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Context-Dependent Control Over Attentional Capture

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A number of studies have demonstrated that the likelihood of a salient item capturing attention is dependent on the "attentional set" an individual employs in a given situation. The instantiation of an attentional set is often viewed as a strategic, voluntary process, relying on working memory systems that represent immediate task priorities. However, influential theories of attention and automaticity propose that goal-directed control can operate more or less automatically on the basis of longer term task representations, a notion supported by a number of recent studies. Here, we provide evidence that longer term contextual learning can rapidly and automatically influence the instantiation of a given attentional set. Observers learned associations between specific attentional sets and specific task-irrelevant background scenes during a training session, and in the ensuing test session, simply reinstating particular scenes on a trial-by-trial basis biased observers to employ the associated attentional set. This directly influenced the magnitude of attentional capture, suggesting that memory for the context in which a task is performed can play an important role in the ability to instantiate a particular attentional set and overcome distraction by salient, task-irrelevant information.

Keywords: attention, learning, memory, attentional capture, context

We're constantly bombarded with sensory information, much of which is irrelevant to our ongoing task goals. As a result, we must effectively select which information is processed and allowed to affect our behavior—when making our morning commute we have to focus on controlling the vehicle and navigating to our destination, while simultaneously evaluating the constantly changing state of the driving environment and ignoring the tantrum being thrown by our child in the back seat. There have been a number of demonstrations that the ability to coordinate behavior and overcome distraction by salient, task-irrelevant information depends on the immediate goals of the task we are performing at a given time, implemented in the form of an "attentional set" (Yantis & Jonides, 1990; Theeuwes, 1991; Folk, Remington, & Johnston, 1992; Bacon & Egeth, 1994; Yantis & Egeth, 1999). The implementation of a specific attentional set presumably relies on voluntary, goal-directed cognitive control processes responsible for maintaining task representations and adjusting performance on a moment-to-moment basis in response to incoming sensory information (e.g., Folk et al., 1992; Yantis & Egeth, 1999; Yantis, 2000, 2008; Theeuwes, 2010).

Although the precise representations that constitute an attentional set are unknown, most theories of attention either explicitly or implicitly propose that these representations are related to the attributes defining task-relevant information in a given situation, which in most visual search experiments is the target of search. It has been proposed that target-defining information is actively maintained in working memory in the form of a "target template," which directly influences the control of attention on a moment-to-moment basis (e.g., Desimone & Duncan, 1995; Bundesen, 1990; Bundesen, Habekost, & Kyllingsbaek, 2005). Similarly, observers may maintain more abstract information regarding the target of search, including the relationship between the target and nontarget items (e.g., "search for the different colored item"; Pashler, 1988; Bacon & Egeth, 1994). Although it is possible that information regarding other attributes of a task beside the target of search may be represented in an attentional set, the concept of a target template has been influential in describing goal-dependent influences on attentional control more generally, gaining empirical support from a number of studies demonstrating that the active maintenance of information in working memory can directly influence the deployment of attention (e.g., Downing, 2000; Awh, Jonides, & Reuter-Lorenz, 1998; Soto, Heinke, Humphreys, & Blanco, 2005; Olivers, Meijer, & Theeuwes, 2006; Woodman & Luck, 2007; Munneke, Heslenfeld, & Theeuwes, 2010; Cosman & Vecera, 2011). Other studies demonstrate a close relationship between working-memory processes and the behavioral and neural consequences of attentional control and capture (Kane & Engle, 2003; Fukuda & Vogel, 2009, 2011; De Fockert, Rees, Frith, & Lavie, 2004; Lavie & De Fockert, 2006; Woodman & Arita, 2011; Carlisle, Arita, Pardo, & Woodman, 2011). Thus, it is likely that in some cases, observers use information about target attributes actively maintained in working memory to voluntarily control the deployment of attention toward behaviorally relevant and away from irrelevant information in the environment.

However, there has been little work examining whether the attentional set responsible for controlling the deployment of attention must always be implemented in an active, voluntary manner

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on the basis of immediate task goals. Returning to the example above, while driving we may have to maintain and switch between multiple levels of goal relevance (e.g., scanning for cars and other obstacles as well as navigating to a destination), which could quickly exceed the capacity of a system relying strictly on discrete working memory representations and deliberate control processes. Instead, it seems likely that repeated exposure to components of tasks and their relations could influence control, and over time lead to longer term influences on behavior, allowing relatively complex, holistic task representations to drive the deployment of attention rapidly and efficiently. For example, theories of automaticity and executive control propose that complex cognitive processes can operate automatically, given sufficient experience with a task and its context (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Norman & Shallice, 1986; Logan, 1988, 2002). Although the nature of the representations responsible for automatic control differs across theories, one commonality is the proposal that working-memory representations responsible for guiding behavior in novel or uncertain task settings eventually give way to long-term memory representations that become increasingly responsible for control following experience (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Logan, 1988, 2002).

For example, Logan's instance theory proposes that extended experience with a given task leads to an accumulation of episodic memories, or "instances" of previous encounters with a specific task configuration. Under this view, each time an observer performs a given task, an episodic trace is formed that includes information about specific attributes of the task being performed and the associated responses. The more times a task is performed (i.e., the more experience an individual has with a task), the larger the knowledge base from which to draw upon in future encounters with the task, and the more likely an observer will be to rely on automatic episodic retrieval processes to drive responses in a given task setting (Logan, 1988, 2002). Of note, this transition need not rely on extensive practice, but instead follows a power law and emerges relatively rapidly (Newell & Rosenbloom, 1981; Logan, 1988). Thus, under conditions in which the behavioral context in which a task is performed is predictable in some way, observers can rapidly offload control to longer term representations, an effect that has been observed during visual search in particular (Chun & Jiang, 1998; Carlisle et al., 2011).

This distinction between working-memory-based control and longer term learned control suggests that the active, deliberate control of behavior via working memory is often short lived; in cases in which an individual has even moderate experience with a task, the attentional set that guides attention may be implemented on the basis of longer term task "episodes." Although this possibility has received relatively little focus within the attentional capture literature, a handful of recent studies provide some support for this notion by showing that past experience can bias an observer's attentional set and directly influence capture by salient, task-irrelevant information, even when this information is unrelated to the immediate goals of a task (Leber & Egeth 2006a, 2006b; Thompson, Underwood, & Crundall, 2007; Leber, Kawahara, & Gabari, 2009; Olivers, 2011; Kelley & Yantis, 2008; Anderson, Laurent, & Yantis, 2011). Furthermore, in most studies showing an influence of working-memory representations on attention, task performance has necessarily relied on long-term information; for example, asking an observer to remember or search for a red square requires the observer to possess long-term semantic knowledge regarding color and shape. Thus, it is possible that long-term representations play a more important role in the implementation of an attentional set and the deployment of attention than previously considered.

In the current work, we examined the possibility that experience with specific stimulus factors may lead to long-term representations that exert a strong influence on attentional processes, typically thought to be under deliberate, voluntary control. More specifically, we were interested in whether contextual information, an essential component of long-term episodic memory representations, could influence the likelihood of attentional capture by salient, task-irrelevant distractors even when context was not directly relevant to the observer's immediate task goals.

Past Experience and Attentional Set

Observers appear to be able to adopt at least two possible attentional sets during visual search, entering either into a more general "singleton-detection" set when searching for a target on the basis of its status as a singleton (i.e., in cases where the target "pops out" of the display), or into a more specific "feature-search" set when searching for a target on the basis of a specific target-defining property, such as shape or color (Pashler, 1988; Bacon & Egeth, 1994; Folk, Leber, & Egeth, 2002). It is important to note, each of these attentional sets leads to different effects on attentional capture and distraction; when attention is configured to search for singletons (a singleton-search set), any salient singleton captures attention (e.g., Theeuwes, 1992), whereas configuring attention to search for a specific feature (a feature-search set) allows observers to effectively ignore salient distractors that do not match the target feature (Bacon & Egeth, 1994; Folk et al., 2002).

In order to examine the influence of past experience on the adoption of a particular attentional set, Leber and Egeth (2006a; see also Leber & Egeth, 2006b) trained two separate groups of observers to use either a singleton-search or feature-search set, and then examined whether this training would bias the set observers chose to use during a testing session in which either could be used to complete the task. The results from the training session of Leber and Egeth (2006a) replicated the basic asymmetry in capture seen in previous studies; during training, robust capture effects were observed for the group who used a singleton-search set, whereas capture was attenuated for the group who used a feature-search set, consistent with the idea that the observers' immediate task demands influenced the likelihood of distraction (Bacon & Egeth, 1994).

Following the training session, observers completed a testing session in which the explicit task goals and stimuli were made identical in both groups, with all observers now being told to search for a circle target among homogeneous nontargets while ignoring a task-irrelevant color singleton when it appeared. Consistent with the idea that past experience can automatically influence the choice of attentional set, observers who had performed a singleton search during training were captured by the task-irrelevant color singleton distractor during the testing phase, suggesting that they continued to employ a singleton-detection set during the testing session. However, observers who had trained on the feature-search task showed no evidence of capture, suggesting that they continued to use a feature-search set during the testing session (Leber & Egeth, 2006a). Thus observers continued to use the same attentional set they had used during training, despite the fact that, during the testing phase, the explicit task goals and stimuli were *identical* between the two groups, suggesting that past experience was the primary factor influencing which attentional set was employed during testing. On the basis of these results, as well as data showing that these effects can persist across delays of up to a week, Leber and colleagues have argued that attentional sets can be learned in a long-term manner, theorizing that observers may come to link particular attentional sets with particular task contexts (Leber et al., 2009).

Although prior studies have not directly demonstrated contextual effects on the implementation of particular attentional sets, this an attractive possibility because it suggests that long-term representations of a task may play a critical role in minimizing demands on active cognitive control processes. Such a possibility seems plausible, given that contextual factors exert a strong, automatic influence on basic memory retrieval processes; episodic memory performance is superior when environmental context is held constant across learning and recall, even when this contextual information is entirely irrelevant to task performance (e.g., Godden & Baddeley, 1975; see Smith & Vela, 2001, for a review). These context effects can be considered a natural consequence of relational memory systems in the brain, which serve to bind disparate perceptual elements at both the local and global levels to form both short- and long-term episodic representations (Cohen & Eichenbaum, 1993; Ryan, Althoff, Whitlow, & Cohen, 2000; Davachi, 2006), suggesting a potent general-purpose memory mechanism that allows past experience with particular task contexts to directly influence online task performance. In the case of attentional control, contextual information may act as a retrieval cue that automatically activates the attentional set(s) employed upon past encounters with a task performed in a given context, allowing goal-directed cognitive control processes to operate quickly and efficiently with little deliberate control. This idea is consistent with theories of automaticity that propose a central role for episodic memory processes in the automatic control of behavior (e.g., Logan, 1988, 2002), and it provides one mechanism through which long-term representations can come to influence processes responsible for goal-directed attentional control.

Current Study

In the current set of experiments, we asked if relational memory mechanisms allow the formation of associations between particular attentional sets and their learned contexts, which might directly influence goal-directed cognitive control processes responsible for overcoming attentional capture. To this end, we adapted the task employed by Leber and Egeth (2006a) in a manner that would allow us to examine whether memory for task-irrelevant contextual information could influence the attentional set observers adopt on a given trial. This task is ideal because it provides conditions in which multiple attentional sets can be used, as well as an assay of which attentional set is being employed by observers at a given time. Of primary interest was whether, within an individual, the choice of attentional set could be directly influenced by learned context on a trial-by-trial basis. To manipulate context, we embedded search displays similar to those used by Leber and Egeth (2006a) in a task-irrelevant scene surround, a manipulation known to drive robust context effects (Figure 1; see Brooks, Rasmussen, & Hollingworth, 2010; Hannula & Ranganath, 2009, for similar manipulations of context).

Observers completed a training session in which they were required to adopt *both* singleton and feature sets in separate blocks of trials, with each set being paired with specific task-irrelevant contextual information (i.e., forest scenes vs. city scenes). Following training, observers completed a testing session that employed a search task in which *either* attentional set could be used to perform the task. It is important to note, during the testing session the instructions were held constant and search displays were identical for the entire session, with subjects searching for a specific target (always a circle) among homogeneous nontargets (always diamonds). However, search displays were embedded within scene contexts that had been paired with one of the two attentional sets during training, with scene context randomly determined on a trial-by-trial basis. Thus, the central question during the testing session was whether we could directly influence the choice of attentional set (and the extent of attentional capture) by simply reinstating the scene context that had been associated with a given set during training.

If observers can learn to associate specific attentional sets with specific task-irrelevant contextual information, we would expect that, during the testing session, the attentional set observers employ on a given trial should depend exclusively on the context in which the search array is presented. Specifically, if the search array is presented within a scene associated with feature search during training, observers should adopt a feature-search set during that trial and should show little evidence of capture. However, if the search array is presented within a scene associated with a singleton search during training, observers should adopt a singleton-search set, and robust capture effects should be observed. Conversely, if context has no effect on choice of set, we would expect large capture effects across all conditions during testing, given that singleton-search mode appears to be the default under the stimulus conditions employed during the testing session (Theeuwes, 1992; Experiment 1; Kawahara, 2010).[1]

As noted above, many accounts have proposed that an attentional set is implemented voluntarily on the basis of immediate task goals or priorities held in working memory, with these goals often relating to the target of search. Thus, finding an effect of scene context on the choice of attentional set would provide evidence for a complementary mechanism of control that may supplement or override active control processes in a given situation. In addition, because context is always irrelevant to performance of the search task, any contextual influence would suggest that an attentional set might include information about both task-relevant information (i.e., the defining attributes of the target) and

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[1] This assumption was verified using stimuli identical to those used in the testing portion of the current experiments. We had 15 observers complete the testing session used in Experiments 1 and 2 without prior training, in order to examine the "default" set during the testing task. The results paralleled those in previous studies (Theeuwes, 1992; Kawahara, 2010), showing that in the absence of prior exposure, robust capture effects are the default, with observers responding more quickly on distractor-absent trials (707 ms) than on distractor present trials (726 ms), $t(14) = 3.9$, $p < .01$. There were no effects of distractor presence on accuracy.

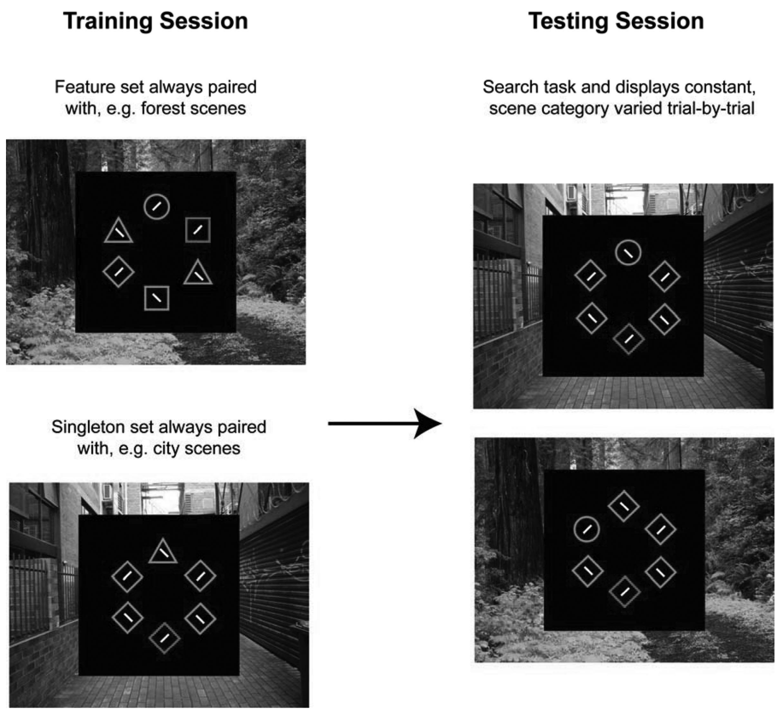

Figure 1. An example of the stimuli and design employed in Experiment 1. During training, observers searched for either the circle (feature-search condition) or the "different shaped" item (singleton-search condition) in separate blocks of trials. Each set was associated with a specific class of task-irrelevant scene (forest vs. city street scenes), counterbalanced across observers. During testing, observers searched for a constant target (a circle) among homogeneous nontargets, and thus either attentional set could be employed. Of interest was whether the presentation of scenes associated with specific attentional sets during training would cause observers to employ the associated set when the scene was encountered during the testing session.

task-irrelevant information that is nevertheless correlated with task performance.

Experiment 1

Method

Observers. Observers were 17 University of Iowa undergraduates who participated for course credit. All had normal or corrected-to-normal vision and were not color blind.

Stimuli. Observers sat approximately 65 cm from the screen, and viewed displays resembling those in Figure 1. A white fixation dot with a diameter of 0.3° was presented at the center of the screen. Search displays were comprised of six outline shapes equally spaced around the circumference of an imaginary circle with a radius of 3° centered around fixation. The shapes used in the search display were outline shapes, and could be a circle (radius 0.7°), a square (1.5° per side), a diamond (1.5° per side), or an equilateral triangle (pointing upward, 1.5° per side). The shapes were colored green (Red-Green-Blue [RGB] values 0, 255, 0), except for the singleton distractor, which always appeared in red (RGB 255, 0, 0) when present. A white vertical or horizontal line segment (0.5° long, 0.1° stroke) was centered inside of each shape. Task irrelevant scenes were high-resolution (1024 × 768) photographs of either forests or city streets (three scenes from each category, for a total of six individual scenes). On each trial, search displays appeared within a 10° × 10° black box centered on each photograph.

Design. During the training phase, observers performed a visual search task using two different attentional sets in separate, alternating blocks of trials. During singleton-search blocks, observers were instructed to search for the *different shaped* item on each trial, and this item could be a circle, square, or triangle, chosen randomly on each trial. In the singleton-search condition, the target was always presented among a homogeneous array of six diamond-shaped nontargets, such that it was a shape singleton that popped out of the display. During feature-search blocks, observers were instructed to search for a circle target on every trial, which was always presented among a heterogeneous array of five nontarget items. The heterogeneous arrays always included at least one diamond, one square, and one triangle; the other two nontargets were chosen at random on each trial, with the constraint that both items were different shapes. On half of the trials in each search condition, one of the nontarget items was red, making it a salient singleton distractor, and in both singleton- and feature-search blocks, the spatial positions of target and distractor items were randomly determined. Of note, during the training task, singleton- and feature-search arrays were always embedded within scenes belonging to a specific category (forest vs. city). For half the subjects, singleton-search arrays were always embedded within "forest" scenes and feature-search arrays were always embedded within "city street" scenes, selected at random from one of three possible scenes for each category; this scene-set association was reversed for the other half of observers. A limited number of semantically consistent scenes was employed to increase the likelihood that contextual associations could be made during a single experimental session.

Following training, observers completed a testing phase that was similar to the training phase, but during testing, observers were always instructed to search for a circle target, presented among an array of homogeneous diamond-shaped nontarget items. Thus in the testing phase, either attentional set provided an effective means of locating the target—observers could either search for the "different" item (singleton-search set) or for the specific feature that defined the target (a circle; feature-search set). During testing, the search arrays were always embedded within either the forest scene or the street scene encountered during training, but in this case, scene identity was completely intermixed and scenes were presented pseudorandomly and equiprobably on each trial. Of primary interest during the testing session was whether simply presenting scenes that had been associated with either feature-search or singleton-search modes would be sufficient to bias the observer's choice of search strategy toward that associated with the scenes during training, influencing the likelihood that a salient distractor would capture attention.

Procedure. As described above, during the training phase, observers were instructed to search for either a different-shaped item among homogeneous nontargets (singleton-search condition) or a specific shape (a circle) among heterogeneous nontarget items (feature-search condition) at the beginning of each block of trials. In both singleton- and feature-search blocks, observers were told that a salient red singleton would appear on half of the trials, and because it would never appear at a target location, they should try their best to ignore it. In both search conditions, upon finding the target, observers were told to report the orientation of the line segment inside of it by pressing either the "Z" or "M" keys on the keyboard, each key corresponding to either horizontal or vertical line orientation, counterbalanced across observers. The search array always appeared within a task-irrelevant scene from one of the two categories, with each scene category being paired with a specific attentional set. At the beginning of each trial, the task-irrelevant scene appeared for 1000 ms, along with the empty (save for a fixation point) black box that would eventually contain the search array. Next, the search array appeared for 1500 ms or until observers responded, whichever came first. Trials in which observers failed to respond within 1500 ms were excluded from reaction time (RT) analyses. Observers performed four blocks of 36 trials each for each of the search modes, with block order (singleton vs. feature search) counterbalanced across observers, resulting in 144 training trials for each search type, or 288 total training trials.

Following a brief break (~5 min), participants began the testing session. During the testing session observers were always told to search for a circle among homogeneous diamond distractors and report the orientation of the line contained inside of the target, while ignoring the salient red distractor when it appeared. Search arrays were presented for 1000 ms and were always embedded within the same forest or street scenes as during the training sessions, but in this case, scene identity was chosen pseudorandomly on each trial. This provided a means of assessing whether task-irrelevant context memory could influence choice of attentional set on a trial-by-trial basis, by examining the effect of particular background scenes on the level of attentional capture. Observers completed three blocks of 72 trials each for a total of 216 total testing trials (108 trials for each scene category). In both sessions, observers were always told to try and ignore the salient distractor when it appeared, and respond as quickly and accurately as possible.

Results

Observers' overall mean correct RTs and error-rate data from both the training and testing portions of Experiment 1 were entered into separate two-factor ANOVAs, with the factors attentional set (singleton search vs. feature search) and distractor presence (present vs. absent) for the training data, and scene type (associated with singleton search vs. associated with feature-search set) and distractor presence (present vs. absent) as factors for the testing data.

Training data. Training data appear in Table 1. For training data, a significant main effect of attentional set was observed, $F(1, 16) = 53.2$, $p < .001$, $\eta^2 = .77$, indicating faster overall responses when observers adopted a feature-search set (780 ms) than when they adopted a singleton-search set (1,028 ms). This is consistent with Leber and Egeth (2006a), who demonstrated a large main effect of RTs between singleton- and feature-search conditions, as well as with previous studies that showed large main effects when observers searched for constant-versus-variable target features during singleton-search tasks (Bravo & Nakayama, 1992; Lamy, Carmel, Egeth, & Leber, 2006; Geyer, Zehetleitner, & Muller, 2010). This effect may have been further exacerbated in the current design by the inclusion of the background scenes and the fact that observers had to switch attentional sets from block to block. In addition to the main effect of attentional set, the main effect of distractor presence was also significant, $F(1, 16) = 16.3$, $p < .01$, $\eta^2 = .50$, with slower RTs on trials in which a distractor was present (923 ms) than on trials in which it was absent (886 ms). Of note, a significant interaction was observed between search type and distractor presence, $F(1, 16) = 5.8$, $p = .03$, $\eta^2 = .27$, indicating that the magnitude of capture by the singleton distractor varied as a function of search type. In order to examine the nature of this interaction, planned comparisons were performed between distractor-present and -absent conditions for each search type, and revealed significant distractor effect in the singleton-search condition, $t(16) = 4.2$, $p < .001$, but not the feature-search condition, $t(16) = 1.5$, $p = .15$. These results indicate that the manipulation

Table 1
Mean RT and Error Rate for the Training Session of Experiment 1

	Distractor absent		Distractor present	
Attentional set	Mean	*SD*	Mean	*SD*
Feature				
RT	773	94	788	110
% E	6	3	5	3
Singleton				
RT	999	75	1056	91
% E	6	6	8	6

of search type was effective and modulated capture by a salient distractor during the training session, replicating previous studies that used a similar search task (Bacon & Egeth, 1994; Leber & Egeth, 2006a). For the error-rate data, no main effects were significant, but a significant interaction between attentional set and distractor presence was observed $F(1, 16) = 9.6$, $p < .01$, $\eta^2 = .38$, with significantly lower accuracy when the distractor was present (vs. absent) in the singleton-search condition, $t(16) = 2.2$, $p = .04$, but not the feature-search condition, $t(16) = 1.5$, $p = .15$.

Testing data. Testing data appear in Figure 2. For testing data, there were no main effects of scene type, $F(1, 16) = 1.0$, $p = .33$, or distractor presence, $F(1, 16) = 1.9$, $p = .18$, however, there was a significant interaction between scene type and distractor presence, $F(1, 16) = 6.0$, $p < .03$, $\eta^2 = .27$, indicating that the effect of the singleton distractor varied as a function of the type of scene in which the search array was embedded, despite the fact that the search arrays themselves were identical across trials. Planned comparisons revealed a significant distractor interference effect on trials in which the task-irrelevant scene matched those associated with singleton search during training, $t(16) = 2.3$, $p = .03$, but not those associated with feature search during training, $t<1$, n.s. There were no significant main effects or interactions in the error-rate data, Fs < 2.4, ps $> .14$.

Discussion

These results demonstrate a clear influence of learned context on an observer's choice of attentional set, leading to a modulation of attentional capture. Scenes associated with a singleton-search set during training biased observers to use a singleton-search set when they appeared during testing, leading to increased capture by a salient distractor. Conversely, scenes associated with a feature-search set during training biased observers to use a feature search when they appeared during testing, allowing observers to effectively overcome capture. The fact that the magnitude of capture could be directly influenced on a trial-by-trial basis simply by reinstating particular contextual information indicates a high level of specificity in the types of representations that may drive the learned control effects demonstrated in this and other studies (e.g., Leber & Egeth 2006a, 2006b; Leber et al., 2009; Thompson et al., 2007; Kelley & Yantis, 2008; Anderson et al., 2011). These findings provide support for the notion that task context can directly influence the ability to overcome distraction by salient, task-irrelevant information; further, the results extend previous work showing an influence of spatial context on visual search (e.g., Chun & Jiang, 1998) by demonstrating that more general contextual associations have the ability to influence the deployment of attention in scenes.

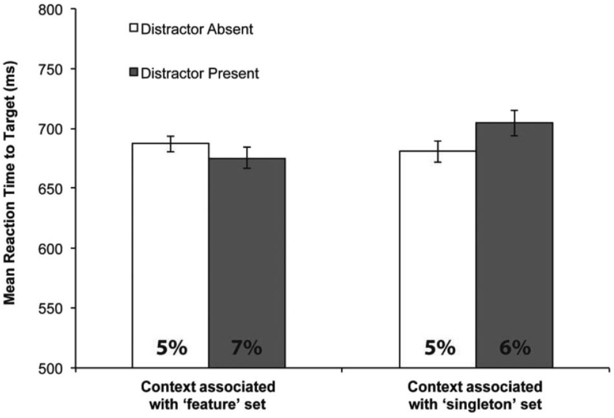

Figure 2. RT data and error rates (bottom of each column) for each condition in the testing session of Experiment 1. During the testing session, observers always searched for a circle among homogeneous diamond non-targets. The search arrays were embedded either within scenes that had been associated with a feature set or singleton set during the training session. Error bars represent 95% within-subject confidence intervals (Loftus & Masson, 1994; Morey, 2008).

Furthermore, the current results suggest that the attentional set adopted by observers may include information regarding task-relevant and task-irrelevant information, both presumably holding the ability to influence task performance in a given situation. In this way, one can think of the attentional set as being comprised of a relatively detailed, distributed representation that codes multiple aspects of a given task space and can drive more or less automatic influences on attentional control. Our findings are particularly striking because they suggest that longer term information regarding global context can trump active attentional control processes related to the immediate, explicit goals of a task—task-irrelevant contextual information appeared to be the primary determinant of which set was adopted on each trial during testing, even though observers' explicit goals with respect to the search task itself were held constant during the testing session (i.e., they were always told to search for a circle while ignoring the salient distractor). These results are consistent with the idea that, over time, observers can offload control from active working-memory processes responsible for representing immediate task demands to long-term representations that contain information about past encounters with a task and its context, with these long-term representations eventually coming to dominate control (Shiffrin & Schneider, 1977; Schneider & Shiffrin, 1977; Norman & Shallice, 1986; Logan, 1988, 2002).

However, rather than resulting from the automatic activation of long-term contextual representations, the effect observed here may be due to the operation of a context-dependent, explicit control strategy. For example, because in the training session specific attentional set/scene combinations were always presented in separate blocks of trials, and observers were always explicitly instructed at the beginning of each block which set to use to perform the task, it is possible that observers noticed this correlation and continued to explicitly switch strategies during testing. Because the task-irrelevant scene appeared for 1000 ms prior to the introduction of the search array, there was likely time for observers to explicitly recognize the scene and adjust their set accordingly. In this way, scene context may have acted as an explicit cue that observers used to voluntarily configure attention on a trial-by-trial basis. Although this seems like a suboptimal strategy since, during the testing session, the target of search was constant (always a circle) and the contextual information switched unpredictably from trial to trial, such a possibility is important to explore, considering that observers can switch rapidly between different attentional sets when instructed to do so (Lien, Ruthruff, & Johnston, 2010). In Experiment 2, we attempted to rule out such a possibility and provide converging evidence for a context-dependent control view by showing that these effects can emerge even in cases where explicit search strategies are held constant across the experiment.

Experiment 2

As reviewed above, the asymmetries in capture between feature- and singleton-search conditions observed in this particular task are often viewed as resulting from differences in the explicit search strategies observers employ during each type of search. However, because feature search always occurs in search displays containing heterogeneous nontargets and singleton search always occurs in search displays containing homogeneous nontargets, it has been argued that differences in capture across feature- and singleton-search tasks may result from differences in display characteristics rather than differences in the explicit strategies observers use to perform each type of search. For example, Theeuwes and colleagues (Theeuwes & Burger, 1998; Theeuwes, 2004, 2010; Belopolsky & Theeuwes, 2010) have argued that the lack of capture during feature search is due to observers adopting a “serial” search strategy during search through heterogeneous displays (cf. Duncan & Humphreys, 1989; Nothdurft, 1993). Consequently, serial search may reduce the spatial scale of attention and decrease the likelihood that a salient distractor will fall inside the focus of attention and cause distraction (Theeuwes & Burger, 1998; Theeuwes, 2004; Belopolsky & Theeuwes, 2010).

In the context of the current study, this suggests the possibility that results such as those observed in Experiment 1 may, under some circumstances, emerge more or less automatically on the basis of display factors, even when explicit search strategies are held constant. In Experiment 2, we tested this possibility by instructing observers to use a feature-search set throughout the entire experiment (i.e., they always searched for a circle target), while manipulating display homogeneity/heterogeneity on a trial-by-trial basis during the training session, in order to discourage observers from developing an explicit switching strategy. Because both homogeneous and heterogeneous displays were intermixed during training, only the instructed feature-search strategy could be used to reliably locate the target from trial to trial (see Bacon & Egeth, 1994, for a similar mixed-display manipulation). It is important to note, similar to Experiment 1, homogeneous search arrays were always paired with one scene category (e.g., forest scenes) and heterogeneous search arrays were always paired with the other scene category (e.g., city scenes). The training session was followed by a testing session identical to that in Experiment 1.

If observers’ explicit search strategies are critical for determining the likelihood of attentional capture and generating the context-dependent control effects, as seen in Experiment 1, then no capture effects should emerge in the data from the training or testing session because observers were only explicitly told/trained to adopt a specific feature-search set (“search for the circle”). In contrast, if display factors can act as a critical determinant of capture in this task, we would expect to see a pattern of results identical to Experiment 1, during both training and testing, reflecting the *spontaneous* adoption of either the feature-search or singleton-search sets in response to differences in display properties across the two conditions. This would provide evidence that explicit strategies are not always necessary for driving the effects observed in Experiment 1, in addition to providing further evidence that display factors play a critical role in determining the likelihood of attentional capture more generally. To directly assess the role of explicit strategies in driving context-dependent control effects, following the experiment observers completed a brief questionnaire to probe the explicit search strategies they used to perform the search tasks during the testing session. This allowed us to directly rule out an explicit switching strategy, as well as examine the relationship between reported strategies and patterns of attentional capture.

Method

Observers. Observers were 15 University of Iowa undergraduates who participated for course credit. All had normal or corrected-to-normal vision and were not color blind.

Stimuli and procedure. The stimuli and procedure were identical to those in Experiment 1, with the exception that during training, observers were always instructed to search for the circle and report the orientation of a line contained inside of it. We varied the composition of the nontarget items in the search arrays in a manner identical to that in the singleton and feature-search conditions in Experiment 1, such that observers always searched for a circle target through either homogeneous (all diamond nontargets) or heterogeneous (diamonds, squares, and triangle nontargets) arrays. It is important to note that during training, homogeneous arrays were always paired with one type of scene and heterogeneous arrays were always paired with the other (forest vs. city street scenes, counterbalanced across observers). The testing session was identical to that in Experiment 1, and observers always searched for a circle target among homogeneous nontargets. Thus the only difference between the current experiment and Experiment 1 is that in this experiment observers explicitly searched for a specific feature (a circle) during both training and testing, with display homogeneity/heterogeneity and their associated scenes being entirely intermixed during the training session.

In Experiment 2, observers also answered a series of questions at the end of the experiment in order to assess the explicit strategies they used to perform the search task during the testing session, so that we could rule out explicit switching strategies, as well as probe how observers’ search strategies influenced capture. First, observers were given an open-ended question and asked to describe the specific strategies they used to perform the search task during the testing session. Following their responses to the open-ended question, they were given a multiple-choice question asking “which of the following strategies best describes how you searched for the target during this task,” and were told to choose from the specific strategies *searched for the circle*, *searched for the different shaped item*, *neither*, or *both*. If they selected neither or both, they were asked to elaborate on the specific strategy they used to find the target, so that we could gain more specific information about how they performed the task. Including this questionnaire provides a strong test of the influence of explicit strategies on the effects observed in this task, because to the extent that observers’ reported strategies aren’t systematically associated with the context-dependent control effect or the magnitude of capture, we can conclude that explicit strategies are not necessary for generating the context-dependent capture effects observed here.

As in Experiment 1, observers performed 144 training trials for each search type (search through homogeneous or heterogeneous nontargets), for a total of 288 training trials. Observers then completed three blocks of 72 trials each for a total of 216 total testing trials. In both sessions, observers were always told to try and ignore the salient distractor when it appeared, and respond as quickly and accurately as possible.

Results

Observers' overall mean correct RT and error rate data for the training and testing sessions were entered into separate two-factor ANOVAs, with the factors search type (search through homogeneous vs. heterogeneous displays) and distractor presence (present vs. absent) for the training data, and scene type (associated with homogenous or heterogeneous search) and distractor presence (present vs. absent) as factors for the testing data, allowing similar comparisons with those made in Experiment 1.

Training data. Training data appear in Table 2. For RT data during the training session, there was a trend toward a significant main effect of search type, $F(1, 14) = 3.9$, $p < .06$, $\eta^2 = .23$, indicating faster overall responses when participants searched through homogeneous arrays (654 ms), compared with heterogeneous arrays (667 ms), which is consistent with previous studies that have shown a decrease in search efficiency in heterogeneous search arrays (e.g., Duncan & Humphreys, 1989; Bacon & Egeth, 1994). The main effect of distractor presence also approached significance, $F(1, 14) = 4.0$, $p < .06$, $\eta^2 = .23$, with slower RTs on trials in which a distractor was present (665 ms) versus when it was absent (656 ms). Unlike Experiment 1 there was no significant interaction between search type and distractor presence, $F < 1$, n.s. However, given our specific interest in the presence versus absence of a distractor effect in either heterogeneous or homogeneous arrays, planned comparisons were performed between distractor conditions (present vs. absent) for each search type. These analyses revealed a significant distractor effect on RTs in homogeneous displays, $t(14) = 2.2$, $p = .04$, but not heterogeneous displays, $t(14) = 1.0$, $p = .32$, replicating the asymmetry in capture effects seen in Experiment 1, as well as previous studies using a similar task (Leber & Egeth, 2006a; Bacon & Egeth, 1994).

Despite the asymmetry in capture across homogenous and heterogeneous displays, the magnitude of the capture effect in the homogeneous search condition was approximately half as large as that observed under identical stimulus conditions during the testing portion of Experiment 1, leading to a nonsignificant interaction. One possible explanation for this decrease is that intermixing display types led to intertrial effects that differentially modulated attentional capture across conditions. In order to test this possibility, we analyzed RTs for homogeneous and heterogeneous search displays as a function of the homogeneity/heterogeneity of the previous trial using pairwise comparisons (see Table 3). For heterogeneous displays, no significant capture was observed regardless of the homogeneity/heterogeneity of the previous trial, ts < 1.3, ps $> .23$. However, for homogeneous displays, a significant capture effect was observed when a homogeneous array was preceded by another homognеous array, $t(14) = 2.5$, $p < .02$, but not when it was preceded by a heterogeneous array, $t < 1$, n.s. This suggests that capture in homogeneous, but not heterogeneous, displays is strongly modulated by the type of search display encountered on the previous trial, a point we will return to in the discussion. Thus the lack of a significant interaction in the current experiment appears to be the result of intermixing display types during training. There were no main effects or interactions in the error rate data, all Fs < 1.

Table 2
Mean RT and Error Rate for the Training Session of Experiment 2

Display type	Distractor absent		Distractor present	
	Mean	*SD*	Mean	*SD*
Heterogeneous				
RT	663	95	669	87
% E	5	4	5	3
Homogeneous				
RT	649	83	659	91
% E	5	4	5	4

Testing data. For the testing data (see Figure 3), there was no main effect of scene type, $F < 1$, n.s., but we observed a main effect of distractor presence, $F(1, 14) = 16.1$, $p = .01$, $\eta^2 = .54$, with faster RTs on singleton-absent trials (570 ms) than singleton-present trials (584ms). In addition, there was a significant interaction between scene type and distractor presence, $F(1, 14) = 4.6$, $p < .05$, $\eta^2 = .25$, indicating that the effect of the singleton distractor varied as a function of the type of scene in which the search array was embedded, replicating the results of Experiment 1. Planned comparisons revealed a significant distractor-interference effect on trials in which the task-irrelevant scene matched those associated with homogeneous search arrays during training, $t(14) = 5.1$, $p < .001$, but not those in which the scene matched those associated with heterogeneous search arrays during training, $t(14) = 1.3$, $p = .22$. This effect was of roughly the same magnitude as that observed in Experiment 1, despite the intertrial effects that diminished capture for homogeneous displays during training, which was somewhat surprising. In addition, an intertrial analysis identical to that performed during the training session (in this case, on the basis of scene type) revealed no effect of scene type on the previous trial on the magnitude of capture; capture effects were large on trials in which the scene had been associated with homogeneous arrays, and capture effects were negligible on trials in which the scene had been associated with heterogeneous arrays, regardless of the identity of the scene in the previous trial. Given this dissociation in intertrial effects across training and testing sessions, it appears that the physical display properties that influenced capture during training are dissociable from the factors responsible for instantiating context-dependent influences on control. Taken together, this suggests that the likelihood of observing capture in a given situation may depend on the synergistic effects of display factors and top-down search strategies, a point on which we elaborate in the general discussion. There were no significant main effects or interactions in the error data, Fs < 1.3, ps $< .26$.

Questionnaire data. On the open-ended question, only four observers reported employing what could be interpreted as a singleton-detection set during the testing session. Of note, none of the observers reported using a switching strategy, and no observers selected the *neither* or *both* option on the multiple choice question, ruling out an account of our effects on the basis of explicit switching. On the multiple choice question, 10 of the 15 observers who participated in Experiment 2 selected the "searched for the circle" option, indicating that the majority of observers employed

Table 3
Experiment 2 Training Session RT Data as a Function of Previous Trial

Display type	Distractor absent RT	Distractor present RT	Capture effect
Homogeneous			
Preceded by heterogeneous	649	649	0
Preceded by homogeneous	640	664	24^*
Heterogeneous			
Preceded by heterogeneous	658	664	6
Preceded by homogeneous	664	667	3

* $p < .05$.

an explicit set that was consistent with the feature-search set suggested in the task instructions. However, the same four observers who noted using a singleton-detection strategy on the open-ended question, as well as one other observer, selected the "searched for the different shaped item" option from the list of possible strategy choices. In order to assess whether this difference in explicitly reported strategies was related to differences in the context-dependent capture effect, the data from the testing session were examined as a function of reported strategy. Consistent with the possibility that explicit strategies aren't a requirement for driving the effect observed here, we observed significant attentional capture in both groups when the search array was embedded within scenes previously associated with search through a homogeneous array during training, ("searched for circle group": $t(4) = 3.4$, $p = .02$; "searched for different shape" group: $t(9) = 3.9$, $p < .01$); however, neither group showed significant capture when the search array was embedded within scenes associated with search through a heterogeneous array (in both groups ts < 1, n.s.). This is in concordance with previous studies that have shown a disconnect between reported search strategies and the behavioral effects of capture (Proulx, 2011; Kawahara, 2010), and demonstrates that learned contextual associations can influence attentional capture, regardless of explicit strategies adopted in response to immediate task goals.

Discussion

These data provide a general replication of those in Experiment 1, showing that observers can link particular attentional sets with specific task-irrelevant contextual information through experience, with context subsequently leading to predictable effects on attentional capture. The fact that no observers reported using a switching strategy, and explicit search strategies had little bearing on the pattern of capture effects during the testing session, seem to suggest that the form of context-specific control demonstrated in our task does not require explicit switching between sets or voluntary control on the basis of explicit task goals. Instead, it appears that characteristics of the search displays can cause a change in the likelihood of attentional capture, which comes to be linked with task-irrelevant global contextual information. This is generally compatible with studies proposing a role for display factors in driving the asymmetries in capture typically seen in this task (e.g., Theeuwes, 2004, 1994; Belopolsky & Theeuwes, 2010). Furthermore, consistent with the results of Experiment 1, it appears that once longer term contextual representations are formed, they may act as the primary determinant of attentional capture, at least in homogeneous search displays such as those used during the testing session of Experiments 1 and 2. Finally, the fact that we observed significant intertrial effects resulting from trial-to-trial variations in the homogeneity/heterogeneity of the search displays during training, but not trial-to-trial variation of scene context during testing, suggests that bottom-up display factors and top-down knowledge may exert separate, complementary influences on attentional capture. Given that most participants reported using the instructed feature-search strategy, but still showed context-dependent effects on attentional capture, it is possible that display factors influence the effectiveness with which top-down strategies are implemented, and extended experience with specific display factors in specific contexts may lead to a lasting modulation of top-down control that can influence future behavior. Given the mounting evidence that both factors influence capture, a better understanding of how these factors interact with one another to enable control could help explain a number of conflicting results in the attentional capture literature (see Theeuwes, 2010).

General Discussion

Our results provide evidence that context is a key factor determining the adoption of a particular attentional set, with learned associations between a given attentional set and specific contextual information influencing how the attention system operates in a given situation. Furthermore, the results of Experiment 2 demonstrate that display factors play an important role in the likelihood of capture, possibly by altering the way in which observers perform the search task (Theeuwes, 2004). These data provide novel insights into how observers configure attentional control across situations, and suggest that, rather than always being implemented in an active, voluntary manner, the attentional set observers use to perform a task can be influenced in a more or less automatic manner by longer term contextual learning. This extends previous work showing automatic influences of intertrial priming on atten-

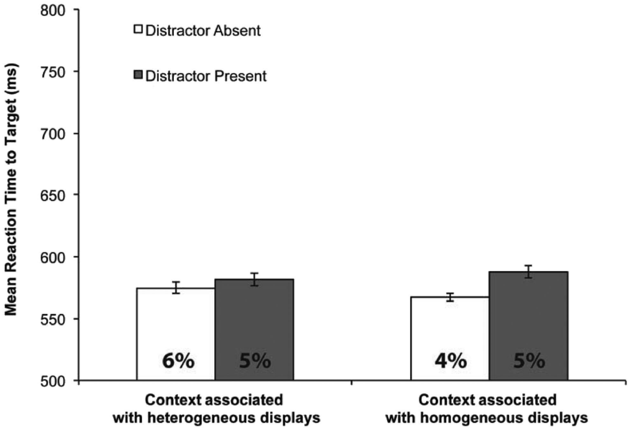

Figure 3. RT data and error rates (bottom of each column) for each condition in the testing session of Experiment 2. During the testing session, observers always searched for a circle among homogeneous diamond nontargets. The search arrays were embedded within scenes that had either been associated with a heterogeneous or homogeneous search display during the training session. Error bars represent 95% within-subject confidence intervals (Loftus & Masson, 1994; Morey, 2008).

tional capture (e.g., Folk & Remington, 2008; Belopolsky, Schreij, & Theeuwes, 2010), as well as work showing an automatic effect of spatial context on visual search processes more generally (Chun & Jiang, 1998). Finally, our results are consistent with a number of recent demonstrations that information not directly relevant to immediate task goals can nevertheless exert a strong, automatic influence on cognitive control systems necessary for overcoming distraction (Lau & Passingham, 2007; Van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009; Boy, Husain, & Sumner, 2010).

Mechanisms of Contextual Control

We hypothesize that the context effects observed here stem from the operation of general relational memory mechanisms responsible for coding the arbitrary relationships between items in a visual scene and their context, forming the basis of episodic memories (Cohen & Eichenbaum, 1993; Davachi, 2006). Such a view is consistent with influential theories of automaticity that propose a central role for episodic memory representations in attentional control following experience with a task (Logan, 1988, 2002), and draws support from studies showing an influence of relational memory systems on visual perceptual and attentional processes more generally (e.g., Warren, Duff, Tranel, & Cohen, 2011; Hannula & Ranganath, 2009; Lee et al., 2005; Ryan et al., 2000; Chun & Phelps, 1999). For example, long-term relational information has been shown to influence the deployment of attention to regions of interest in scenes, and these effects have been shown to be dependent on medial temporal lobe memory systems responsible for episodic encoding, suggesting a tight linkage between episodic memory and attentional processes (Hannula & Ranganath, 2009; Ryan et al., 2000; Chun & Phelps, 1999). Consistent with this view of the current work, we have obtained parallel results demonstrating that amnesic patients with bilateral damage to the medial temporal lobes show no influence of past experience on the instantiation of a particular attentional set (Cosman & Vecera, 2012), despite having an intact ability to overcome distraction in a training session in which they search heterogeneous displays for a specific target (i.e., when adopting a feature-search set). Thus, traditional long-term relational and episodic learning mechanisms may play a more general role in attentional control than previously considered, providing one possible unifying mechanism through which task-specific learning may influence goal-directed attentional control and capture (as in Carlisle et al., 2011; Anderson et al., 2011; Kelley & Yantis, 2008; Leber & Egeth, 2006a; 2006b; Leber et al., 2009).

The current results are also related to those observed in the contextual cueing phenomenon, in which implicitly learned spatial associations between targets and distractors facilitate visual search performance (Chun & Jiang, 1998). Like the current results, contextual cueing effects have been shown to rely on both lower level (local) display factors and global contextual factors (Olson & Chun, 2002; Brockmole, Castelhano, & Henderson, 2006; Kunar, Flusberg, & Wolfe, 2006; Brooks et al., 2010). For example, local contextual information regarding the spatial location of target and near-by distractor items in the task-relevant search array exert a strong influence on contextual cueing effects (Olson & Chun, 2002), but the instantiation and magnitude of these effects have been shown to rely on the global context in which the displays are embedded (Brooks et al., 2010; see also Kunar et al., 2006). However, the current work diverges from typical contextual cueing effects in terms of the type of contextual information used to influence control. Whereas contextual cueing effects are dependent on predictive spatial relationships between elements of a search array and their specific locations, the effects of context observed here operate at a more abstract, nonspatial level; in our task, context was not predictive of the location of either the target or salient distractor items, but was still able to produce a strong, predictable influence on attentional capture. Therefore, the current work provides evidence that, in addition to spatial information, the attentional system can use nonspatial contextual cues to influence the deployment of attention.

Lastly, the view that we attempted to advance here is consistent with recent results showing that the target template responsible for guiding visual search may often rely primarily on long-term memory representations, provided the search target is held constant across trials (Carlisle et al., 2011; Woodman et al., 2007). Specifically, Carlisle et al. (2011) demonstrated that, in cases where observers searched for the same target item on each trial, the magnitude of the electrophysiologcal marker of visual working memory maintenance (the contralateral delay activity; CDA) diminished quickly, presumably representing a handoff of the target template to longer term memory mechanisms. Conversely, when the target switched unpredictably from trial to trial, the CDA remained robust, indicating that visual working memory was more likely to be involved in control under conditions of target uncertainty. Along with the current results, this suggests that in cases where attributes of the task space are unpredictable, goal-directed attentional control may rely more heavily on active working memory processes, whereas such control may become increasingly dependent on long-term memory when attributes of the task and environment are predictable, an idea central to theories of control and automaticity (Logan, 1988, 2002; Norman & Shallice, 1986; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). This raises the possibility that a number of other attentional effects typically attributed to volitional control processes and/or working memory may be heavily influenced by long-term, automatic responses to components of a task and the context in which the task is performed.

Display Factors, Strategies, and Capture

Our results also speak to the debate regarding the relative influence of strategic modes of search and display factors on attentional capture (Theeuwes, 2004; Leber & Egeth, 2006a).

Specifically, it is typically proposed that the asymmetry in capture between feature- and singleton-search tasks is the result of strategic modes of search employed by observers in each type of task (Bacon & Egeth, 1994; Folk et al., 2002; Leber & Egeth, 2006a,2006b), with attentional capture being reduced during feature search because of a mismatch between the dimension defining the observers' explicit search goals ("search for the circle") and the salient attribute of the distractor item (typically color). However, in both of the experiments presented here, we observed asymmetries in capture on the basis of learned context, regardless of the observers' explicit strategies vis-à-vis the target of search. Furthermore, when explicit search goals were held constant in Experiment 2, observers showed patterns of data during both training and testing that would be consistent with feature- and singleton-search sets. This suggests that explicit, strategic factors may not always be necessary or sufficient to drive effective control over capture.

As an alternative to the "strategic" view outlined above, Theeuwes and colleagues (Theeuwes & Burger, 1998; Theeuwes, 2004, 2010; Belopolsky & Theeuwes, 2010) have proposed that the asymmetry in capture between feature and singleton searches results from differences in the displays used to study each set, arguing that the lack of a distractor effect during feature search is due to observers adopting a "serial" search strategy during search through heterogeneous displays (cf. Duncan & Humphreys, 1989; Nothdurft, 1993), leading to a reduction in the spatial scale of attention and decreasing the likelihood that a salient item will fall inside the focus of attention and cause distraction (Theeuwes & Burger, 1998; Theeuwes, 2004; Belopolsky & Theeuwes, 2010). Although set-size manipulations or endogenous manipulations of attentional scale have traditionally been used to provide evidence for this view, if serial search processes are necessary for attenuating distraction during feature search, one would expect that during the testing session of both experiments, overall search RTs should have been significantly slower when search arrays were embedded within a scene that had been associated with feature search during training (because little capture was observed in this condition). However, we observed no difference in overall RTs as a function of scene type, and hence argue against interpretations that account for differences in capture across feature and singleton search solely in terms of serial versus parallel search mechanisms.

Thus, neither interpretation can fully account for the results observed here, and we argue that other factors may be influencing capture in this task. Similar to Theeuwes and colleagues, we think it is likely that differences between heterogeneous and homogeneous displays may be important for driving the difference in capture between feature- and singleton-search conditions. However, we would argue that rather than resulting from differences in attentional scale across serial versus parallel searches, these asymmetries may instead result from differences in the strength of top-down control engendered by each type of display (Torralbo & Beck, 2008; McMains & Kastner, 2011). Recent work has demonstrated that the strength with which top-down attention operates to select a target is directly related to the amount of competition left unresolved by bottom-up competition between objects in a scene (McMains & Kastner, 2011). With respect to the current results, it is possible that increased interitem competition in heterogeneous displays may engender stronger top-down control, ultimately leading to less distraction by salient, task-irrelevant information. This view is supported by a number of recent studies demonstrating reduced attentional capture in heterogeneous relative to homogeneous search arrays (e.g., Lamy & Tsal, 1999; Cosman & Vecera, 2009, 2010a, 2010b), as well as studies showing that other manipulations that influence local competition modulate the likelihood of distraction (Torralbo & Beck, 2008; Proulx & Egeth, 2006; Roper, Cosman, & Vecera, 2012). However, we don't wish to argue that either explicit, strategic factors or differences in the scale of attention play no role in influencing attentional capture, but rather that that the attentional control system likely relies on multiple bottom-up and top-down factors that interact to determine capture in a given situation (see Cosman & Vecera, 2010a). For example, Leber (2010) showed, in a homogeneous search task nearly identical to the one used here, that the magnitude of attentional capture fluctuated in a predictable manner with activity in a cortical region that may contribute to cognitive control (middle frontal gyrus, MFG; Leber, 2010). When MFG activity was relatively high, behavioral capture effects were attenuated, and when MFG activity was relatively low, robust capture effects were observed. Thus, it may be the case that display factors that lead to increases in, for example, bottom-up competition or differences in the scale of attention, bias the effectiveness with which the cognitive control system is able to use explicit top-down information to overcome distraction by salient information.

Conclusions and Future Directions

Taken together, our results demonstrate a central role for contextual information in the acquisition and implementation of specific attentional sets, and complement recent work showing effects of task-specific learning on attentional control and capture (e.g., Leber, 2006a, 2006b, Leber et al., 2009; Kelley & Yantis, 2008; Anderson et al., 2011) by providing one possible mechanism through which these learned control effects may operate. This suggests that other attributes central to long-term memory representations may similarly influence the efficiency and effectiveness with which attentional control processes operate, and future work should focus on determining precisely which factors are critical for driving these learned influences on control. For example, it isn't clear whether the effects demonstrated here are the result of categorical processes (i.e., at the level of "forest" or "city street" categories) or instead are exemplar specific; in other words, does the *category* of a scene act as a contextual cue, or can the identities of *individual scenes* themselves drive these effects? Similarly, the time course of our effects are unknown, and it may be the case that, as in spatial contextual cueing, observers require sufficient time to process the scenes before context can influence the implementation of a specific attentional set (e.g., see Kunar, Flusberg, & Wolfe, 2008). Finally, although explicit strategies don't appear to be necessary for generating the context effects demonstrated here, understanding how explicit control may modulate these effects may provide critical information regarding which memory systems are important to their emergence. Regardless of the exact mechanisms involved, the current work demonstrates that longer term, nonspatial contextual memory can directly influence attentional capture, and precisely characterizing the relationship between long-term memory and attentional control provides a fruitful avenue for future research.

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