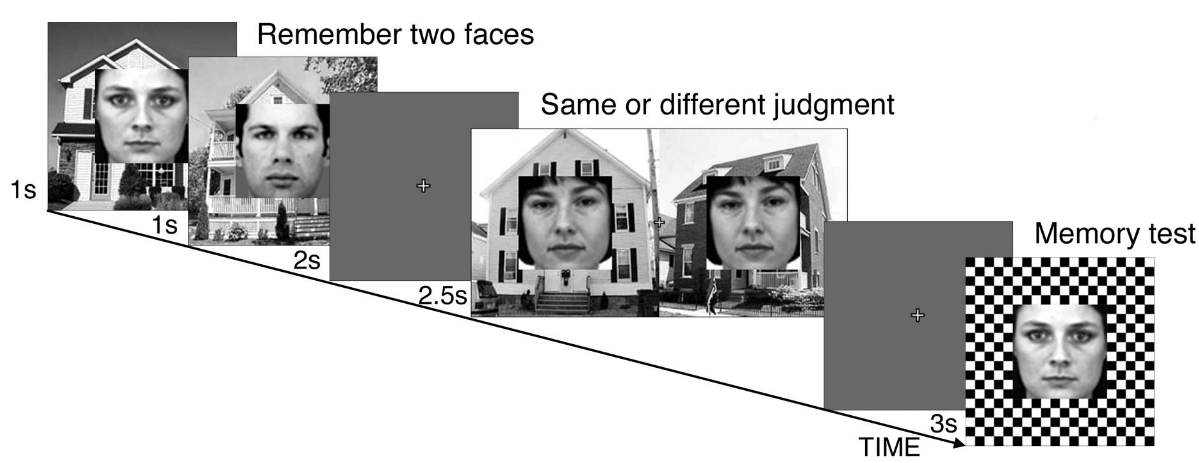

Figure 1. Schematic illustration of the experimental procedure in Experiment 1. At the beginning of each trial, two memory items were presented for 1 s each (200-ms display followed by an 800-ms blank interstimulus interval). Across separate blocks, participants were asked to encode and maintain either two faces, two houses, or nothing at all in working memory. The matching task stimuli appeared after 2s of fixation and were displayed for up to 2.5 s. Participants in the face-matching group made same/different judgments of the two faces. Participants in the house-matching group made same/different judgments of the two houses. A memory probe followed and stayed on for 3 s. Participants answered whether the memory probe was one of the items they had maintained in working memory from the beginning of the trial.

Experiment 1

Experiment 1 tested whether type of working memory load had different effects on the ability to focus on targets and ignore distractors. Participants were randomly assigned to either a face-matching task group or a house-matching task group. The target task conditions (face-matching task or house-matching task) were tested as a between-participants variable, whereas the memory load conditions (target load, distractor load, and no load) were tested as a within-participant variable.

Method

Participants. Fifty students participated for course credit or cash compensation. Twenty-five of the students participated in the face-matching task, and the other 25 students participated in the house-matching task. The data from 2 participants, 1 from the face-matching task group and the other from the house-matching task group, were excluded from the analyses because their error rates on the matching task were more than 2 standard deviations higher than the mean error rates. All participants had normal or corrected-to-normal visual acuity and normal color vision.

Apparatus and stimuli. The experiment was conducted on a Macintosh computer with a 17-in. (43.18-cm) screen. Participants viewed the display from an unrestrained distance of approximately 57 cm, at which distance 1 cm on the display subtended 1° of visual angle. The experiment was programmed using MATLAB software equipped with Psychophysics Toolbox extensions (Brainard, 1997).

As shown in Figure 1, the working memory stimuli were a sequence of two composite images. Each composite image consisted of a small face (5.5° × 5.5°) occluding the center of a large house (10.9° × 10.9°), similar to that used by Yi, Woodman, Widders, Marois, and Chun (2004). Faces had constant facial expressions, and houses were taken from similar viewpoints. Both face and house images appeared in only one same/different trial and did not reappear. A black frame (thickness = 1 pixel) bordered the house stimulus, but there was no frame segregating the face and the house to enhance response conflict between faces and houses.

The matching task presented two house–face composite images simultaneously next to each other. The only critical variable between the two participant groups was whether the target stimuli for the matching task were the faces or the houses; the specific faces and houses presented were always different from those presented for the working memory task. All stimuli and presentation times were identical for the two participant groups. One group made a same/different judgment for the two face targets, ignoring the background house distractors, whereas the other group made a same/different judgment for the two background house targets, ignoring the face distractors. To induce interference on the target task, we made the distractors either congruent or incongruent with the target responses (same/different). The two target response conditions (same and different) were counterbalanced across trials. Congruent and incongruent conditions were also counterbalanced for each response.

The memory probe stimuli were similar to the composite images presented in the working memory sequence. However, memory-irrelevant images were replaced with checkerboard images. For example, in the face memory blocks, the probe was a small face occluding the center of a checkerboard image that replaced a house image (see Figure 1). In the house memory blocks, the probe consisted of a small checkerboard image occluding the center of a large house. In the no memory blocks, the probe was a combination of large and small checkerboard images in which a small checkerboard image occluded the center of a large checkerboard. Probe conditions (present or absent) were counterbalanced across trials so as to be equally likely to follow same/different response trials and congruent/incongruent distractor trials.

Design and procedure. There were three memory load conditions: target load, distractor load, and no load. In the target load condition, participants had to maintain items in working memory that were of the same category as (but always of different identity than) the targets in the matching task (e.g., holding faces in working memory while performing the face-matching task). In the distractor load condition, working memory items were of the same category as (but always of different identity than) the distractors in the matching task (e.g., holding houses in working memory while performing the face-matching task). We emphasize again that the working memory images were always different from the images used in the matching task; they were simply from the same category and predicted to consume the same type of processing mechanism (resources). In the no load condition, participants did not have to maintain any images in working memory. The three memory load conditions were blocked into three separate blocks, and the orders were fully counterbalanced across participants. Each block had 64 trials and was preceded by one block of 16 example trials that contained 4 trials from each of the four conditions (two response conditions [same/different] × two distractor conditions [congruent/ incongruent]).

Participants were asked to hold a working memory load while performing the matching task (see Figure 1). Each trial started with an 800-ms presentation of a fixation cross at the center of the screen. Two working memory stimuli were presented sequentially for 1 s each (a 200-ms display followed by an 800-ms blank interstimulus interval). In face memory blocks, participants were instructed to memorize the two faces from the composite image sequence. In house memory blocks, participants were instructed to memorize the two houses. Participants were required to maintain these two items for the duration of the trial while they performed the matching task. They were informed that there would be a memory test at the end of each trial. In the no memory block, participants were instructed not to memorize anything and told that they would not be tested for working memory throughout this block.

The matching task stimuli appeared after the second working memory stimulus, with a 2,000-ms blank fixation cross in between. The matching task stimuli remained on the screen for up to 2.5 s, providing sufficient time to perform the task. When participants responded within 2.5 s, the matching task stimuli were replaced by a blank fixation cross until 2.5 s had elapsed from the onset of the matching task. Participants used the index or middle finger of their right hand to press the *N* or *M* key on the computer keyboard to make a same/different judgment for the two targets. Same or different response assignments to the two keys were counterbalanced across participants. Participants were instructed to respond as quickly and as accurately as possible. A 200-ms computer tone immediately followed all incorrect responses and when participants failed to respond within the given time window in the matching task.

After the 2.5-s matching task interval, a memory probe was presented on the screen for 3 s and was replaced by a fixation cross until the participant responded. Participants were instructed to indicate if the probe matched or did not match any one of the two memory images presented at the beginning of the trial. Participants were encouraged to respond as accurately as possible, and they were additionally told that speed was not important for the memory probe response. For the no memory blocks, in which participants did not memorize any items, they were instructed to press either of the two buttons for the probe (checkerboard). A 200-ms computer tone was presented immediately following all incorrect memory probe responses.

Results and Discussion

Our primary interest was whether target load and distractor load differently modulate the magnitude of distractor interference in the matching task. A repeated measures analysis of variance (ANOVA) was conducted with working memory load types (target load, distractor load, or no load) and congruency (congruent or incongruent) as within-participant factors and task type (face-target task or house-target task) as a between-participants factor. Only trials that were correct both on the working memory task and on the matching task were included in the analysis. Response times (RTs) under 200 ms and over 2.5 s were excluded from analysis. These cutoff points were used for all the RT analyses reported in this article and comprised less than 1% of all responses. Working memory task accuracy was 85% correct for face working memory blocks and 87% correct for house working memory blocks. A paired-samples *t* test did not show a significant performance difference between the two working memory tasks, $t(47) = 1.89$, $p = .10$.

Table 1 shows the mean correct RTs and error rates on the matching task as a function of working memory loads, target task types, and distractor congruency. Matching task accuracy was above 96% correct in all experimental conditions and did not show any tradeoff with RTs. There were no significant main effects or interactions in task accuracy for the factors of congruency, memory load, or task type.

Matching task RT analyses revealed that participants were slower in incongruent trials than in congruent trials overall, $F(1, 46) = 67.96$, $MSE = 20{,}781$, $p < .001$, demonstrating a significant response conflict effect. Matching task RTs in both memory load conditions (target load and distractor load) were longer than in the no load condition (Fs > 8.6, ps $< .01$), but they did not differ between the target and distractor load conditions, $F(1, 23) < 1$, $MSE = 15{,}144$, $p = .40$. No main effect of response type (same or different) was found, $F(1, 23) = 1$, $MSE = 10{,}644$, $p = .30$. Of greatest importance, there was a significant interaction between memory load type and the magnitude of response conflict, $F(1, 46) = 10.57$, $MSE = 1{,}646$, $p < .001$. Response conflict can be summarized with an incongruence index, obtained by subtracting the RT mean of congruent trials from the RT mean of incongruent trials. Positive incongruence values indicate greater response conflict—namely, greater distractor intrusion. Figure 2 shows the incongruence effect as a function of memory load, collapsed across face and house tasks. When maintaining a target load, participants showed larger interference compared with the no load condition, $F(1, 46) = 5.83$, $MSE = 1{,}528$, $p < .05$. In contrast, when participants maintained a distractor load, they showed reduced interference, or facilitation of performance, compared with when they had no load at all, $F(1, 46) = 4.51$, $MSE = 1{,}882$, $p < .05$.

Although task type did not interact with any of the other factors, $F(1, 46) < 1$, $MSE = 107{,}875$, $p = .40$, we conducted two separate within-participant repeated measures ANOVAs to examine performance within the face-matching task and house-matching task groups. Both groups showed longer RT performance in incongruent trials than in congruent trials, demonstrating response conflict from incongruent distractors (Fs > 29.33, ps $< .001$).

In the face-matching task group, RTs for the matching task in the no load condition were significantly shorter than they were in both the distractor load, $F(1, 23) = 7.35$, $MSE = 17{,}958$, $p < .05$, and target load conditions, $F(1, 23) = 9.80$, $MSE = 15{,}949$, $p < .01$. The interaction between the incongruence effect and memory type was significant, $F(1, 23) = 7.35$, $MSE = 1{,}582$, $p < .01$.

Table 1
Mean Correct Response Times (in Milliseconds) and Error Rates on the Same/Different Task as a Function of Task Type, Working Memory Task, and Distractor Congruency in Experiment 1

	Face-target task					House-target task				
	I		C			I		C		
Working memory load	*M*	*SD*	*M*	*SD*	I − C	*M*	*SD*	*M*	*SD*	I − C
Target load										
M correct	1,074	179	990	164	84	1,036	130	955	128	81
% error	2	3	1	2	1	3	3	3	3	0
Distractor load										
M correct	1,061	191	1,034	171	27	1,030	121	999	129	31
% error	3	3	1	2	2	2	4	2	4	0
No load										
M correct	1,005	160	929	143	76	965	191	929	173	36
% error	3	3	2	2	1	3	3	3	5	0

Note. I = incongruent; C = congruent.

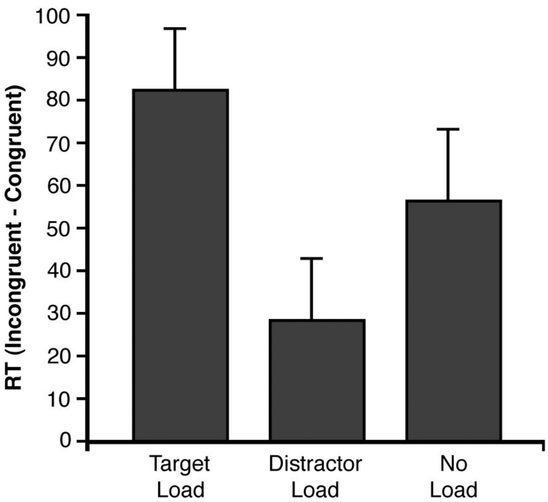

Figure 2. The incongruence effect, measured as the response time (RT, in milliseconds) difference between incongruent and congruent trials, plotted separately for the target load, distractor load, and no load conditions. Compared with the incongruence effect in the no load condition, the incongruence effect was greater when participants maintained a target load in working memory, whereas it was lower when participants maintained a distractor load in working memory. Error bars represent standard errors.

Holding the distractor load (houses) in working memory significantly decreased the interference effect in RT compared with the no load condition, $F(1, 23) = 8.53$, $MSE = 1{,}712$, $p < .01$. The incongruence effects in the target load (faces) and no load conditions were not statistically different, $F(1, 23) < 1$, $MSE = 1{,}710$, $p = .50$. However, the most critical interaction between the two memory load conditions was significant, $F(1, 23) = 15.00$, $MSE = 1{,}325$, $p < .01$. When participants held a target load (faces), they showed greater interference in RT than they did when they held a distractor load (houses) in working memory.

In the house-matching task group, main effects of memory type on RT were marginally significant overall, $F(1, 23) = 3.10$, $MSE = 18{,}648$, $p = .05$, suggesting that participants were faster in the no load condition than in the other load conditions. The magnitude of the incongruence effect significantly interacted with memory type, $F(1, 23) = 29.33$, $MSE = 1{,}982$, $p < .001$. When participants maintained a target load (houses), the RT difference between incongruent and congruent trials was the largest, compared with when they maintained no load at all, $F(1, 3) = 9.54$, $MSE = 1{,}346$, $p < .01$, or a distractor load, $F(1, 23) = 8.70$, $MSE = 1{,}733$, $p < .01$. When participants held a distractor load (faces) in working memory, the magnitude of RT interference was not significantly different from that in the no load condition, $F(1, 23) < 1$, $MSE = 2{,}053$, $p = .60$.

The pattern of greater response conflict in target load conditions than in distractor load conditions was consistent across all between-groups and within-group analyses; the critical interaction for target and distractor load conditions was robust in both task groups. However, face-matching and house-matching groups showed some differences in their results with respect to the no load baselines. In the face-matching group, distractor interference did not increase with target load relative to the no load condition. In the house-matching group, distractor interference did not decrease with distractor load relative to the no load condition. There are two possible explanations for these group/task differences. First, as shown in Table 1, the level of baseline distractor interference in the no load condition was approximately two times larger in the face-matching group (76 ms) than in the house-matching group (36ms), $t(23) = 1.777$, $p = .08$. This difference in baseline might have created a ceiling effect for the face-target task group that limited greater distractor interference in the target load condition and a floor effect for the house-target task group that limited lesser distractor interference in the distractor load condition. These baseline differences might have arisen because the two tasks were tested across two different groups of participants as well as because of stimulus size and configuration differences between the two tasks, which are discussed in more detail below. To equate the baselines between two task types, in Experiment 2 we tested task type (face-target task and house-target task) as a within-participant variable.

Second, the relative size of the central faces and peripheral houses might have contributed to the different baselines and different patterns of interaction with memory types. Large house distractors interfered more with small face targets than small face distractors interfered with large house targets. Also, in both tasks, maintaining large peripheral memory items (house load) produced the largest changes in distractor interference (reduction of interference in the face-matching task or increase of interference in the house-matching task) compared with smaller, central memory items (face load). In other words, it is possible that rather than the type of processing resource overlap, the size of the images in working memory may have modulated distractor interference in the matching task.

Another possible confound regarding the stimulus configurations is that they may have induced interference between location-based imagery and perception rather than an overlap in processing resources between working memory and perception (Podgorny & Shepard, 1978). Because it looked more natural to do so, faces always appeared in the center, whereas houses always appeared around the periphery in the stimuli used in Experiment 1. Although the center–periphery configurations of the matching task and the memory task stimuli never overlapped directly in screen location, it is possible that the relative center–periphery configuration of the matching task images interacted with the center–periphery configuration of the working memory images. For example, when face target group participants maintained a load of central faces, the overlap between central faces in working memory and central face targets in the matching task might have reduced the saliency of target faces, resulting in increased distractor processing. Similarly, when other participants maintained a load of peripheral houses, the overlap between peripheral houses in working memory and peripheral distractor houses in the matching task might have decreased the saliency of distractor houses, reducing the interference. To rule out these potential problems arising from the use of small, central face and larger, peripheral house configurations, we fully counterbalanced the stimulus arrangements in Experiment 2.

Experiment 2

In Experiment 2, we aimed to replicate Experiment 1 while testing whether the center–periphery overlap between the matching task target and memory stimulus configuration affected distractor interference for each working memory type. To test this, we fully counterbalanced the stimulus configurations of the matching task targets. When participants performed the face-matching task, on half of the trials they based their judgments on the two peripheral faces while ignoring the central house distractors (see Figure 3a); on the other half of trials, they based their judgments on the two central faces while ignoring the peripheral house distractors (see Figure 3b). Likewise, for the house-matching task, on half of the trials participants based their judgments on the two peripheral houses while ignoring the central face distractors; on the other half of trials, they based their judgments on the two central houses while ignoring the peripheral faces. Working memory stimuli were always small faces in the middle of bigger houses, as in Experiment 1. Thus, on half of the trials, when faces appeared at the center of the matching task stimuli configurations (see Figure 3b), the working memory load items overlapped in center–periphery configuration with the matching task stimuli (e.g., maintaining a central face load while matching two central faces). But on the other half of trials, when faces appeared in the peripheral region of the matching task stimuli configurations (see Figure 3a), the working memory load items did not overlap in center–periphery configuration with the matching task stimuli (e.g., maintaining a central face load while matching two peripheral faces). An important thing to note is that in both cases, there was the hypothesized overlap in category-specific processing mechanisms (a face load while matching face targets). If the center–periphery configuration overlap between the two task stimuli caused the distractor interference, we would expect to replicate the pattern of results from Experiment 1 only when working memory load and the matching task items overlap in their relative center–periphery locations, not when there is no overlap. However, if the overlap in category-specific processing between working memory load and the matching task is what modulates the distractor interference effect, then we should replicate the results of Experiment 1 with both types of stimulus configurations.

Method

The method was identical to that of the previous experiment, except as specified below.

Participants. Twenty-four participants were tested in this experiment.

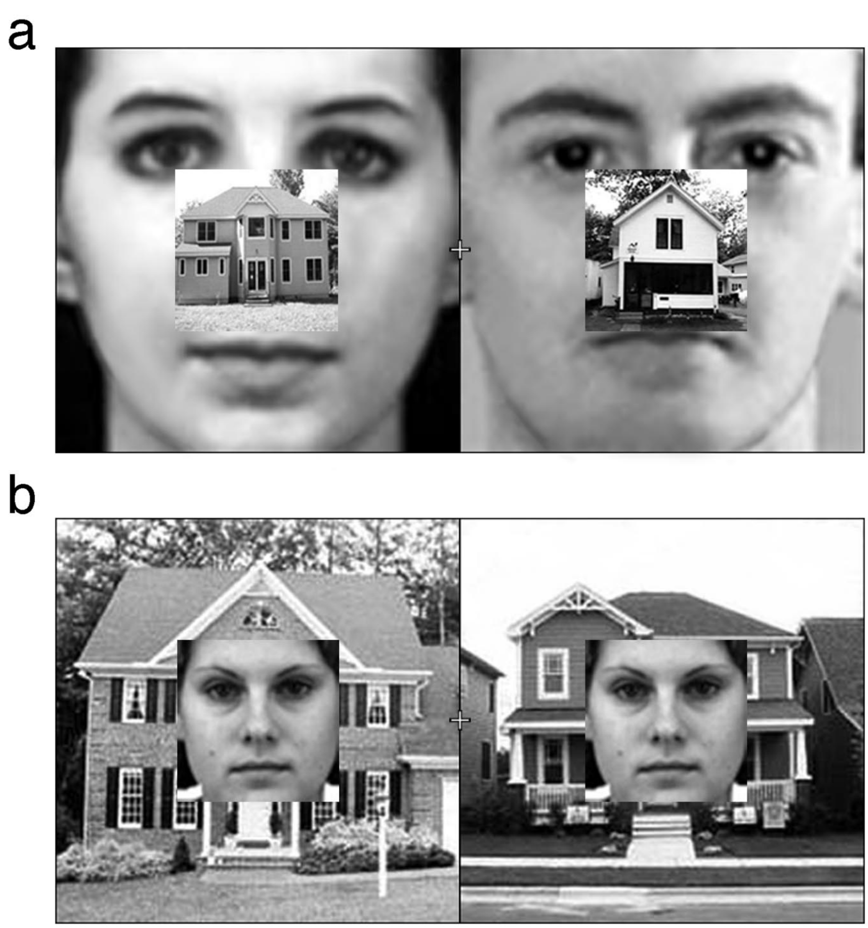

Figure 3. Matching task stimuli used in Experiment 2. On half of the trials, composite images consisted of small houses on top of bigger faces (a). On the other half of the trials, composite images consisted of small faces on top of bigger houses (b), just as in Experiment 1. The two types of stimulus configuration displays were randomly intermixed.

Stimuli and design. There were two major changes in the stimuli and design. First, we tested both the face-matching task and the house-matching task as within-participant variables so as to minimize the baseline differences between the two tasks that occurred in Experiment 1. Target tasks were blocked within each memory load condition. For example, while maintaining a face working memory load, each participant performed the face-matching task and the house-matching task in separate blocks of trials. The three memory load conditions (target load, distractor load, and no load) were also blocked within participant, just as in Experiment 1. The order of task types and memory load types was counterbalanced across participants.

Second, the matching task itself now had to be performed over two types of house–face composite image configurations (see Figure 3). On half of the trials, the composite image consisted of a small face (4.4° × 4.4°) occluding the center of a bigger house, whereas on the other half of trials, the composite image consisted of a small house (4.4° × 4.4°) occluding the center of a bigger face (10.9° × 10.9°). Thus, targets for a matching task could either appear in the center or around the periphery. These two different display types were intermixed within each task type.

Because eyes are critical for face identification, we reduced the size of the small, central image in the composite image from 5.5° × 5.5° to 4.4° × 4.4° to ensure that both eyes would be visible when faces were presented in the periphery and occluded by houses on top. Presentation timing and all other aspects of the procedure were identical to those in Experiment 1.

Results and Discussion

A repeated measures ANOVA was conducted with target task type (face-matching task or house-matching task), display type (overlap in center–periphery configuration or nonoverlap), working memory load type (target load, distractor load, or no load), and congruency (congruent or incongruent) as within-participant factors. As in Experiment 1, only trials that were correct on both the working memory task and the matching task were included in the analysis. Working memory task accuracy was 83% for face working memory blocks and 85% for the house working memory block, showing a nonsignificant difference, $t(23) = 1.7$, $p = .10$.

Table 2 shows the mean correct RTs on the matching task as a function of task, display configuration overlap, working memory load, and distractor congruency. Average matching task accuracy was 93%, and accuracy did not interact with any factors. We first present the overall main effects and interactions of these four factors and then follow with more specific analyses.

The four-way ANOVA found no main effect of target task type, $F(1, 23) = 0.7$, $MSE = 37{,}520$, $p = .40$. There was a marginal interaction between task type and the display overlap type, $F(1, 23) = 2.8$, $MSE = 32{,}100$, $p = .08$, but the task type did not interact with either memory or congruency types (Fs < 0.1). The within-participant design and intermixed display types balanced the overall no load baseline RTs between the face-target task and the house-target task, $t(23) = -0.26$, $p = .80$. Thus, the manipulations were successful in eliminating the no load baseline differences observed across the two task groups in Experiment 1.

Importantly, there was no main effect of display type, $F(1, 23) = 2.2$, $MSE = 8{,}837$, $p = .16$. There was an interaction between display type and memory type, $F(2, 46) = 4.9$, $MSE = 14{,}207$, $p < .05$; however, the display type did not interact with congruency, $F(1, 23) = 3.0$, $MSE = 3{,}788$, $p = .13$, nor was there a three-way interaction between display type, congruency, and memory type, $F(2, 46) = 1.4$, $MSE = 3{,}952$, $p = .25$. Thus, the amount of distractor interference was not affected by whether the working memory items overlapped in center–periphery configuration with the matching task stimuli. This rules out the possibility that the specialized load effects observed in Experiment 1 were a result of location-based image–perception interactions.

There was a significant main effect of memory load type, $F(2, 46) = 5.9$, $MSE = 24{,}399$, $p < .01$. Participants were slower on both target load and distractor load conditions compared with the no load condition (Fs > 3.8, ps $< .05$). There was also a robust main effect for distractor congruency overall, $F(1, 23) = 67.4$, $MSE = 5{,}099$, $p < .001$. Participants were 49 ms slower on average in the incongruent trials than in the congruent trials, $t(23) = 8.2$, $MSE = 6$, $p < .001$, demonstrating a significant response conflict effect. Most important, there was a significant interaction between memory load type and the magnitude of response conflict, $F(2, 46) = 15.8$, $MSE = 2{,}575$, $p < .001$. When participants maintained a target load, distractor response conflict increased compared with the no load condition, $F(1, 23) = 6.3$, $MSE = 599$, $p < .05$. In contrast, when participants maintained a distractor load, distractor response conflict decreased compared with the no load condition, $F(1, 23) = 7.0$, $MSE = 915$, $p < .05$.

Table 2
Mean Correct Response Times (in Milliseconds) on the Matching Task as a Function of Task Type, Display Type, Working Memory Load Type, and Distractor Congruency in Experiment 2

	Face-target task										House-target task									
	Display overlap					Nonoverlap					Overlap					Nonoverlap				
	I		C			I		C			I		C			I		C		
Working memory load	*M*	*SD*	*M*	*SD*	I − C	*M*	*SD*	*M*	*SD*	I − C	*M*	*SD*	*M*	*SD*	I − C	*M*	*SD*	*M*	*SD*	I − C
Target load	1,121	183	1,024	97	97	1,220	213	1,120	210	100	1,145	269	1,070	233	75	1,136	228	1,071	210	66
Dist. load	1,148	224	1,134	213	14	1,126	208	1,120	201	6	1,163	212	1,118	200	45	1,110	157	1,100	179	9
No load	1,101	186	1,018	160	83	1,106	218	1,089	198	17	1,097	223	1,045	190	52	1,094	234	1,029	200	65

Note. I = incongruent; C = congruent; Dist. = distractor.

This replicates the dissociable target and distractor load effects observed in Experiment 1.

When each task type was analyzed individually, both face target and house-target tasks showed robust interactions between memory load and congruency (Fs > 4.8, ps $< .05$). Figure 4 shows the incongruence effect by function of task type and memory load. Both tasks showed a larger incongruence effect when people maintained target load compared with when people maintained distractor load (Fs > 13.0, ps $< .01$). In the face-matching task, maintaining target load significantly increased the incongruence effect relative to the no load condition, $F(1, 23) = 6.0$, $MSE = 1{,}487$, $p < .05$, and maintaining distractor load significantly decreased the incongruence effect relative to the no load condition, $F(1, 23) = 4.0$, $MSE = 2{,}095$, $p < .05$. Similarly, in the house-matching task, maintaining target load numerically increased the incongruence effect relative to the no load condition, $F(1, 23) < 1$, $MSE = 1{,}190$, $p = .20$, and maintaining distractor load significantly decreased the incongruence effect relative to the no load condition, $F(1, 23) = 4.3$, $MSE = 1{,}005$, $p < .05$. A subsequent analysis revealed that the nonsignificant trend in target load was mainly attributable to the nonoverlapping display condition of the house-matching task—namely, when people had to base their judgments on small houses while ignoring big face distractors. However, this was not a result of the configuration overlap factor, because the nonoverlapping display condition of the face-matching task showed a significant increase of the incongruence effect with target load relative to the no load condition. We discuss this in more detail below.

We have already shown that the overlap in center–periphery configuration between the working memory items and matching task items did not matter. In addition to this display type factor, we examined a new factor called the *target-size factor*, which could be either small or large. There was a trend for the matching task target size to influence the amount of congruency by memory type, $F(2, 46) = 2.8$, $MSE = 5{,}449$, $p = .07$. Without any working memory load, large (peripheral) distractors interfered more with small (central) targets than small distractors interfered with large targets, $F(1, 23) = 3.3$, $MSE = 7{,}242$, $p = .083$. In both face- and house-matching tasks, when targets were small in the center, the incongruence effect in no load condition was high ($M = 74$ ms), so the decrease of the incongruence effect with distractor load was significant compared with the no load condition, $F(1, 23) = 7.0$, $MSE = 3{,}265$, $p < .05$. However, because the incongruence effect was already high without any working memory load, the predicted increase of the incongruence effect with target load was not significant, despite a numerical increase compared with the no load baseline, $F(1, 23) < 1$, $MSE = 1{,}739$, $p = .50$. In contrast, when targets were large in the periphery and distractors were small in the center, the small distractors interfered less with large targets, so the incongruence effect in the no load condition was low ($M = 34$ ms). Thus, the increase of the incongruence effect with target load was significant compared with the no load condition, $F(1, 23) = 8.0$, $MSE = 2{,}533$, $p < .05$, but the decrease of the incongruence effect with distractor load was not, although the numerical difference was in the predicted direction, $F(1, 23) < 1$, $MSE = 2{,}458$, $p = .70$. These target-size effects explain why there were baseline differences as well as biased patterns observed for task type in Experiment 1. In Experiment 1, the face-matching task always had small targets, and the house-matching task always had large targets. In Experiment 2, both small target and large target conditions were intermixed within each task, so the no load baselines for each task were equated. When each target-size type was examined separately, target-size effects remained, but still, the interaction between the incongruence effect under target load and that under distractor load remained significant with any task type or display condition (Fs > 16, ps $< .01$). In sum, although the incongruence effect was generally larger for small targets with large distractors, the critical modulation of the incongruence effect by working memory load depended on whether the working memory content overlapped with targets or distractors, not on task type or stimulus size.

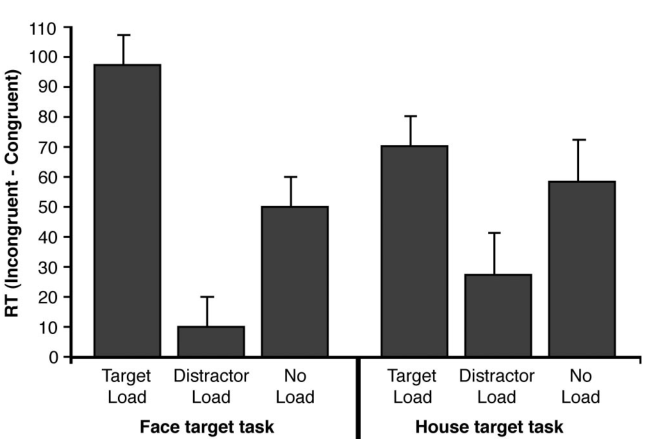

Figure 4. The incongruence effect in Experiment 2, measured as the response time (RT, milliseconds) difference between incongruent and congruent trials, plotted separately for task types and working memory load types. Error bars represent standard errors.

It is important to note that this target size effect is different from the center–periphery display overlap effect that we discussed earlier. Small target and large target conditions each had an equal number of overlapping and nonoverlapping trials with respect to the working memory displays. For example, when targets were small at center, half of the time the target's relative position overlapped with the working memory item's relative position, and half of the time it did not. Thus, the target-size effect is independent of the relative-position overlap (image–perception interaction) hypothesis that was rejected earlier. Instead, the target-size effect shows that large peripheral distractors produce stronger interference on small central targets overall compared with the opposite arrangement. In any case, target load always produced larger interference effects than distractor load, regardless of target size. In sum, the dissociable effect of target and distractor load on distractor interference cannot simply be attributed to different sizes of target and distractor displays, nor can it be attributed to center–periphery configuration overlap. Instead, the specialized load account provides the best explanation for all of our data.

Although not a primary focus of the present study, it is useful to consider why peripheral distractors produced stronger interference than did central distractors. It could simply be that physically larger stimuli produce bigger interference than smaller stimuli do. Or the effect could be a result of differential rates of attentional deployment to stimuli at fixation and the periphery. Regarding the latter hypothesis, one should expect stimuli at fixation to be privileged, and supporting this, Beck and Lavie (2005) showed that distractors presented at fixation were harder to filter out than distractors presented in the periphery. These results seem to apparently contradict our results, because we observed greater distractor interference from peripheral distractors. However, as Figure 1 illustrates, none of our central or peripheral stimuli directly appeared at fixation. In fact, because of the side-by-side configuration of the matching task, the "peripheral" stimuli actually appeared at fixation. Thus, our results are perfectly consistent with Beck and Lavie's demonstration that distractors presented at fixation produce larger response compatibility effects.

General Discussion

This study examined the interaction between cognitive control and selective attention by looking at how different types of working memory load modulate distractor processing and interference. Consistent with prior studies (de Fockert et al., 2001; Lavie et al., 2004), loading working memory with items that demanded common processing mechanisms with the target in a selective attention task increased distractor interference. The novel result is that a distractor-related working memory load actually reduced interference from distractors. Our demonstration of reduced interference from a distractor working memory load appears counterintuitive from the perspective of dual-task studies, but it can be explained by a multiple-resource view of attention, as we discuss below. First, we consider and dismiss alternative explanations for our results.

Several aspects of our experimental design and results rule out alternative explanations of our findings. Statistically equivalent performance on face and house working memory argues against the possibility that the dissociable effects of face and house loads might be attributable to differential difficulty between the two working memory tasks. Although both working memory loads increased the general RT compared with the no load condition, they clearly showed opposite patterns of effects on distractor interference.

We also ruled out alternative explanations for Experiment 1 stemming from the use of a single type of stimulus configuration that always presented faces in the middle of houses. In Experiment 1, category effects were confounded with stimulus size and with the degree of configurational overlap between the memory task and matching task images. These confounds were eliminated in Experiment 2 by adding stimuli with houses in the center and faces in the periphery. Furthermore, both face- and house-matching tasks were tested within participant. Regardless of target task, target size, or configurational overlap, there were dissociable effects of target load and distractor load across the two experiments. Maintaining target load always produced larger distractor interference effects than an equally difficult distractor load did. Thus, the most important variable was how working memory load overlapped with target or distractor processing in the selective attention task.

Implications for Load Theory: Toward a Specialized Load Account

The dissociation between the effects of target load and distractor load on distractor interference adds a novel twist to the current view that distractor interference should always increase under high working memory load (de Fockert et al., 2001; Lavie et al., 2004). The present results show that loading active control processes (e.g., working memory load) does not always result in a loss of control and increased distractor interference. The interaction between working memory load and distractor processing can be influenced by whether the two processes overlap in processing demands.

Initial evidence for loss of control had combined a verbal working memory load with a name categorization task (de Fockert et al., 2001). In our view, the verbal working memory task occupied some mechanisms required for target name categorization in the selective attention task, a condition comparable to our target load condition. Also consider the predictions for when target and distractors are of the same category. Lavie et al. (2004) observed an increased flanker effect with verbal working memory when both targets and distractors were letters (verbal information). In this case, verbal working memory load overlapped similarly with both target and distractor processing. However, it is highly unlikely that target and distractor processing require identical amounts of resources. Instead, target processing should be prioritized, and hence, targets would compete more strongly for limited-capacity processing consumed by the working memory load. In other words, target load effects should dominate, resulting in increased distractor interference under high verbal load, even when targets and distractors both required verbal processes, as was the case in Lavie et al.'s study. Overall, the results from our target load condition, which caused increased distractor interference, are consistent with the initial experiments by Lavie and colleagues.

However, an amendment to Lavie's load theory is needed to explain what happens when the working memory load items share similar processing mechanisms with *distractors* alone (Lavie et al., 2004). Our new results show that distractor load decreases the interference effect, contradicting the initial hypothesis that all forms of working memory load should cause a loss of control and increased distractor interference. We note that our distractor working memory load produced the same effect that one would predict that perceptual load should induce. In fact, we endorse the basic assumptions of perceptual load theory, which posits that when high perceptual load consumes processing resources required for distractor processing, there will be reduced distractor interference (Lavie, 1995; Lavie et al., 2004; Lavie & de Fockert, 2003; Lavie & Tsal, 1994). However, one must distinguish perceptual load from working memory load, and our study clearly manipulated the latter. The decrease of distractor interference in this study was caused by increased working memory load, not higher perceptual load.

Thus, we propose the following amendment to Lavie's general load theory (Lavie et al., 2004). According to our *specialized load account*, the critical distinction is not just between working memory and perceptual load but, rather, between different types of dissociable processing mechanisms, each with independent, limited capacity (multiple resources). Again, we emphasize that our results support the central tenet of load theory, which is that increased load in a task reduces processing of individual items that share processing mechanisms with the load. However, our results do not support the idea that working memory load should always increase distractor interference. Our results with distractor working memory load suggest that one must also consider how the working memory load overlaps with perceptual processing of targets or distractors, at least for visual tasks performed under concurrent visual working memory load. With respect to the current experiments, our specialized load account assumes that there are separate mechanisms involved in processing face and house stimuli and that task interference occurs when working memory items and attention task targets are both faces, or both houses, demanding the same limited-capacity processing mechanisms.

In line with our results, a number of classic studies demonstrated that multiple tasks can involve multiple mechanisms, and task interference occurs when two tasks compete for similar processes or structural components of tasks (Brooks, 1968; Treisman & Davies, 1973). As further support for specialized load, modern neuroimaging studies suggest that working memory encoding, maintenance, and response selection processes are specific to stimulus types or representations (Ranganath, DeGutis, & D'Esposito, 2004; Schumacher, Elston, & D'Esposito, 2003; Yoon, Curtis, & D'Esposito, 2006). Even when face and scene perceptual input is equated, the FFA and PPA demonstrated higher encoding- and maintenance-related activity when their favored stimulus was task relevant (Ranganath et al., 2004). Another study showed that during working memory maintenance of faces, maintenance activity in the lateral prefrontal cortex was disrupted by face distractors but not by scene distractors (Yoon et al., 2006). Thus, there is growing support for the notion of multiple mechanisms from such neuroimaging evidence for stimulus-specific encoding and maintenance in working memory. Our new behavioral results add to this literature by showing that the response conflict between two stimuli can be modulated selectively by the specific processing demands of the concurrent working memory load.

The most direct support for our specialized load account can be found in a different line of experiments that used Stroop tasks (Stroop, 1935). S.-Y. Kim, Kim, and Chun (2005) observed larger Stroop interference when the working memory load overlapped with the target category and a decreased Stroop effect when the working memory load overlapped with the distractor category. Specifically, a concurrent verbal working memory task increased the interference effect in RT of a meaning-comparison Stroop task in which participants responded to the meaning of the written word while ignoring the occasionally incongruent color of the word. However, the same verbal working memory task decreased the interference effect of a color-comparison Stroop task in which participants responded *same* or *different* to the color of the word while the semantic meaning served as the distractor. In addition, when participants had to respond *left* or *right* to the meaning of the word and ignore spatial interference elicited by a simultaneously presented arrow, verbal working memory load increased Stroop interference, whereas spatial working memory load decreased Stroop interference. The dissociation between verbal and spatial processing is well supported by neuroimaging studies that found separate neural pathways for verbal and spatial processes (Awh & Jonides, 2001; Smith et al., 1996). Our findings confirm the proposal that changes in the magnitude of the Stroop effect depend on whether the concurrent working memory load items share processing mechanisms with the targets or distractors.

The present study further extends the S.-Y. Kim et al. (2005) study finding in several ways. First, we generalized their results using a flanker interference task rather than a Stroop task. Second, we were able to use a common set of stimuli across all load and attention task manipulations within participant, whereas S.-Y. Kim et al. had to vary stimuli and tasks across conditions and across participants. Finally, we were able to demonstrate that beyond verbal and spatial dissociations, there could be separability in processing mechanisms within the object pathway itself, at least for faces and houses. Numerous fMRI studies have suggested that there are separate brain areas specifically involved in processing faces and scenes within the object pathway (Aguirre et al., 1996; Epstein & Kanwisher, 1998; Kanwisher et al., 1997; McCarthy et al., 1997). Clear structural dissociation between these two object categories supports our conclusion that there are separate processing mechanisms involved. Consistent with this neural dissociation, a recent fMRI study has shown that increasing the demands on face working memory decreased face-related activity in the FFA when participants were trying to ignore distractor faces in a concurrent selective attention task (M.-S. Kim, Min, Kim, & Won, 2006). An interesting question for future research would be whether there is further selectivity in interference patterns between categories of objects that do not have such clearly delineated neural substrates (e.g., shoes vs. chairs).

Other behavioral evidence lends more support to the specialized load account. For example, visual search is impaired under spatial working memory load but not under verbal or object working memory load (Logan, 1979; Oh & Kim, 2004; Woodman & Luck, 2004; Woodman et al., 2001). Another recent study showed that holistic processing of faces was impaired by a working memory load of faces, which engages holistic processing, but not by a working memory load of watch stimuli, which does not (Gauthier & Cheung, 2005).

Our work makes the novel demonstration that certain types of working memory load can actually benefit attentional selection by reducing the interfering effects of distractors. The studies show that active control mechanisms are not dependent on a unitary working memory but on the degree to which working memory load specifically overlaps with the processing mechanisms needed for target or distractor processing.

General Load Versus Specialized Load

Overall, we observe good support for our specialized load account, but it does not explain all of the load effects in the literature. Thus, a productive issue for future research will be to identify and predict a priori when specialized load effects should occur versus when general load effects should dominate. Currently, it appears that specialized load effects are the rule when performing visual tasks using visual working memory loads. Evidence for general load effects can be found in (a) tasks that use verbal working memory loads, (b) tasks that test cross-modal interference, and (c) and tasks that increase demands on executive control processes.

Lavie's group has published several demonstrations of general load effects using verbal working memory loads even when such loads do not overlap with target or distractor processing in a selective attention task (Brand-D'Abrescia & Lavie, 2007; Dalton, Lavie, & Spence, 2007; Lavie & de Fockert, 2005). For example, one could argue that verbal load did not overlap with the semantic categorization of written names in the de Fockert et al. (2001) study, in which case, one would have to attribute the increased interference to the general effects of verbal working memory load used in that task. However, even if the phonological processing for digit rehearsal did not overlap with semantic categorization of the names (via direct access from the orthography without phonological mediation), these two tasks share more similarities than do digit rehearsal and face processing. Thus, the relative balance between processing demand overlaps might well have resulted in higher distractor processing according to the specialized load account. In any case, both general load and specialized load accounts predict increased distractor interference in the de Fockert et al. task.

More recent studies provide stronger evidence for general load effects. Lavie and de Fockert (2005) showed that digit working memory load increased capture by an irrelevant color singleton in a shape-based visual search task. Because it is unlikely that digit working memory consumes processing required for color detection, this result is not consistent with our present findings or with those of other studies showing specialized load effects (S.-Y. Kim et al., 2005; Oh & Kim, 2004; Woodman & Luck, 2004; Woodman et al., 2001). It is possible that salient singleton distractors may be so potent that they are sensitive to any type of load effects. However, the more parsimonious conclusion is that their verbal working memory load induced general interference effects. Further reinforcing such a general load account, a recent neuroimaging study showed that digit working memory interfered with suppression of visual distractors (scenes), suggesting that suppression of visual distractors demands similar cognitive control resources to the concurrent digit working memory task (Rissman, Gazzaley, & D'Esposito, 2006). Yet, verbal working memory load does not always increase distractor interference, because in the S.-Y. Kim et al. study, high verbal load reduced interference from verbal distractors. This brief survey indicates that the general role of verbal working memory deserves further systematic investigation.

Cross-modal tasks provide stronger support for general load theory. Our specialized load account cannot easily account for increased interference induced by a load in a different modality. Brand-D'Abrescia and Lavie (2007) demonstrated that an auditory working memory load of pure auditory tones increased interference on a visual flanker task. Even more strikingly, Dalton et al. (2007) demonstrated that verbal working memory load increased interference from tactile distractors on a tactile discrimination task.

Finally, general load effects have been found in studies that increase the overall demands on executive control processes. For example, increased flanker interference is found when participants switch between a flanker task and a visual search task in a mixed-trial design compared with when they perform the same task on consecutive trials (Brand & Lavie, 2005). Similarly, working memory load does not need to be high or even concurrent with the selective attention task if participants are required to alternate between a memory task and the flanker task from trial to trial. Increased interference is observed when such task switches are required (Lavie et al., 2004).

Altogether, these results illustrate general cognitive control load effects beyond specialized, resource-specific load effects, so a fruitful challenge for future work would be to clarify when load effects are general and when they are resource specific. Such investigation will benefit from large-scale theories of how perception, attention, and cognitive control interact. As a comprehensive theory of cognitive processing, the multiple-entry modular memory system model of Johnson and colleagues (Johnson & Hirst, 1993; Johnson & Reeder, 1997) proposes various subsystems in perceptual and cognitive processing. Two subsystems are devoted to perceptual processes: The P–1 system includes simple processes such as locating stimuli, resolving stimulus configurations, tracking stimuli, and extracting invariants from perceptual arrays. P–2 processes are relatively complex perceptual processes such as identifying objects, placing objects in spatial relation to other objects, or structuring a pattern of order in temporally extended stimuli. The R–1 and R–2 systems indicate simple and complex reflective processes such as refreshing, shifting attention, noting relations, and reactivating for the R–1 subsystem and rehearsing, initiating, discovering, and retrieving processes for the R–2 subsystem (Johnson & Reeder, 1997). Within this concrete, influential framework, maintaining distractor load in R–2 processes might interfere with either of the two perceptual subsystems. The maintenance processes (R–2 subsystem) might interfere with P–1 processing of distractors, which involves simple perceptual processing. Or it might interfere with a higher level of perceptual processing by blocking the transit of distractor information from the P–1 subsystem to the P–2 subsystem. This will block stimulus identification from conflicting with target processing. Further investigations are needed to understand where the interaction between selective attention and working memory load occurs in the general cognitive architecture.

Conclusion

In conclusion, working memory load can either impair or benefit selective processing depending on how the concurrent load overlaps with the primary task. When the working memory item shares limited-capacity processing with *targets* in a selective attention task, the load induces loss of control that results in increased distractor interference, in accord with Lavie's load theory (Lavie et al., 2004). Our novel finding is that when the working memory item shares limited-capacity processing with *distractors* only, the load can actually attenuate distractor interference, improving target selection. Thus, in addition to the general effects of load, one needs to additionally consider these specialized load effects in a range of visual tasks. A complete understanding of how attention, working memory, and perception interact will require a careful analysis of both general load and specific load effects in the executive control of task performance.

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