Task-specific learning supports control over visual distraction

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TASK-SPECIFIC LEARNING SUPPORTS CONTROL
OVER ATTENTIONAL CAPTURE

by

Joshua Daniel Cosman

An Abstract

Of a thesis submitted in partial fulfillment of the
requirements for the Doctor of
Philosophy degree in Neuroscience in
the Graduate College of
The University of Iowa

May 2012

Thesis Supervisor: Professor Shaun P. Vecera
ABSTRACT

There is more information in the visual environment than we can process at a given time, and as a result selective attention mechanisms have developed that allow us to focus on information that is relevant to us while ignoring information that is not. It is often assumed that our ability to overcome distraction by irrelevant information in the environment requires conscious, effortful processing, and traditional theories of selective attention have emphasized the role of an observer’s explicit intentions in driving this control. At the same time, effortful control on the basis of explicit processes may be maladaptive when the behaviors to be executed are complex and dynamic, as is the case with many behaviors that we carry out on a daily basis. One way to increase the efficiency of this process would be to store information regarding past experiences with a distracting stimulus, and use this information to control distraction upon future encounters with that particular stimulus. The focus of the current thesis was to examine such a “learned control” view of distraction, where experience with particular stimuli is the critical factor determining whether or not a salient stimulus will capture attention and distract us in a given situation. In Chapters 2 through 4, I established a role for task-specific learning in the ability of observers to overcome attentional capture, showing that experience with particular attributes of distracting stimuli and the context in which the task was performed led to a predictable decrease in capture. In Chapter 5, I examined the neural basis of these learned control effects, and the results suggest that neocortical and medial temporal lobe learning mechanisms both contribute to the experience-dependent modulation of attentional capture observed in Chapters 2-4. Based on these results, a model of attentional capture was proposed in which experience with particular stimulus attributes and their context critically determine the ability of salient, task-irrelevant
information to capture attention and cause distraction. I conclude that although explicit processes may play some role in this process under some conditions, much of our ability to overcome distraction results directly from past experience with the visual world.

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Thesis Supervisor

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Joshua Daniel Cosman

A thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in Neuroscience in the Graduate College of The University of Iowa

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CHAPTER
INTRODUCTION

The environment contains more information than we can process at a given time. As a result, selective attention mechanisms have developed that allow us to attend to information that is relevant to us while ignoring information that is not. For example, most of us are able to read a book in a crowded coffeehouse with little problem despite the sights, sounds, and conversations around us. At the same time, information that is not relevant to our goals often captures our attention, distracting us from the task at hand – we are likely to pay attention to someone who just dropped their coffee mug on the floor in front of us, even though it should be clear that paying attention to this event will detract from our ability to finish our reading. On the other hand, in some cases distraction from a task is adaptive, allowing us to notice and react to changes in the environment that demand our attention – for example, a child jumping into the street to fetch a ball in front of our car. Thus a better understanding of mechanisms mediating distraction is important not only from a basic science standpoint, but has implications for applied research across a number of domains. For example, understanding the root of selective attention impairments in older drivers may allow us to develop countermeasures (e.g., effective in-vehicle alerting systems) that increase driver and pedestrian safety (see Lees, Cosman, Fricke & Rizzo, 2010).

There has been a great deal of debate surrounding the psychological and neurophysiological mechanisms of distraction in cognitive psychology and neuroscience, and much of the work on distraction has focused on determining whether salient information can “capture” attention in an automatic manner; Researchers interested in
attention capture have traditionally focused on the extent to which information in the environment draws attention to itself even when it is irrelevant to the immediate goals of the observer. Much of the contemporary work on this subject has come from studies in the visual modality, and thus the debate over the nature of capture effects has been limited primarily to the domain of visual attention (however, see Spence, 2010, for a review of multimodal influences on capture). Generally speaking, there are two views of attentional capture, with some arguing that salient information can capture our attention automatically, regardless of task relevance (e.g., Posner, 1980; Yantis & Jonides, 1984; Yantis, 1993; Theeuwes, 1991; 1992; 1994; 2010) and others arguing that capture is primarily dependent on our immediate task goals (Folk, Remington, & Johnston, 1992; Bacon & Egeth, 1994; Leber & Egeth, 2006a; Eimer & Kiss, 2008).

Stimulus-driven accounts of attentional capture emphasize the role of salience in the capture of attention; To the extent that salient events are present in the environment, the attention system will prioritize these events and attention will be deployed to them in an automatic manner, regardless of whether they are relevant to task performance. Such a view is rooted in work showing that salience is computed very early in visual processing, presumably preattentively and in parallel across a scene (e.g., Treisman & Gelade, 1980; Koch & Ullman, 1985; Itti & Koch, 2001; Li, 2002;), and go a step further by proposing that the output of this salience computation causes mandatory shift of attention to the most salient item in a given scene (Theeuwes, 2010; Hickey, McDonald, & Theeuwes, 2006). Under this view it is proposed that goal-directed control processes operate only after this initial, salience guided shift of attention, occurring via feedback connections from high level regions (e.g., prefrontal cortices) responsible for goal
maintenance and cognitive control (Theeuwes, 2010). In support of stimulus-driven theories of attentional capture, a number of studies have demonstrated that certain types of salient visual information can capture attention even when entirely unrelated to or in opposition to an observer’s goals (Theeuwes, 1991; Yantis & Jonides, 1984; Schreij, Owens, & Theeuwes, 2008; Belopolsky et al., 2010; Hickey, McDonald, & Theeuwes, 2006). For example, abrupt stimulus onsets (Yantis & Jonides, 1984; Jonides & Yantis, 1988; Theeuwes, 1994), visual singletons (Theeuwes, 1991; 1992; 1994), the onset of motion (Abrams & Christ, 2003; Franconeri & Simons, 2003), have been argued to capture attention in a purely automatic, bottom-up manner (see Ruz & Lupiñez, 2002; Theeuwes, 2010 for reviews).

Conversely, goal-directed accounts of capture emphasize the role of deliberate control based on immediate task goals in determining whether salient events capture attention (e.g., Folk et al., 1992; Leber & Egeth, 2006a; Eimer & Kiss, 2008). Under this view, salience alone plays little role in determining what is attended, with capture instead depending on a match between an observer’s goals and incoming stimulus information; Salient information captures attention if and only if it matches an observer’s search goal. In support of this view, a number of studies have demonstrated that the goals of an observer, implemented in the form of an “attentional set” critically determine whether or not attention is captured (e.g., Folk et al., 1992; Bacon & Egeth, 1994; Leber & Egeth, 2006a; Eimer & Kiss, 2008; Cosman & Vecera, 2009; 2010a; 2010b). For example, when a task requires an observer to search for a target defined by a particular feature (e.g., its color or shape) only items matching the target feature capture attention even if other salient items are present in the display (Folk et al., 1992; Folk & Remington, 1998;
Folk, Leber, & Egeth, 2002). Likewise, if an observer voluntarily directs attention to a particular location of interest, salient events at other locations fail to capture attention (Yantis & Jonides, 1990; Theeuwes 1991). Finally, if observers are engaged in a difficult, attention-demanding task, salient but task irrelevant information fails to capture attention despite the fact that this information captures attention during similar but less demanding tasks (Cosman & Vecera, 2009b; 2010a; 2010b see also Bryant & Gibson, 2008; Santangelo & Spence, 2008; Lamy & Tsal, 1999).

Mechanistically speaking, as noted above proponents of stimulus-driven accounts of capture have typically minimized the role of goal-directed processes on early visual processing, arguing instead that these processes act after the initial selection of information on the basis of salience (Theeuwes, Atchley, & Kramer, 2000; Belopolsky et al., 2010; Theeuwes, 2010). This view derives from influential models of attention that propose a role for pre-attentive feature analysis in determining the saliency of particular regions of the environment, by computing local feature contrast across a number of feature dimensions (e.g., color, orientation, motion direct, etc.; Treisman & Gelade, 1980). This information is then used to construct a “saliency map” that represents the locations in space containing the greatest feature contrast (e.g., Koch & Ullman,1985; Itti & Koch, 2001), and one could think of the salience map as serving to reduce the number of possible “objects of interest” present in the visual field to a manageable number that the visual system can handle. In other words, salience can act as a constraint on where an observer decides to attend in a scene, and may be the critical determinant of whether attention is captured by a particular stimulus – highly salient items may be prioritized by the visual system, receiving privileged access to limited capacity attentional mechanisms.
This view has been formalized by Theeuwes and colleagues (1991; 1992; 2000; 2010), and proposes that salience computation causes a *mandatory* shift of attention toward the region of space with the highest salience within the salience map. Once attention selects the most salient item in the display, this item’s identity is derived, and it is only at this point that top-down information regarding an observer’s goals influences the control of attention – if the item matches some aspect of the observer’s task goal, the item is subjected to further scrutiny and if not attention is quickly directed away toward other, presumably more relevant information. Thus, under this view goal-directed control has no effect on the initial allocation of attention – attention is always captured in a bottom-up, stimulus-driven manner by the most salient item in a scene (Theeuwes, 2010 – see Figure 1).

![Diagram](diagram.png)

Figure 1. A simple diagram outlining the mechanisms of attentional control (adapted from Theeuwes, 2010). The primary point of contention between stimulus-driven and goal-directed theories of attentional capture is whether information regarding an observer's goals can influence the initial attentional selection process.

On the other hand, proponents of goal-directed accounts of capture have proposed that information regarding the goals of a task can be used to filter incoming sensory information pre-attentively on the basis of how well it matches a particular goal state,
with only goal-compatible information receiving attentional processing. It has been proposed that goal-directed control is implemented on the basis of an “attentional set” that includes information regarding the goals of a task, and is used to flexibly guide attention on a moment-by-moment basis toward behaviorally relevant information in the environment (Folk et al., 1992; 1993; 1994; Folk, Leber, & Eggeth, 2002; Bacon & Eggeth, 1994; Leber & Eggeth, 2006a; 2006b). This view has been formalized in Folk and colleagues’ *contingent involuntary orienting hypothesis*, which states that even highly salient information will only capture attention when it is compatible with the observer’s attentional set (Folk et al., 1992). For example, when observers are instructed to search for a red target, only red distractors will capture attention even if other salient items are present in the visual environment. Thus, whereas the stimulus-driven theories of capture proposes a central role for salience in determining capture, goal-directed theories emphasize the role of task goals in determining capture.

Although the studies of Folk and colleagues have not specified exactly how, mechanistically speaking, such an attentional set may be implemented, influential theories of attentional control have proposed a central role for working memory representations in the instantiation of search goals in the form of a “target template” that represents attributes of the target of search (Bundesen, 1990; Bundesen, Habekost, , 2005; Desimone & Duncan, 1995; Duncan & Humphreys, 1989). Presumably, incoming sensory information can be compared against this template and affect attentional selection, such that information matching the template is subjected to further processing whereas non-matching information is not (Luck, 2008). This provides a mechanistic description of how particular task-specific attentional sets can directly influence the
control of attention, with templates in working memory being compared against incoming sensory information to determine whether this information warrants a shift of attention. Such a view has been highly influential in describing goal-related influences on search processes, and has gained support from a number of studies demonstrating that discrete information (colors, simple shapes, spatial locations, etc.) held in working memory can bias the allocation of attention during search tasks (Downing, 2000; Awh, Jonides, & Reuter-Lorez, 1998; Soto et al., 2005; Olivers et al., 2006; Woodman & Luck, 2007; Munneke et al., 2010; Cosman & Vecera, 2011) as well as data showing a close relationship between working memory processes and the behavioral and neurophysiological effects of attentional control (Fukuda & Vogel, 2009; 2011; DeFockert et al., 2004; Lavie & DeFockert, 2006).

It has been proposed that goal-directed control operates via feedback connections from frontal regions responsible for maintaining goal representations in working memory to regions responsible for sensory processing (Miller & Desimone, 1991; Goldman-Rakic, 1996; Kastner & Ungerleider, 2000; LaBar, Gitelman, Parrish, & Mesulam, 1999; Miller & Cohen, 2001). Under this view maintenance is achieved through sustained activation in relevant sensory regions, providing a candidate mechanism for how the processing of incoming sensory information can be directly influenced by the goals of an observer (Serences et al., 2009; Soto et al., 2007; D’Esposito, 2007; Pasternak & Greenlee, 2005; Ranganath et al. 2004; Awh & Jonides, 2001; Courtney et al., 1997; Chelazzi et al., 1993; 1998; Miller et al., 1993).

**Automaticity and intentionality in attentional capture**

As discussed above, the central question of interest in the capture literature has
been one of automaticity: to what extent do salient events capture attention automatically, and to what extent can our explicit goals override capture when this salient information is irrelevant? Historically, one of the primary criteria used to define automatic processes is intentionality, and a process that occurs without the explicit intent of an observer is often said to occur automatically (Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Jonides, 1981; Norman & Shallice, 1986; Yantis, 1993). Following this logic, the approach in most attention capture paradigms is to pit stimulus salience against an observer’s intentions and look for effects on behavior. For example, the standard instruction in most capture tasks is “search for X while ignoring Y” where X is some target and Y is some irrelevant distractor. If capture effects are observed, it is concluded that attention was allocated “automatically” toward a salient item, and if not it is concluded that the observer exerted effective goal-directed control. Thus, stimulus-driven capture is viewed as an automatic process, occurring despite the intentions of the observer, whereas goal-directed control is typically viewed as an intentional process carried out by observers on the basis of some explicit task goal (e.g., “search for the red square”). In this way, capture effects have been situated within the larger framework of automatic vs. voluntary processes – passive, stimulus-driven processes engender capture, whereas voluntary, goal-directed processes are necessary to overcome it (e.g., Egeth & Yantis, 1997; Yantis, 2000; 2008; Theeuwes, 2010). Such a view derives in part from influential theories of attentional control that propose competition between stimuli in the environment and the goals of an observer in determining the allocation of attention (Treisman & Gelade, 1980; Duncan & Humphreys, 1989; Wolfe, 1994; Bundesen, 1990; 2005; Desimone & Duncan, 1995; Yantis, 2000; Corbetta & Shulman, 2002).
This conceptualization has provided a useful framework for understanding how stimulus factors and task goals compete with one another to bias the allocation of attention, leading to a better understanding of both the psychological and neural mechanisms responsible for stimulus-driven and goal-directed forms of control (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000; Corbetta & Shulman, 2002; Yantis, 2000; 2008). Furthermore, capture paradigms have been extremely popular because they provide a test bed for a number of assumptions regarding the types of information that may “automatically” draw attention, allowing researchers to better understand how an organism decides where to attend and the extent to which salient information can be explicitly ignored when it is irrelevant. The basic logic used in capture tasks has been applied across a number of domains to test questions regarding the ability of, e.g., social (Theeuwes & van der Stigchel, 2006; Ro, Russell, & Lavie, 2001; Vuilleumier, 2002), emotional (Ohman, Flikte, & Estevez, 2001), and linguistic (Salverda & Altmann, 2011) information to capture attention, as well as to assess goal-directed control and distractibility in aging and clinical populations (Costello et al., 2010; DuCato et al., 2008; Mason, Humphreys, & Kent, 2005; Cosman et al., in press.).

At the same time, this approach to the study of attentional capture is at least partially responsible for the now decades long debate over the precise mechanisms underlying attentional capture effects. This is because such an approach forces stimulus-driven and goal-directed control to be considered as opposing, non-overlapping processes, leading proponents of both stimulus-driven and goal-directed theories of control to focus on trying to prove that one mode of control or the other represents the “default” mode of control in all situations (Theeuwes 2010; Folk et al., 1993; Yantis,
1993; 2008; Kawahara, 2010). Given that there is a great deal of support for both modes of control, it seems likely that rather than capture ever being entirely dependent on either stimulus factors or an observer’s intentions, these factors dynamically interact and constrain each other to determine the extent of attentional capture in a given behavioral context. However, proposing such a dynamic account of capture effects has proven difficult within the constraints of the traditional view of attentional capture. Furthermore, differentiating between stimulus-driven and goal-directed control processes on the basis of intentionality requires a number of assumptions that leave a great deal of theoretical “wiggle room” for proponents of both views of capture. The fact that the field has progressed rapidly with little acknowledgement of these issues has led to a theoretical impasse in recent years, with little tangible progress being made in understanding the mechanisms responsible for driving the behavioral effects of capture (see, e.g, Theeuwes 2010 and responses). In the current thesis, I will offer a critique of the traditional view of attentional capture, before proposing and testing a possible alternative that overcomes these criticisms. My hope is to provide a unified framework for understanding how stimulus factors and an observer’s goals or intentions interact with one another to modulate attentional capture.

*Assessing the diagnosticity of intentionality

*in differentiating modes of control*

As noted above, automatic processes are often described as those processes that occur without intention (Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Kahneman & Treisman, 1984; Jonides, Naveh-Benjamin, & Palmer, 1985), and intentionality has traditionally been one of the primary criteria used to differentiate between stimulus-
driven and goal-directed processes in the attention capture literature (e.g., Yantis & Jonides, 1990; Egeth & Yantis, 1997; Theeuwes, 1991; 2010 Theeuwes & Burger, 1998). Stimulus-driven selection is described as the automatic capture of attention on the basis of stimulus salience, whereas goal-directed control is described as the modulation of capture on the basis of an observer’s explicit intentions. However, this view can be criticized on a number of grounds (see, e.g., Jonides et al., 1985), and in the context of attentional capture in particular most of these criticisms arise from the fact that using intentionality to differentiate between stimulus-driven and goal-directed processes requires us to accept a number of assumptions that run contrary to knowledge regarding the basic psychological and neurophysiological mechanisms involved in the control of behavior.

For example, the traditional view of capture effects assumes that intentionality is a necessary precursor for driving goal-directed control, even though there is no reason to think that all goal-directed processes are carried out in an intentional manner. In fact, it’s likely that a great deal of goal-directed control occurs without intention or explicit control, given that decades of research on automaticity has shown that many forms of complex goal-directed control (e.g., flying an airplane, evaluating social situations, or learning to perform mental math) can come to be performed in an automatic manner with sufficient experience (e.g., Schneider & Shiffrin, 1977; Kahneman & Treisman, 1984; Bargh, 1982; Bargh & Ferguson, 2000; Logan, 1988; 2002). Thus despite the fact that intentional, effortful processes are assumed to drive effective goal-directed control over capture, it is also possible that experience with a task may enable goal-directed processes to operate with very little intention or effort on the part of the observer.
Additionally, this view assumes that intentionality is *sufficient* for driving goal-directed control. As mentioned above, in cases where goal-directed control is shown to be effective, it is often assumed that control was implemented intentionally on the basis of some explicit task set. However the instructions in most capture tasks are nearly identical ("search for the thing I’m supposed to find, and ignore the thing I’m supposed to ignore"), and as such the intentions of observers and the resulting task set should be more or less identical across tasks. Despite this, capture by task-irrelevant information is routinely observed in some capture tasks and not others. Thus it is likely that the intention to attend one stimulus and ignore another is not always sufficient to drive the types of highly specific goal-directed control over capture routinely observed in the capture literature (e.g., Folk et al., 1992; 1994; 2002; Bacon & Egeth, 1994; Leber & Egeth, 2006a; 2006b).

The fact that different levels of capture are observed across different tasks, with these tasks varying primarily in their stimulus properties points to a critical role for an observer’s experience with particular stimulus-factors in determining the circumstances in which task-irrelevant information will or will not capture attention. Put another way, stimulus factors themselves may play a direct role the instantiation of goal-directed control regardless of what the observer is explicitly told to do or intends to do in a given task. In this way, control may emerge as a by-product of the observer’s interactions with particular stimuli in the environment, with some stimulus factors engendering more effective goal-directed control than others (see, e.g., Beck & Kastner, 2005; Reynolds, Chelazzi, & Desimone, 1999; Cosman & Vecera, 2009; 2010a; 2010b; McMains & Kastner, 2011)
In support of such a view, a number of studies have shown that minor tweaks to a task’s stimuli can cause effective goal-directed control to be observed in tasks that typically show stimulus-driven capture (e.g., Bacon & Egeth, 1994; Leber & Egeth 2006a), and capture to be observed in tasks that normally show effective control (Belopolsky et al., 2010; Schreij et al., 2010; Cosman & Vecera, 2010b) again despite the fact that the instructions (and thus the “intentions” of observers) are more or less constant across these tasks. Furthermore, a handful of studies have demonstrated that task-specific learning can directly alter the effectiveness of goal-directed control, further arguing for experience with a task and its stimuli as a major component of goal-directed control (Leber & Egeth, 2006a; 2006b; Kelley & Yantis, 2009; 2010; Tang & Posner, 2009). At a minimum, then, it would seem that an observer’s intentions alone are not responsible for driving goal-directed control over capture, with effective control instead arising through the interaction of stimulus factors and an observer’s goals. This view is much different than that offered by the status quo description of capture effects, and provides the potential for reconciling between conflicting findings in the capture literature.

**The role of past experience in attentional control**

Based on the above criticisms there seems to be no reason to assume that intentions are necessarily involved in generating effective goal-directed control, and by the same token there is no reason to assume our intentions are sufficient for effective goal-directed control. The goal of the current thesis is to show that, whereas an intention to ignore alone doesn’t directly affect whether salient information captures attention, experience with particular attributes of a task does. For example, in the late 1990’s/early
2000’s, there was a move toward using flashing banner ads on websites in an attempt to increase ad click-throughs – the flashing ad captured attention, making unsuspecting web browser’s more likely to notice and therefore click the ads. However, systematic studies of looking behavior have shown that over time, consumers have come to avoid attending to flashing banner ads, as a result of the fact that these ads rarely provide important information on the other side of the click (Dreze & Hushherr, 2003). Thus in recent years there has been a decrease in the use of these banner ads due to the fact observers no longer pay attention to them, as well as the negative impact they have on return visits to websites that use them (Thota, Song, & Larsen, 2010). This example highlights the fact that even in relatively mundane tasks our experiences critically determine the likelihood that certain salient information is attended and allowed to affect our behavior.

As I will argue throughout this thesis, a similar principle likely applies to basic research on attentional capture; conflicting findings in the capture literature, which traditional views of attentional capture have had difficulty reconciling, can be easily understood within a framework by which goal-directed control is a learned process. Under this view, an observer’s interaction with particular stimulus factors is critical in determining the extent to which attention will be captured in a given situation, a much different approach than traditional approaches to capture. This approach is based on a combination of complementary lines of research that have operated mostly in parallel to one another, but that taken together provide a compelling case for how extended experience with specific aspects of the visual world can shape attentional control. Specifically, I will attempt to situate attentional capture effects within the larger framework of visual skill learning, focusing on studies of visual perceptual learning.
(VPL), visual statistical learning (VSL) and the rules of basic skill acquisition that enable the performance of a number of complex behaviors, ultimately arguing that goal-directed control is best described as a skill acquired through experience.

In the context of the current thesis, studies of visual learning and skill learning provide an empirical basis for the notion that efficient goal-directed control over capture may rely critically on experience. Given that the visual system can tune to specific perceptual properties at a low-levels (at the level of individual features) as well as at higher-levels of abstraction (at the level of global stimulus context), it seems plausible that learning to exercise precise control over what information captures attention may be no different than the learning of other skills. This “learned control” approach provides a unified framework for understanding how stimulus factors and goals interact to influence capture, viewing control as an emergent property of learning and long-term memory mechanisms responsible for information acquisition and skilled task performance. Such an approach could be viewed as complementary to current conceptualizations of capture effects, because currently these views place little or no emphasis on the role of experience-dependent, long-term task representations that likely determine the effectiveness goal-directed control. In the following sections, I will provide a brief review of the both the visual learning and skill learning literature to provide a more explicit basis for how experience may shape control processes responsible for affecting attentional capture.

Visual learning and attentional control

Visual perceptual learning (VPL) is typically defined as a practice-induced improvement in an observer’s ability to perform a specific perceptual task (see Hochstein
& Ahissar, 2004; Lu et al., 2011 for reviews). For example, the ability of a skilled x-ray technician to recognize a tumor could be considered a perceptual skill, to the extent that an unskilled observer would have a hard time noticing the same tumor. Researchers studying VPL are primarily interested in the types of changes in low-level perceptual processes that enable this type of perceptual skill to arise. VPL has a high level of specificity, often being observed only in cases in which stimulus conditions are held more or less constant; in other words, there is very little transfer of these acquired visual skills outside of their learned context (Fahle & Poggio, 2002). As a result of this specificity it has been argued that perceptual learning occurs as the result of plasticity in low-level visual processing mechanisms (Karni & Sagi, 1991), an idea supported by neurophysiological studies in non-human primates (Crist et al., 1997; 2011; Crist, Li, & Gilbert, 2001). Visual perceptual learning mechanisms therefore represent one means by which experience can alter the functioning of the visual system in response to specific types of sensory information – tuning the visual system to particular perceptual features in can lead to enhanced processing of those features upon future encounters with them. Furthermore, this effect can be strengthened through reinforcement, providing a simple mechanism through which the perception of particular features in particular contexts can be improved to enhance goal-directed behaviors (Seitz, Kim, & Watanabe, 2009; Roelfsma, von Ooyen, Watanabe, 2010)

In addition to this highly specific, experience-dependent change in the processing of low-level visual perceptual information, experience with visual information can also lead to changes at higher levels of processing. Specifically, there have been a number of demonstrations that the visual system is sensitive to stimulus regularities
present in the visual environment, and these results have been described as instances of visual statistical learning (VSL), in that an observer learns the structure of the visual environment in probabilistic manner (Fiser & Aslin, 2001; Fiser, 2009; see Orban, Fiser, Aslin, & Lengyel, 2008 for a formal Bayesian model of VSL). For example, knowing that ketchup bottles are usually red and usually found in the door of the refrigerator rather than the bottom drawer could both be considered real-life instances of such a probabilistic visual learning process. Indeed, the visual system shows sensitivity to spatial, temporal, feature, and contextual regularities, and it is presumed that these regularities are exploited to optimize goal-directed control in complex visual environments (Fiser & Aslin, 2001; 2002a; 2002b; Turk-Browne et al., 2005; 2008; Chun & Nakayama, 2000). Thus, whereas visual perceptual learning is considered highly specific, depending on a close match between a specific visual features and their trained context, visual-statistical learning could be considered a form of “visual stereotyping,” acting as a more general visual learning mechanism that can be used to predict the likelihood of certain visual events or configurations across a diverse range of contexts (e.g., condiments are usually found in the door of the refrigerator).

This notion that the visual system learns information regarding relevant perceptual and associative attributes of stimuli in the environment has gained a great deal of support in recent years, with a number of studies demonstrating that visual regularities can influence subsequent visual behavior despite the fact that such learning often occurs outside of direct awareness (e.g., Chun & Jiang, 1998; Seitz & Watanabe, 2003; Watanabe et al., 2001; Fiser & Aslin, 2001; Baker, Olson, & Behrmann, 2004; Turk-Browne, Junge, & Scholl, 2005; Vickery & Jiang, 2009). This learning has been shown
to influence the deployment and spread of visual attention in scenes, suggesting a role for these learning processes in structuring attentional control on the basis of experience (Chun & Jiang, 1998; Jiang & Leung, 2005; Vickery & Jiang, 2009; Makovski, Vazquez, & Jiang, 2008; Turk-Browne, & Scholl, 2009). Much of the early work demonstrating the robustness of visual learning in the formation of higher-level visual representations was carried out by Fiser & Colleagues, who probed the ability of observers to extract various statistical relationships between visual objects during more or less passive viewing conditions (Fiser & Aslin, 2001; 2002a; 2002b; Fiser, 2009). Across a number of studies, Fiser et al. have demonstrated that simply viewing implicitly structured arrays is sufficient for observers to extract complex visual relationships between objects in both the temporal (Item A always appears after item B, Fiser & Aslin, 2002a), and spatial (i.e, item C always appears above and to the right of item D, Fiser & Aslin, 2001) domains, even though observers in these tasks were never explicitly told to attend to these relationships. More recent work has demonstrated that in addition to spatial and temporal information, the visual system can extract information regarding the co-occurrence of particular visual features (Item A is always blue; Item B is usually Green; Turke-Browne, Isola, Scholl, & Treat, 2008; Jiang & Song, 2005), suggesting that complex, probabilistic relationships between multiple categories of visual information can be encoded by the visual system. The fact that observers are able to spontaneously derive these relationships indicates that a great deal of information regarding the structure of the visual world is acquired incidentally on the basis of mere exposure to configural relationships present in the environment (see Fiser, 2009 for a review). Furthermore, these learning effects have been observed in both infants (Fiser & Aslin, 2002b) and non-
human primates (Hauser, Newport, & Aslin, 2001), suggesting a powerful, generalized
learning mechanism by which visual regularities can be extracted from the environment
and used as a scaffold for later learning processes and behavioral control.

Perhaps the most compelling evidence implicating this form of probabilistic
visual learning in the control of attention comes from tasks examining the phenomenon
of contextual cueing (Chun & Jiang, 1998). In one of the first demonstrations that
learned regularities in the visual environment can directly guide the allocation of
attention, Chun & Jiang (1998) demonstrated that repeating the spatial layout of targets
and distractors during a search task leads to more efficient search for a target than if the
locations are determined randomly. As observers learned the spatial configuration of
target and distractor items in the repeated displays, the appearance of a search display
with a learned spatial layout came to “cue” the location of the target item, leading to
faster reaction-times to the target in the repeated displays relative to novel displays.
Furthermore, when observers were given a two-alternative forced-choice test in which
they were presented with both a repeated and novel search display and asked to choose
which they had seen during the search task, accuracy was at chance (Chun & Jiang,
1998). This suggests that although the learning of repeated spatial layouts helped guide
attention to the likely target location, observers were entirely unaware of the contextual
regularities that drove this effect. This latter result has been used to argue that context-
based attentional control occurs outside of awareness, since observers appear to have no
explicit knowledge for the repeated displays that guide their attention (Chun & Jiang,
1998; Chun & Phelps, 1999; Chun & Nakayama, 2000). In this way, the visual system
can probabilistically learn the location of goal-relevant information, increasing the
efficiency with which attention is deployed to that information upon future encounters, even if the observer is does not consciously direct attention on the basis of this information.

More recently, it has been demonstrated that in addition to spatial information, the visual system is able to implicitly acquire and use feature regularities (e.g., surface feature and shape information) to guide the allocation of attention in repeated search arrays (Jiang & Song, 2005; Jiang & Leung, 2005). For example, changing either the shape or color of distractor items can disrupt the contextual cueing effects described above, given that these features provide predictive information about the location of targets in repeated displays (Jiang & Song, 2005). This suggests that spatial information regarding item locations is bound to feature information regarding item identities to create a bound, long-term representation that is used to guide attention when encountering familiar task contexts. This type of holistic, experience-dependent representation of a visual scene provides a basis for the type of experience-dependent control advocated for in the current thesis. For example, it’s possible that in order for an observer to ignore salient, task-irrelevant visual stimulus they must learn specific information regarding, e.g., its shape, color, and possible locations in order to effectively ignore it. In this way, the strong spatial and feature-based selectivity that is a hallmark of goal-directed control over attentional capture (e.g., as in Yantis & Jonides, 1990; Theeuwes, 1992; Folk et al. 1992; 2002) may be driven, at least in part, on learned relationships between the to-be-ignored stimulus and its defining attributes.

Skill learning and control

The cognitive mechanisms of skill learning have been an intense subject of study
for decades (Anderson, 1982; 1995; Schenider, 1985; 2003; Logan, 1988; 2002; Newell & Rosenbloom 1981), leading to a number of detailed functional models that serve to understand how control processes differ between novice and skilled performance of a task. Whereas the VPL and VSL literature have traditionally focused on the front-end processes responsible for changes in perceptual processing, studies of skill learning have typically focused on the control mechanisms responsible for acquiring and executing complex skills. Importantly, a number of these theories have focused on experience-dependent changes in control processes responsible for information selection in particular (Schneider & Shiffrin, 1977; Shiffrin & Schnieder, 1977; Schneider, 1985; 2003; Logan & Gordon, 2001; Logan, 2002; see also Cohen, McClelland, & Dunbar, 1990). Thus, whereas the visual learning literature has focused primarily on what information is extracted from the environment, the skill learning literature has focused on primarily on how the acquisition of information affects later control processes necessary for carrying out more complex attentional behaviors efficiently.

Although there are number of distinct, detailed mechanistic explanations of skilled performance (Anderson, 1982; 1995; Schenider, 1985; 2003; Logan, 1988; 2002; Newell & Rosenbloom 1981), one commonality is that they all propose a central role for long-term learning and memory mechanisms in the shift from novice to skilled performance; As experience is accumulated with a task, skilled performance arises because observers are able remember and retrieve effective strategies from memory. A number of theories of skill learning have been proposed in the context of specific skills such as chess (Chase & Simon, 1973) reading (LaBerge & Samuels, 1974), or problem solving (Anderson, 1982), whereas other influential theories of skill learning have been
developed within the context of attentional control or have been adapted/extended to
describe attentional control processes more broadly (Schneider & Shiffrin, 1977; Shiffrin
& Schneider, 1977; Schneider 1985; Schneider, 2003; Logan, 1988; 2002; Logan &
Gordon, 2001).

One commonality between these models is that each proposes a shift from more
effortful “algorithmic” control toward less effortful, “automatic” control as a function of
experience. Generally speaking, when an individual has little experience with a task,
they use instructions or other abstract information to bootstrap control and use as a
scaffold for understanding the task space and guiding behavior during the learning
process. During this early stage the algorithm (i.e., instruction) being employed to
perform the task may be held in working memory to enable task performance (Schneider
& Shiffrin, 1977). This could be likened to the “attentional set” or “target template”
typically proposed to enable goal-directed control (see Carlisle et al., 2011). However, as
experience is gained performance becomes increasingly efficient and effortful
algorithmic processing based on rehearsal in working memory is abandoned in favor of
faster, less effortful experience-based solutions retrieved from long-term memory
(Schneider & Schiffrin, 1977; Schneider & Detweiler, 1987; Schneider & Chein, 2003;
Logan, 1988; 2002). Notably, the retrieval process need not be deliberate, operating in a
more or less automatic manner to allow skilled task performance with little effortful
control (Schneider & Chein, 2003; Logan, 1988; 2002).

The nature of the long-term learning processes that underlie skilled performance
have been described in different ways by each of these theories, but in both cases long-
term representations serve to increase the efficiency with which a task is performed. In
Schneider and colleagues’ theory, learning is proposed to occur over two separable processes that are affected by task experience, and both of these processes serve different functions. First, learning can serve to prioritize attention toward relevant information in the environment on the basis of acquired knowledge. In this way, experience can directly affect attentional control, providing a means of prioritizing attention toward task relevant information with little effortful control (as in the contextual cueing effect reviewed above). Second, the model includes an associative learning component in which particular stimuli become associated with particular responses. When encountering a particular stimulus in the environment, this associative learning mechanism would allow a particular response to be initiated automatically, such as when we jump back from the curb when hearing a car horn. The critical component of this model is that skilled performance is acquired by increasing the strength between particular stimuli and particular responses, making performance faster and less effortful through experience (see also Cohen, Dunbar, & McLelland, 1990). Thus an expert pilot may have their attention drawn automatically (i.e., prioritized) to a critical region of the instrument panel when a warning LED changes color, leading to an automatic corrective flight maneuver (e.g., to avoid another plane in the same airspace) whereas a novice pilot may have to search effortfully for the same change, and execute a corrective maneuver in a more “deliberate” manner.

In contrast to Schneider and colleagues’ two-process model, Logan’s instance theory posits that skilled performance results from a single learning mechanism, episodic memory. This theory proposes that skilled performance arises as the result of the accumulation of episodic memories, or “instances” of previous encounters with a task.
Under this view, each time an observer performs a task, an episodic memory for attributes of the task is formed. The more times a given task is performed (i.e., the more experience an individual has with a task), the larger the knowledge base to draw from upon future encounters with the task, and the more likely an observer will be to rely on past experience to drive their behavior in a given task setting. Under this view skills are memories - skilled task performance is simply as an emergent property of episodic memory retrieval, with skilled performance arising when an observer can rely on memory-based solutions to problems within the task space. Thus, whereas Schneider and colleagues’ model emphasizes the strengthening of stimulus-response associations, Logan’s model emphasizes the role of stored memories of past performance in driving skilled performance.

Two primary tenets of Logan’s instance theory are the obligatory encoding of information into long-term memory and the obligatory retrieval of past experiences from long-term memory. Obligatory encoding is the mechanism by which instance formation occurs – attended information is obligatorily encoded into memory, such that repeated exposure to a given task and its context builds a rich episodic representation of the task space that can be used to facilitate future performance. Under this view, episodic memory formation is viewed as a by-product of attending particular attributes of the environment, and any information that is attended is encoded into the episode for a given task. Such a notion of obligatory encoding has received support in the context of skill learning in general and from a number of studies of visual learning more specifically (as in the visual learning literature outlined above – see also Logan & Eatherton, 1992; Logan, 2002), providing a possible means by which episodic memory formation can
come to directly affect the efficiency of a particular behavior. Once information has been encoded into episodic memory, instance theory proposes that it is retrieved in an obligatory manner upon future encounters with a given task. When entering a familiar task context, attending to familiar information causes a mandatory retrieval of past encounters with the task. In turn, once sufficient experience with a task is gained, the retrieval of memories is sufficient to drive even complex behaviors in a more or less automatic manner, allowing the goal-directed behavior to run to completion with little effort (Logan, 1988; 2002; Logan & Gordon, 2001; Bargh, 1989).

Generally speaking, there is a great deal of support for both of the above theories, and it is likely that elements of each theory contribute in some way to our ability to acquire skills. Although it is unlikely that either theory fully captures how experience shapes our ability to carry out complex skills, these theories offer a basis for understanding how ones experience with particular stimulus attributes in the task environment may come to shape future behaviors. Importantly for the current work, these theories provide a basis for testing the notion that goal-directed control over capture need not be an intentional, effortful process. In particular, through practice with a given visual task, the ability to overcome capture may come to be automated in manner similar to other skills.

Thesis overview: goal-directed control over capture as a learned skill

What should be apparent from the brief review above is that there is no good reason to think that all goal-directed control by necessity relies on intentional processes, calling into question the usefulness of a distinction between stimulus-driven and goal-
directed control on the basis of intentionality. Instead, experience with a task may be as, if not more important than our intentions or explicit goals in determining whether attention will be captured in a given situation. We are constantly acquiring information regarding stimuli in the visual world, and this information can be applied to increase the efficiency of processing across a number of visual domains even when it is acquired without our awareness (Umemoto, et al., 2010; Geng & Behrmann, 2005; Ahissar & Hochstein, 2004; Chun & Jiang, 1998). As I will argue throughout this thesis, this ability of the visual system to acquire visual information and use it to alter the efficiency of control processes should be viewed as an important factor in our ability to overcome distraction by salient, task-irrelevant information. Under this “learned control” view, goal-directed control over capture is viewed as a skill acquired through experience, just like learning to ride a bike, play chess, perform mental arithmetic, or navigate social interactions.

By viewing goal-directed control in this way, it is possible to leverage decades of work from the literature on visual learning, skill learning, and memory to better understand how control over capture comes to be implemented, as well as to generate a number of testable hypotheses regarding attentional control processes more generally. Furthermore, thinking of goal-directed control as a skill acquired through experience allows us to move past thinking about stimulus-driven and goal-directed control as entirely opposing automatic vs. intentional processes, instead arguing that these modes of control interact with one another to shape control processes. Under this view, stimulus-driven control may provide a basis for learning something about what we are trying to ignore, and this learning may subsequently play a major role in whether that information
will capture attention again in the future.

Thus, I will argue that a major determinant of which type of control dominates in a given task may be a direct result of an observers’ experience with that particular task. When one has little experience with a task, it is possible control is more likely to be driven by stimulus properties because in a novel task space one has little or no prior knowledge of which stimulus information should receive processing priority. In this case, particular stimulus attributes such as salience may play an important role in directing attention to possible regions of interest within the task space. If the stimulus is useful, attending to it will be reinforced and if not it will be discounted. In either case, an observer needs experience with a task in order for these associations to be formed. In turn, this experience leads to a strengthening of some stimulus-response associations and a weakening of others, which may culminate in specific patterns of goal-directed control (c.f. Dayan, Kakade, & Montague, 2000; Mackintosh, 1975).

Despite the fact that experience with a task almost certainly affects our ability to overcome distraction, to date there has been very little work explicitly designed to examine the role of task experience in attentional capture. Instead, traditional views of attentional control have emphasized the role of salience and intentional control processes, in the form of “attentional sets” or “target templates” in determining attentional capture. The broad purpose of this thesis is to better understand the relationship between experience with particular stimulus factors and an observer’s task goals in determining the extent of attentional capture, with an emphasis on how experience with the visual environment critically determines what information will ultimately capture attention. Specifically, the thesis has the following goals:
1) Establish the phenomenon of learned control

The primary goal of this thesis is to demonstrate that task experience is critical to the effectiveness of goal-directed control over capture. The goal of Chapters 2 and 3 in particular is to determine a role for task experience in driving the highly specific form of goal-directed control observed in Folk and colleagues’ contingent attentional capture task. This particular task was chosen because it has provided the primary basis for arguments regarding the goal-directed nature of attentional capture effects, in the form of Folk and colleagues’ *contingent involuntary orienting hypothesis* (Folk et al., 1992; 1993; 1994; Folk & Remington, 1998; 2008). Recall that the gist of this theory is that a goal related to the target of search is responsible for determining what information will capture attention; Observers maintain an attentional set for goal relevant information, and incoming stimuli that do not match this set do not capture attention. For example, when searching for a red target only other red information has the ability to capture attention even if other highly salient stimuli are present in the environment.

There is little argument that a specific pattern of goal directed control exists in this task, and as a result this task has implicitly been treated as a “gold-standard” for assessing goal-directed control in both behavioral and neurophysiological studies of capture. Of interest in the experiments presented in Chapter 2 are two primary issues. First, this view proposes little inherent role for stimulus salience in attentional capture, instead proposing that an attentional set for task-relevant attributes of a search target determines what information will be allowed to capture attention. Thus, under this view efficient control over capture could be seen as the default mode of control – salient information never captures attention, unless it is consistent with an observers search
goals. In Chapter 2, I tested whether this is in fact the case by manipulating observers’ exposure to salient, task-irrelevant stimuli, and showed that capture effects depend critically on experience with salient distractors. In order to determine what types of information contributed to the learned control effects seen in this task, I manipulated properties related to the distractor of search and showed that observers use highly specific feature-based representations to implement control, arguing that acquired knowledge of specific stimulus attributes is critical to effective control.

The goal of the experiments presented in Chapter 3 was to extend this line of inquiry, attempting to determine whether explicit intentions related to the goal of a search task (e.g., search for the red target) are necessary for generating the type of highly selective goal-directed control outlined above, or whether incidental exposure to particular stimulus features can drive a more or less “automatic” form of goal-directed control as would be suggested by theories of visual skill learning. In order to do this, in Chapter 3 I manipulated explicit search goals orthogonally to the attributes that were likely to define targets and distractors, an approach similar to that in studies of probabilistic visual learning (e.g., Fiser & Aslin, 2001; Chun & Jiang, 1998). For example, if the goal of a task is to search for a target on the basis of its form (e.g., search for the letter B vs. letter H) but the target happens to be red on a large proportion of trials (80%), will observers develop goal-directed orienting behaviors similar to those observed when explicitly told what feature defines the target of search (e.g., search for the red target)? I show that observers are in fact able to learn contingencies between targets and their defining features in an implicit manner, and this leads to implicit goal-directed control that mimics that typically observed in case when target-color contingencies are
made explicit. I then demonstrate that this form of implicitly learned control can trump explicit processes to determine the extent of attentional capture.

2) *Show that the instantiation of learned control is determined by stimulus context*

Using simple visual context manipulations, in Chapter 4 I demonstrate that learned control is context-specific, not unlike other forms of visual skill learning described above. More specifically, I show that observers can come to link specific search strategies with the context in which they are learned, and this process critically determines the extent of attentional capture. Furthermore, I examined the extent to which these strategies emerged as a result of specific stimulus factors, rather than an explicit goal related to the target of search, to complement the experiments in Chapters 2 and 3. The hope is to show that the types of stimulus-dependent learned control effects examined in these first two chapters are highly context dependent, providing a basis for how experience with low-level stimulus information can be used flexibly to determine capture across different stimulus contexts.

3) *Provide a first pass at determining the memory mechanisms of learned control*

Given my emphasis on the learning of goal-directed control on the basis of associations between particular stimulus attributes, in Chapter 4 I assessed whether learned control relies on brain structures known to be involved in general associative learning and memory processes. Of primary interest was the effect of medial-temporal lobe damage on the acquisition and instantiation of the learned control observed in Chapters 1-3. Given that the medial temporal lobe memory system has been shown to be involved in basic associative and relational learning processes, it seems plausible that
learning necessary for driving learned control may rely critically on an intact MTL. To test this possibility, amnesic patients with damage to the MTL were tested on tasks similar to those used in Chapters 2-4, and the results helped constrain the mechanisms underlying the learned control observed in the behavioral experiments presented in these chapters. Given the somewhat complicated nature of these data, I leave discussion of these results until Chapter 5.
CHAPTER 2

ESTABLISHING A ROLE FOR TASK EXPERIENCE IN GOAL-DIRECTED CONTROL OVER CAPTURE

As described in the introduction, advocates of goal-directed views of capture have proposed that representations of an observer’s goals critically determine what incoming sensory information will capture attention and receive further attentional resources. Traditionally, the primary task used to study goal-directed control over capture is Folk and colleagues’ contingent attentional capture task (Folk et al., 1992; Folk & Remington, 1998; see also Folk, Leber, & Egeth, 2002). This task is a variant of a typical attentional cueing paradigm (e.g., Posner, 1980), adapted in order to examine how an observer’s search goals influence the ability of salient cues to capture attention (see Figure 2). In the typical Posner-style cueing task, an observer is asked to search for a particular target and report its identity. Prior to the presentation of the search display, a cue is briefly presented at either the target location (valid trials) or one of the distractor locations (invalid trials) with equal probability. Critically, the cue is considered task-irrelevant because it predicts the location of the target at a chance level, and observers are given this information at the beginning of the task and explicitly told to ignore the cue for this reason. Attentional capture is then assessed by comparing reaction times to the target when it is validly vs. invalidly cued, and the presence of a cueing effect indicates that attention was captured by the cue – since the cue is not predictive of the target location and observers are explicitly told to ignore it, any cueing effect represents the automatic capture of the attention by the cue. Observers are typically faster and more accurate at responding to the identity of the target when it is validly cued than when it is invalidly
cued, even though the cue is not predictive of the target’s location. Given the non-predictive nature of the cue, any effect of the cue has been argued to indicate the automatic capture of attention (on the basis of the intentionality criterion described above; see Posner, 1980; Posner, Snyder & Davidson, 1980).

The critical manipulation introduced in the Folk et al. version of the task is whether the cue shares features with the target of search, and the cue is typically either consistent with the observers search goals or not. For example, an observer may be asked to search for the red target and report its identity. Critically, the color of the cue can either be consistent with this goal (i.e., the cue appears in red) or not (the cue appears in blue). Importantly for goal-directed theories of attention capture, cueing effects are only observed when the cue matches the goal of observers’ search, indicating the intention to search for a particular target feature directly influences the ability of salient information to capture attention (Folk et al., 1992; Folk & Anderson, 2010). Results from this and similar tasks (e.g., Bacon & Egeth, 1994) have been used to argue for a strong, goal-directed mechanism of control over attentional capture, whereby even salient bottom-up information won’t capture attention unless it is consistent with an observer’s intentions, implemented in the form of an “attentional set.” As noted in the introduction, this idea has been formalized in Folk and colleagues’ contingent involuntary orienting hypothesis (Folk et al., 1992; 1994; Folk & Remington, 1998; Folk, et al., 2002).

From a mechanistic standpoint, it has been hypothesized that observers actively maintain this “attentional set” in working-memory, and use it to control the allocation of attention on a moment by moment basis (Theeuwes, 2010; Theeuwes, Olivers, & Belopolsky, 2010; Olivers, 2009). In this way, capture is said to be contingent on an
observer’s intentions – to the extent that the bottom-up information does not match the
target template observers are using to actively guide search, it will not capture attention.
This “target centric” view of contingent capture effects (and goal-directed control more
generally) has received little direct study, instead being inferred on the basis of related
work showing that the contents of working memory can bias attention during visual
search (e.g., Olivers, 2009; see also Theeuwes, 2010; Soto et al., 2005). In fact, it has
recently been demonstrated that loading visual working-memory has a negligible effect
on contingent attentional capture effects, arguing against a strong version of this view
(Wang & Most, 2008; Wang & Most, 2010). In the studies of Wang & Most (2008;
2010) active rehearsal processes were presumably occupied by the concurrent memory
task, and the fact that normal contingent capture effects were still observed seems to
provide a strong argument against accounts of the contingent capture effect that
hypothesize a central role for intentional, working-memory dependent control
mechanisms.

Furthermore, in most visual search experiments, including the Folk et al. task
mentioned above, the target of search is typically held constant or limited to a small
number of possible identities across an entire experiment (e.g., Folk et al., 1992; 2002;
Folk & Anderson, 2010; Lien, Ruthruff, & Johnston, 2010; Sledge-Moore & Weissman,
2010). This may have the effect of minimizing intentional control on the basis of
attentional sets in working memory (see Vickery, King, & Jiang, 2005; Woodman et al.,
2007; Woodman & Luck, 2010). Indeed, recent work has called into question the notion
that working memory is obligatorily involved in the maintenance of an attentional set
during search tasks in which search goals are held constant. Specifically, using ERP
measures of goal maintenance in working memory (the contralateral delay activity, or CDA; Woodman & Arita, 2011), Carlisle, Arita, Pardo, & Woodman (2011) showed that the electrophysiological signature of memory maintenance diminished quickly (over the course of 2-5 trials) as observers gained experience with the search task, so long as the target of search was held constant. These results were interpreted in the context of theories of skill learning (e.g., Logan, 1988; 2002), and it was proposed that rather than playing a direct role in guiding search on a moment to moment basis, working memory processes may be important instead for establishing more robust, long-term representations of the target item that are used to drive efficient search performance for the duration of the task (see also Woodman, Luck, & Schall, 2007). Such an interpretation fits well with theories of skill learning in which long-term memory representations come to play an increasingly important role in task performance as sufficient experience with the layout of a task is gained (Logan, 1988; 2002; Schnieder & Shiffrin, 1977; Anderson, 1982).

Given that tasks used to study attentional capture are adapted search tasks very similar to that used by Carlisle et al. (2011) it’s possible that a similar long-term learning process may be responsible for generating the types of highly specific, feature-based goal-directed control observed in this task. Along these lines, given that most attention capture tasks include a rich context (multiple target locations, distractor locations, distractor identities, timing parameters, etc.) it is possible that information regarding the target of search alone is not sufficient to drive goal-directed control over capture, even early in a task. Instead, it is possible that goal-directed control relies on detailed representations of the task environment that are used to control the allocation of attention
in specific situations, similar to the rich episodic representations proposed by Logan and colleagues to drive more complex forms of goal-directed control (Logan, 1988; Logan & Gordon, 2001; Logan, 2002).

In other words, the “attentional set” may be more complex than assumed by most theories of attentional capture (see Becker et al., 2010 for a similar argument). It is possible that detailed information regarding the attributes of a task may be extracted from the visual environment over time, with the acquisition of more complex representations of the task space being necessary for the operation of strong goal-directed control. For example, in the Folk et al. task described above, the instructions given to observers are similar to the following:

“In this task you will search for a red target presented among white distractors. Your task is to search for the red target and report if it is an “=” or an “x.” If the target is an “=” you will press the “z” key on the keyboard, and if it is an “x” you will press the “/” key. Prior to the presentation of the search display, a colored “cue” object will appear briefly at one of the target locations. Try as best you can to ignore this item, as it will not predict the location of the target and may therefore slow your search…."

As should be apparent from the above instructions, there are a number of task elements not directly related to the target of search that may be represented in an observer’s attentional set. Furthermore, these instructions provide no information regarding other important aspects of the task, including timing parameters or possible target and distractor locations. Therefore, longer-term learning of the gestalt of the task may be critical to establishing goal-directed control over capture, and this possibility will be tested in the experiments presented in this chapter.
Experiments 1a and 1b

In Experiment 1, I tested the sufficiency of an observer’s intentions regarding the goals of search in generating effective goal-directed control in the cueing task of Folk and colleagues. Specifically, as reviewed in the introduction common approaches to studying capture rely critically on the assumption that an observer’s intention to attend one thing and ignore another is sufficient to attenuate capture. In order to directly test this notion, I ran an exact replication of the typical Folk et al. cueing task, but instead of solely examining aggregate data as in previous examinations of this effect, I tracked observers’ performance over time to look for effects of task experience on the ability to overcome capture. Figure 2 shows an example of the stimuli and time course of events in a typical trial. In my version of the task, observers were always told to search for a red target among white non-targets, and to report its identity. Critically, prior to the presentation of the search array, a task-irrelevant white “abrupt onset” cue (Experiment 1a) or distractor (Experiment 1b) appeared briefly at one of four locations. In this way, observers’ intent should have always been to attend the red item and ignore the onset, which in the typical version of this task leads to a lack of capture by the salient, white abrupt onset cue.

In Experiment 1a, the onset was a “cue” in that it appeared at any of the four possible locations with equal probability, such that on 75% of trials it cued one of the three non-target locations (i.e., it was an “invalid” cue), and on 25% of trials it cued the target location. In this way, the cue was non-predictive and as a result observers should have had little incentive to pay attention to the cue because it would actually hurt performance on most trials (Folk et al. 1992; Folk & Remington, 1998). In Experiment 1b the white onset was always a “distractor” that never appeared at the target location,
Figure 2. The cueing task used in Experiments 1-4. A white onset appeared prior to the presentation of a search display. Observers’ task was to report the identity of the red target item on each trial, while ignoring the white onset.

and it appeared on half of the trials and was absent on the other half of the trials (similar to the logic used in the additional singleton paradigm of Theeuwes, 1992). In both cases, as part of the instructions observers were always explicitly told to ignore the white onset and focus on finding the red target, because attending to the onset would hurt their performance – in other words, in each experiment it should have been the observers’ intention to attend only the red target and ignore the white onset. It is important to point out that the addition of Experiment 1b is important for the argument I wish to make in these experiments, since it is possible that in Experiment 1 even a few trials in which the target appeared at the cued location would drive observers to strategically (i.e., intentionally) attend the cue, especially early in the task, and given that I am interested in
examining the sufficiency of an intention to attend the relevant target feature and ignore the irrelevant cue/distractor on the ability of the onset to capture attention, the inclusion of Experiment 1b was critical because it eliminated any ambiguity regarding the relevance of the abrupt onset.

With this design, traditional theories of attentional capture and the “learned control” theory I’m attempting to advance in this thesis make competing predictions with respect to how capture will be affected by practice. Specifically, if the intention to search for a particular target and ignore a salient onset is sufficient to overcome capture from the first exposure to this information as would be predicted by current theories of attentional capture, we would expect to see no effect of task experience on control, as observers know from the first trial what they are supposed to attend to and what they are supposed to ignore. On the other hand, if observers need concrete experience with stimuli in the search display in order to effectively block them from capturing attention, we would expect capture early on in the task, with the magnitude of capture diminishing as experience is gained. In other words, we would expect a steep “learning curve” in which observers would quickly learn to attenuate processing of the onset, similar to the types of learning seen in other studies of skill acquisition (Logan, 1988; 2002; Newell & Rosenbloom, 1981).

**Method**

**Observers.** Observers were 30 University of Iowa undergraduates (15 in Experiment 1a and 15 in Experiment 1b) who participated for course credit. All had normal or corrected to normal vision and were not color blind.
**Apparatus.** Stimuli were presented on a 15” CRT monitor powered by a Macintosh Mini computer, using MATLAB and the Psychtoolbox (Brainard, 1997).

**Stimuli.** Observers sat approximately 65 cm from the screen, and viewed displays resembling those in Figure 2. The fixation display consisted of 4 placeholder boxes measuring 1.4 x 1.4 and positioned on the corners of an imaginary diamond centered around fixation. The distance from fixation to the center of each placeholder box was 5.2. The placeholder boxes were light gray (RGB 160, 160, 160) on a black background. Cues (Experiment 1a) and distractors (Experiment 1b) consisted of 4 white dots (radius .21) centered on the edges of one placeholder box and were always presented as abrupt onsets, with each dot positioned .46 peripheral to the side of the placeholder box. On each trial, a single target was presented in red (RGB 255, 0, 0) within one of the placeholder boxes, and the target was equally likely to be an ‘X’ or ‘=’ symbol, drawn in 56 pt Helvetica bold font. White ‘X’ or ‘=’ non-target search items were presented in each of the three remaining placeholder boxes, with non-target item identities being determined randomly on each trial.

**Design.** Given my interest in capture by abrupt onsets against an attentional set for color, in both experiments cues/distractors were always presented as white abrupt onsets and observers searched for a red target symbol and reported its identity on each trial. Thus, observers should have established an attentional set for color and any effect of the abrupt onset cue on reaction time would be produced in the face of this attentional set (Folk et al., 1992; 1993; 1994; 2002). In other words, any effect of the onset would indicate capture. Furthermore, in Experiment 1a onset cues were spatially non-predictive and appeared at each of the four locations with equal probability. This led to a 25%
probability that the cue validly predicted the target location, and a 75% probability that
the cue invalidly predicted the target location, providing little incentive for observers to
use the cues strategically. In Experiment 1b, the onset distractors appeared on half of the
trials and were absent on the other half of trials, and never appeared at the target location.
Instead, they appeared with equal probability at any of the non-target locations on a given
distractor present trial.

Procedure – Experiment 1a. Observers completed the experiment in a single
session lasting approximately 25 minutes, and prior to beginning were given oral
instructions and (static) visual instructions regarding the task. It was stressed that the cue
would not predict the target location, and observers were explicitly told to ignore it and
focus on finding the target on each trial. On each trial, a fixation display was presented
for 1000ms, followed by a single non-predictive, white onset cue for 50 ms, and then by a
100ms ISI in which only the fixation display was presented, producing a cue-target SOA
of 150ms. Directly following this, a target character was presented for 50 ms, and could
be either a ‘X’ or ‘=’ symbol, chosen pseudorandomly on each trial. Thus the duration
from the time of cue onset to the time of target onset was 200ms, a duration short enough
to preclude eye movements to the cue or target locations. The fixation display was then
presented until observers made a response using either the ‘Z’ or ‘M’ keys, with target-
response mappings counterbalanced across observers. Observers were told to perform the
task as quickly and accurately as possible. Observers completed 8 blocks of 24 trials, for
a total of 192 trials, with no distinct “practice” block. Therefore the first trial of the
experiment was the observers’ first exposure to the stimulus displays.

Procedure – Experiment 1b. The general procedure was identical to that in
Experiment 1a, with the following exceptions: Observers were informed that the white onset was a distractor that would appear on only half of the trials, and when it appeared it would never appear at the target location. For this reason, as in Experiment 1a, it was stressed to observers that they should ignore the white onset if it appeared. Thus, any effect of the cue should occur in the face of a strong intention to ignore it, as well as a strong attentional set for the target color. The timing of events was identical to that in Experiment 1a, except that on distractor absent trials the fixation display was presented for 50ms longer (thus keeping the timing between fixation onset and target onset constant across conditions and experiments). Observers were told to perform the task as quickly and accurately as possible, and completed 8 blocks of 24 trials, for a total of 192 trials.

Results

For both Experiment 1a and 1b, incorrect trials and outlier trials with reaction times (RTs) greater than 3 SDs above individual means were excluded from further analysis, with this outlier trimming resulting in a removal of less than 3% of the total RT data. Observers’ overall mean correct reaction time data appear in Figure 3 (Experiment 1a) and Figure 4 (Experiment 1b), and both RT and error rate data for each experiment are shown in Appendix A.

Experiment 1a. Experiment 1a represented a straight replication of Folk et al. (1992), and demonstrated that the current stimuli and design generate a normal contingent capture effect when analyzed in the typical manner, (i.e., when the first block of 24 trials is treated as an unanalyzed “practice” block and remaining data are aggregated). Specifically, planned comparisons between validity conditions (valid vs. invalid) were conducted on the aggregate RT and error rate data. This comparison
revealed no significant cueing effects for the onset cues in RTs, $t(14) = 1.1, p = .28$, or error rate, $t(14) < 1$, n.s., indicating that an attentional set for a color target attenuated onset capture in this experiment, just as in Folk et al. (1992) and subsequent work (Folk et al., 1994; Folk & Remington, 1998).

Given my interest in the role of task experience in the emergence of contingent capture effects, I included data from the 24 practice trials and then epoched the data in bins of 24 trials (the length of a block), resulting in eight bins of 24 trials in order to assess capture by onset cues over time. Epoched data for each validity condition are shown in Figure 3. A two-factor ANOVA with epoch (1-8) and cue validity (valid vs. invalid) as factors was performed on both RT and error rate data. For RTs, there were significant main effects of epoch, $F(7,98) = 7.69, p < .001$, $\eta^2 = .35$, and validity, $F(1,14) = 9.92, p < .01$, $\eta^2 = .42$. Importantly, a significant interaction between epoch and validity was observed, $F(7,98) = 2.29, p = .03$, $\eta^2 = .15$, indicating that when observers are set for color, capture by onset cues varies as a function of epoch (i.e., task experience). In order to further elaborate on this interaction, planned comparisons were performed for valid vs. invalid RTs in each epoch. These comparisons revealed a significant effect of cue validity during the first epoch, $t(14) = 3.22, p < .01$, but none of the subsequent epochs, $t_s < 1.74, p_s > .11$, indicating that despite a set for color, onset cues retain the ability to capture attention and produce capture effects early in the task. Analysis of error rates showed neither main effects nor interactions, indicating that the cues did not have an effect on error rates and providing general evidence that there were no speed accuracy trade-offs in the current data.
Figure 3. Reaction time data from Experiment 1. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Experiment 1b. Identical analyses were performed on the data from Experiment 1b, and epoched data appear in Figure 4. Planned comparisons between distractor present and absent conditions on the aggregate RT and error rate data revealed no significant interference effects from the task-irrelevant onset distractors in RTs, $t(14) = 2.0, p = .07$, or error rate, $t(14) < 1.28, p = .22$, paralleling the results from Experiment 1a. A two-factor ANOVA with epoch (1-8) and distractor presence (present vs. absent) as factors was performed on both RT and error rate data from Experiment 1b. For RTs, there was a significant main effect of epoch, $F(7,98) = 8.98, p < .001, \eta^2 = .40$, and marginal effect of distractor presence, $F(1,14) = 4.2, p < .06, \eta^2 = .23$. As in Experiment 1a, a significant interaction between epoch and distractor presence was observed, $F(7,98) = 2.53, p = .02, \eta^2 = .16$, demonstrating that when observers are set for color, capture by
onset distractors, varies as a function of task experience. In order to elaborate on this interaction, planned comparisons were performed for distractor present vs. absent RTs in each epoch. These comparisons revealed a significant effect of the onset distractor during the first epoch, $t(14) = 4.12, p < .01$, but none of the subsequent epochs, $t < 1.50, ps > .16$, indicating that onset distractors retain the ability to capture attention and produce capture effects early, but not later, in the task. As in Experiment 1a, analysis of error rates showed neither main effects nor interactions, indicating that the cues did not have an effect on error rates.

![Figure 4](image)

Figure 4. Reaction time data from Experiment 1b. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Discussion

The results of Experiment 1 are clear and indicate that despite an explicit set for
color and an intention to ignore the white abrupt onset cues/distractors, these onsets retained the ability to capture attention early in a task when observers have little experience with the specific stimulus attributes they are instructed to either search for or ignore. However, this effect dissipates rapidly, with goal-directed control becoming effective at attenuating capture following 24 trials or less of exposure to the task. These results suggest that giving observers precise, explicit goals regarding the defining dimensions of both the search target and the distractor they are to ignore is insufficient to modulate attentional capture by salient, task irrelevant information. Even in a case in which observers know with 100% certainty that the onset will never signal the target location (as in Experiment 1b), they are still susceptible to capture early in the task.

One explanation for this effect is that observers rely critically on experience with specific instances of the stimuli they are to attend and ignore in order to tune the attention system to exert effective goal-directed control over capture (e.g., as in Logan’s instance theory, 1988; 2002). The fact that error rate was generally high from the beginning of the task (see data in Appendix A) suggests that observers were able to perform the search task with little problem even early on, though performance was generally much slower at the beginning of the task. In the context of the skill learning theories outlined in the introduction this may represent the use of a more effortful, “algorithmic” task representation by observers, based on task instructions. This may have allowed observers to perform the search task accurately, albeit relatively slowly, early in the task. Importantly, despite the fact that observers performed the search task accurately from the beginning of the task, they were unable to overcome distraction within this same time frame, suggesting the possibility that exercising effective goal-directed control over
capture is directly modulated by experience with the particular stimulus attributes present in a task. For example, observers may need to actually attend and represent at a neural level the specific stimulus features they are to attend (red, equals, X) or ignore (white, onset, circles) before control becomes effective. Such a notion would fit well with both theories of visual learning and skill learning, which have demonstrated a high level of specificity in the mechanisms responsible for experience-dependent acquisition of visual information (See Fahle & Poggio, 2002; Logan, 1988; 2002).

However, there are alternative explanations for these results. Each relates to the fact that early in the task, in addition to having little experience with specific target/distractor attributes, observers have also had little experience carrying out the search task itself which would likely be considered the primary goal of this experiment since the main response being made corresponds to the target of search. Thus, one could construct a plausible argument that early in a task, the “executive” demands of the task are greater (e.g., in the form of increased working memory load; Carlisle et al., 2011; D’espositio et al., 1999), given that observers are likely attempting to maintain instructional information about the search task during the first few trials of the experiment. If these same resources are involved in distractor inhibition, as has been shown in a number of related lines of work (DeFockert et al., 2001; 2004; Lavie & DeFockert, 2005), we would expect an increase in distractor interference early in the task, as opposed to late in the task, because processes responsible for distractor inhibition would be occupied representing the instructions of the search task before performance becomes “automated” (Schneider & Shiffrin, 1977; Logan, 1998).

Another related alternative is more specific to the mechanisms posited to drive the
typical “contingent capture effect” observed in this task. As described above, it has been hypothesized that an attentional set held in working memory acts as a filter for incoming sensory information, allowing capture only by information that matches this template (Folk et al., 1992; Folk & Remington, 2006; Muller, Reimann, & Krummenacher, 2003). Under this view, the ability to overcome capture by task irrelevant information is simply a by-product of the robust target representation in working memory, and observers do not necessarily need to know anything about the attributes that define the distractor. In the current experiments, the reason capture was observed early in the task may not have anything to do with how the distractor is represented, but instead may have more to do with the fact that observers have a relatively weak representation of the target of search in working memory, leading to increased capture by task-irrelevant information during the initial trials of the task; in other words a weak target representation may lead to a weaker filtering of incoming sensory information than if the target of search were more robustly represented within the attentional system.

In Experiment 2, I attempted to differentiate between the “learned control” hypothesis and these possible alternatives by giving observers practice with the search task prior to the introduction of task-irrelevant cues (Experiment 2a) or distractors (Experiment 2b). Specifically, observers were given 192 trials of practice with the search task itself, and after 192 trials the cue/distractor was introduced. Thus, if the reason capture was observed early in the task in Experiment 1 is because either 1) executive resources were occupied with instructional rehearsal early in the task, or 2) observers had a weak representation of the target early in the task, we would expect that the introduction of the cue/distractor would have little effect on performance, since observers
should have had sufficient practice with the task to overcome both issues prior to the introduction of the distractor. On the other hand, if observers must learn something specific about the cue/distractor to overcome being captured by it, we would expect to see an effect similar to that observed in Experiment 1, in which the cue/distractor captures attention directly following its introduction.

**Experiments 2a and 2b**

**Method**

*Observers.* Observers were 30 University of Iowa undergraduates (15 in Experiment 2a and 15 in Experiment 2b) who participated for course credit. All had normal or corrected to normal vision and were not color blind.

*Stimuli & Procedure.* In both Experiment 2a and 2b, the stimuli and procedure were identical to that used in Experiment 1a and 1b, respectively, with the exception that observers performed 8 blocks of 24 trials (192 total trials) in Experiment 2a or 6 blocks of 24 trials in Experiment 2b (144 total trials) of the search task prior to the introduction of the onset cue. After the introduction of the cue, observers completed another 8 blocks of 24 trials (192 total trials) in Experiment 2a and 6 blocks of 24 trials (144 total trials) in Experiment 2b. Observers were given identical instructions to those used in Experiment 1, and were thus informed of the presence of task-irrelevant cues from the outset of the experiment.

**Results**

For both Experiment 2a and 2b, incorrect trials and outlier trials with RTs greater than 3 SDs above individual means were excluded from further analysis, with this outlier trimming resulting in a removal of approximately 2% of the total RT data. Observers’
overall mean correct reaction time (RT) data appear in Figure 5 (Experiment 2b) and Figure 6 (Experiment 2b), and both RT and error rate data for each experiment are shown in Appendix A.

Given my primary interest in the effect of more extensive practice on the search task on the experience-dependent capture effects observed in Experiment 1, only data from the post-practice blocks in which the cue/distractor was present were analyzed. However, data from the practice session is included in both Figures 5 and 6, as well as Appendix A) As in Experiment 1, data were epoched in bins of 24 trials, resulting in eight bins of 24 trials. Epoched data for each validity/distractor condition for the post-practice blocks of each experiment are shown in Figure 5 and 6.

Experiment 2a. A two-factor ANOVA with epoch (1-8) and cue validity (valid vs. invalid) as factors was performed on both RT and error rate data only for the epochs in which the cue was present. For RTs, there were significant main effects of epoch, $F(7,98) = 5.28, p < .001, \eta^2 = .28$, and validity, $F(1,14) = 18.1, p < .01, \eta^2 = .56$. In this case, the two-way interaction between epoch and validity was not significant, $F(7,98) < 1, n.s.$, likely reflecting the more gradual decrease in capture in this experiment. However, given the specific question being addressed in this experiment, planned comparisons were performed for valid vs. invalid RTs in each epoch. As in the previous experiments, these comparisons revealed a significant effect of cue validity during the first epoch, $t(14) = 2.37, p = .03$, but none of the subsequent epochs, $ts < 1.69, ps > .12$, replicating the effects observed in Experiment 1 as well as Experiment 2a. Again, analysis of error rates showed neither main effects nor interactions, indicating that the cues did not have an effect on error rates and providing general evidence that there were
no speed accuracy trade-offs in the data from this experiment.

Figure 5. Reaction time data from Experiment 2a. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Experiment 2b. Again, a two-factor ANOVA with epoch (1-6) and distractor presence (present vs. absent) as factors was performed on both RT and error rate data. For RTs, there were significant main effects of epoch, $F(5,70) = 10.8$, $p < .001$, $\eta^2 = .44$, and distractor presence, $F(1,14) = 10.8$, $p < .001$, $\eta^2 = .53$. Again, a significant interaction between epoch and distractor presence, $F(5,70) = 2.3$, $p = .05$, $\eta^2 = .14$, demonstrating that even after 192 trials of practice with a task in which observers are set to search for color, capture by onset distractors varies as a function of epoch (i.e., task experience). Planned comparisons again revealed a significant effect of the onset
distractor during the first epoch, $t(14) = 3.12, p < .01$, but none of the subsequent epochs, $ts < 1.44, ps > .17$, indicating that despite a set for a specific color, onset cues retain the ability to capture attention and produce capture effects early in the task. Analysis of error rates showed neither main effects nor interactions, indicating that the cues did not have an effect on error rates.

![Figure 6. Reaction time data from Experiment 2b. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).](image)

Discussion

In Experiment 2, introduction of a distractor again caused capture even after
nearly 200 trials of practice with the search task itself. This finding is consistent with the notion that observers need experience with specific attributes of the distractor before they can ignore it, even if they have a great deal of experience with the goal-relevant attributes of the task (e.g., the target, locations, timing parameters, etc.) in the absence of distractors. Taken together with the results of Experiment 1, these results further discount the notion that an intention to ignore specific task-irrelevant visual information is sufficient to stop that information from capturing attention and causing distraction. Instead it appears that, at a minimum, observers represent information regarding both the target of search and to-be-ignored distractors in order to implement the form of goal-directed control over capture observed in this task, with this information being acquired through experience. This is inconsistent with accounts of feature-based, goal-directed control that emphasize a solitary role for the active maintenance of target information in the filtering of task-irrelevant information (e.g., Vogel, McCollough, & Machizawa, 2005; McNab & Kilngberg, 2007), instead arguing that such control arises on the basis of experience with multiple task attributes (as in Carlisle et al., 2011).

With a general role for experience established, in Experiment 3 I turn attention to the types of information that contribute to the experience-dependent control observed in this task. More specifically, in the previous experiments I showed that observers can learn to ignore an abrupt onset distractor given sufficient experience, but from these experiments it’s unclear exactly what type of information observers use to drive experience-dependent control over capture in this task. For example, it is possible that observers simply learn to ignore visual transients, such that as exposure to task-irrelevant transients increases (such as the onset distractor used in these experiments) there is a
habituation of the orienting response normally elicited by these transients (see, e.g., Sokolov, 1975; Neo & Chua, 2006; Cosman & Vecera, 2010). Under this view, consistent exposure to the onset distractor should cause it to lose its ability to capture attention regardless of changes to, e.g., information about its defining surface features or form.

Alternatively, it is possible that observers learn specific information regarding the identity of the transient distractor itself, developing a specific representation of the to-be-ignored stimulus such that salient transients that don’t match the specific identity of the ignored stimulus retain the ability to capture attention. Such a mechanism could be considered adaptive, since transient events often signal significant changes in the environment, and blanket attenuation could lead an organism to ignore these changes even when they are important. This highly specific representation is consistent with studies of visual learning (Fahle & Poggio, 2002; Turk-Browne et al., 2008; Jiang & Song, 2005; Schwartz et al. 2002; Furmanski & Engel, 2000) and skill learning (Logan, 1988; 2002) that propose a central role for identity information in the representations that control skilled visual performance. To disambiguate between these possibilities, in Experiment 3 I employed a design similar to that used in Experiment 2, but once observers ceased to show capture effects to the onset transient, I introduced a change in the surface feature associated with the distractor (in this case color).

As may be apparent from the above descriptions, the two possibilities outlined above make differing predictions regarding how changing the surface features associated with the distractor will affect capture; if the effects observed in Experiments 1 and 2 reflect general habituation to the presence of a distracting transient, we would expect that
changing the color of the distractor should not affect capture, since the distractor will maintain its status as a transient. On the other hand, if observers are tuning attention to specific attributes of the distractor, we would expect color change to lead to an increase in capture for a brief period of time following the change. In this case, observers would need to “re-learn” the distractor defining feature in order to effectively overcome capture by it.

Experiment 3

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 & Procedure. In Experiment 3, the stimuli and timing parameters were nearly identical to that used in Experiment 2a. Since in this experiment I was interested in examining the influence of changes in the distractor defining color on its ability to capture attention, I used four possible cue colors, white (255, 255, 255), red (255, 0, 0), blue (0, 0, 255), or green (0, 255, 0). For a given observer the target was a single color for the entire experiment (either red, blue, or green), counterbalanced across observers, and this color determined the observer’s “attentional set” for the search task. Importantly, the cue never matched the observer’s set, and as a result should not produce a capture effect in this task; this resulted in 3 possible cue colors, with the order in which each cue color was presented being counterbalanced across observers (e.g., the target was red, and the cue color for epochs 6-10 = green, for epochs 11-15 = white, and for 16-20 = green).
Observers first performed a block of 120 trials of the search task in which no cue was presented in order to provide a replication of the basic findings from Experiment 2a when examining the transition from no cue to cue trials in epoch 6. Following this block, and for the rest of the trials in the experiment, on each trial the search array was preceded by a cue that either validly (25% of trials) or invalidly (75% of trials) predicted the target location as in the previous experiments. Critically, to test the specificity of learning for cue properties, the color of the cue switched every 120 trials, such that the cue appeared for the first time on trial 121 (the first trial of epoch 6), and switched colors on trials 241 (the first trial of epoch 11) and 361 (the first trial of epoch 16). Thus, observers performed 480 trials total, completing 5 blocks of 24 trials for each cue color. Observers were informed during the instructions at the beginning of the task that 1) the cue could appear in any of three possible colors and 2) that the cues were task-irrelevant and should be ignored because they would hurt performance. Thus, as in the previous experiments, any effect of the cue should occur in the face of a strong intention to ignore it.

Results

Again, incorrect trials and outlier trials with RTs greater than 3 SDs above individual means were excluded from further analysis, with this trimming resulting in a removal of approximately 4% of the total RT data for Experiment 3. Observers’ overall mean correct reaction time (RT) and error rate data for each condition of each experiment are shown in Appendix A. Given my primary interest in the effect of color changes on the cue’s ability to capture attention, only data from trials in which a cue was present were analyzed. However, data from the initial 120 trials is included in both Figure 7 and Appendix A. As in Experiment 1 I epoched the data in bins of 24 trials, resulting in 15
bins of 24 trials each. Epoched data for each validity condition for each of the cue-present blocks of the experiment are shown in Figure 7.

A three-factor ANOVA was performed on both RTs and error rate data, with cue color, epoch, and validity as factors. This analysis revealed a main effect of epoch, $F(4, 56) = 3.1, p = .02, \eta^2 = .18$, with RTs generally decreasing across epochs, and validity, $F(1, 14) = 7.5, p = .02, \eta^2 = .35$, with RTs on valid trials being faster than those on invalid trials, but no main effect of cue color was observed, $F(2, 28) = 3.0, p < .07$.

The interaction between epoch and validity was significant, $F(4, 56) = 2.8, p = .05, \eta^2 = .15$, indicating that the cue’s ability to capture attention depended critically on the amount of experience an observer had with the cue. Critically, there was no three way interaction between cue color, epoch and validity, $F < 1$, n.s., indicating that the epoch X validity interaction did not vary with the color of the cue.

To probe the nature of the epoch X validity interaction, planned comparisons were performed on the magnitude of the cueing effect within each epoch. When the cue was first introduced it produced a significant capture effect during the first 24 trial epoch (epoch 6), $t(14) = 2.3, p = .04$, but not during any subsequent epochs prior to the cue color change. This replicates the findings of Experiment 2a, and provides further evidence that observers needed experience with the cue before they were able to effectively ignore it. Planned comparisons were performed for cueing effects during the first epoch following a color change (epochs 11 and 16), and significant cueing effects were observed in both epoch 11, $t(14) = 2.7, p = .02$, and 16, $t(14) = 2.3, p = .04$. Thus the cue captured attention and produced cueing effects during the first epoch that it was introduced (epoch 5) or following a color change (epochs 6 and 11), suggesting that
observers need both experience with the distractor and its associated features (in this case, color) in order to effectively ignore it.

For the error rate data, there was a trend toward a significant main effect of validity, $F(4,56) = 2.8, p = .06$, but no other main effects or interactions approached significance $F_s < 1.5, ps > .17$.

![Figure 7. Reaction time data for Experiment 3. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).](image)

**Discussion**

The results of Experiment 3 demonstrate that changing the surface feature associated with a distractor leads to an increase in capture effects in the epoch directly following the change, suggesting that observers code information about the defining
features of a distractor, in this case color. However, it is impossible to tell from these results whether this represents an increase in capture in response to a novel distractor color, or to a change in the distractor defining color. For example, it is possible that any time a distractor changes color, it may be more likely to capture attention even if the observer has had extensive practice with a distractor of that particular color in the past. On the other hand, it’s possible that observers use specific knowledge about distractor defining features to overcome capture, such that increased capture only occurs when the distractor changes to a novel color observers have had little or no experience with.

To disambiguate these possibilities, I have included a condition in Experiment 4 in which the surface feature is reverted to a color that observers have already had experience ignoring. If any change in feature information is sufficient to disrupt control, we would expect larger capture in the epoch following the color change regardless of the specific color the distractor changes to. However, if observers are tuning to specific distractor features, we would expect that changing a distractor to a novel color would lead to increased capture effects in the epoch following the change, but that changing it to a previously ignored color would do little to affect capture since observers have already had experience ignoring distractors defined by that particular color. This latter result would argue for a strong, feature-specific mechanism of goal-directed control, whereby observers use specific information regarding the association between distracting information and its defining features to overcome capture.

**Experiment 4**

**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 & Procedure.** This experiment was identical to Experiment 3, with the following exceptions. In the current experiment, I was interested in the feature-specificity of the effect observed in Experiment 2, and as a result I included a condition in which the color of the distractor reverted to a color observers already had extensive experience ignoring. For the “novel color change” conditions, the order in which each cue color was introduced was counterbalanced across observers. In the “familiar color change” condition, the cue reverted to the color in which it was originally introduced, with this change always occurring during Epoch 16. For example, for a given observer the target color was always red, and the cue was absent for epochs 1-5, the cue color for epochs 6-10 was green, for epochs 11-15 it switched to white, for epochs 16-20 it switched back to green, and for epochs 21-25 it switched to blue. With this design, it is possible to dissociate the effects of any change in distractor color from those of changes to specific colors. In particular, if any color change leads to an increase in capture, we would expect increased capture (i.e., a large cueing effect) in the epoch directly following the change in distractor color. On the other hand, if observers tune to specific distractor features, we would expect large cueing effects in the epoch following the change only for cue colors that observers had not previously been exposed to.

Observers first performed a block of 120 trials of the search task in which no cue was presented. Following this block, and for the rest of the trials in the experiment (epochs 6-25), on each trial the search array was preceded by a cue that either validly
(25% of trials) or invalidly (75% of trials) predicted the target location as in the previous experiments.

Observers performed 600 trials total, completing 5 blocks of 24 trials for each cue condition. Observers were informed during the instructions at the beginning of the task that 1) the cue could appear in any color and 2) that the cues were task-irrelevant and should be ignored because they would hurt performance. Thus, as in the previous experiments, any effect of the cue should occur in the face of a strong intention to ignore it.

Results

Again, incorrect trials and outlier trials with RTs greater than 3 SDs above individual means were excluded from further analysis, with this trimming resulting in a removal of approximately 3% of the total RT data for Experiment 4. Given my primary interest in the effect of novel vs. familiar color changes on the cue’s ability to capture attention, I collapsed across cue color and analyzed only data from the epoch following a color change using a two-factor ANOVA with cue color (novel vs. familiar) and cue validity (valid vs. invalid) as factors, similar to the planned comparisons used in Experiment 3. However, data from each epoch, including the initial 120 “no cue” trials is included in Appendix A. This analysis revealed a significant main effect of cue color, $F(1,14) = 3.1, p = .03, \eta^2 = .28$, but not cue validity, $F(1,14) = 1.3, p = .26$. Importantly, an interaction between cue color and cue validity was observed, $F(1,14) = 6.4, p = .02, \eta^2 = .31$. Specifically, a significant cueing effect was observed in the epoch following a novel color change, $t(14) = 3.1, p < .01$, but not in the epoch following a familiar color
change, $t < 1, n.s.$ This suggests that observers represent distractors in a highly specific manner, coding information about their defining surface features, in this case color.

However, one could argue that these rather than indicating specificity in capture effects, these results instead indicate serial position effects in the magnitude of capture over time. Specifically, given that the familiar color change always occurred following 360 trials of practice, it may simply be that color changes introduced following more extensive practice are less likely to affect capture. In order to rule out this possibility, a planned comparison was performed on RTs from the epoch following the final color change, which in this case occurred 120 trials after the familiar color change (epoch 21). A significant cueing effect was observed following this change, $t(14) = 2.3, p = .04$, indicating that amount of practice has little effect on the ability of novel color changes to induce capture. Taken together, these results indicate that the learned representations used to influence attentional capture in this task are highly feature specific, with capture effects being sensitive to changes in surface features only when an observer has had no prior experience with the particular feature.

### Chapter 2 Discussion

Experiments 1-4 consistently showed that effective goal-directed control arises as a result of experience with task-irrelevant distractors, even when observers are told specifically to ignore them and steps are taken to make them entirely task-irrelevant (e.g., as in Experiments 1b & 2b where the onset never appeared at the target location). The fact that robust capture effects were observed even though observers should have had a strong intention to ignore the onset distractor suggests that the intention to ignore a specific salient distractors and attend a specific target isn’t sufficient to drive goal-
directed control even in a task in which such control is normally observed (Folk et al. 1992; Folk & Remington, 1998; Folk & Anderson, 2010; a finding I replicated when observers were given sufficient experience in each of the above experiments).

Additionally, Experiments 3 and 4 showed that observers were sensitive to changes in features associated with distractors, arguing for a mechanism of goal-directed control in which, at a minimum, features of to-be-attended (e.g., the target) and to-be-ignored information (the distractor) are represented in a specific manner. Taken together, these experiments demonstrate that task experience plays a critical role in determining the extent of attentional capture, and provide a basis for conceptualizing goal-directed control as a skill that is acquired through experience with a particular task. This view is in
opposition to traditional views of capture that delineate between stimulus-driven and goal-directed control on the basis of intentionality. Given that I found little support for the assumption that intentions are sufficient for goal-directed control over capture, the use of intentionality is as a criterion for differentiating between the effects of stimulus-driven and goal-directed control no longer seems tenable.

Instead, these results fit the predictions of a “learned control” view of capture effects, whereby at a minimum observers require experience with task-irrelevant distractors before they are able to effectively ignore them. The current results also provide an extension of traditional demonstrations of visual learning, in showing that the specificity that is a hallmark of visual learning can play an important role in goal-directed control over capture. This novel functional role for stimulus-specific visual learning in “higher-level” cognitive control processes demonstrates that one benefit of such specificity is that it attenuates the influence of specific salient but task-irrelevant information on behavior, without attenuating the ability for salient information to capture attention when it somehow changes or deviates from learned expectations. In other words, the stimulus-specific nature of the learning demonstrated both here and in traditional forms of visual learning enables stimulus-specific effects on control processes, providing behavioral flexibility in a dynamic world; when distractor information changes in some way, the distracting information regains the ability to capture attention.

Relatedly, the current results fit well with an instance-based account of control (Logan, 1988; 2002), again because of the specific nature of the learned representations that enable effective control over capture. Instance-based accounts of skill learning would predict such specificity because skilled performance is viewed as a direct result of
the accumulation of episodic memories (or “instances”) regarding past experience with successfully performing a task. As such, in cases such as those encountered in Experiments 3 and 4 it is possible that the reason capture effects were observed after novel color changes was because these changes forced observers to “re-learn” the distractor defining features, accumulating a sufficient number of instances with the new distractor color before they were able to effectively ignore it (Logan, 1998; 2002).

Thus, the results generally fit within the context of theories of both visual learning and skill learning, and together these two lines of work provide a plausible mechanism by which experience can directly affect the likelihood of attentional capture. Importantly, these results show that the intention to ignore something is not sufficient in and of itself to attenuate capture, whereas experience with specific stimulus properties is. At the same time, it is still possible that an observer’s intentions play some role in the ability to overcome capture, albeit not in the direct manner proposed by current views of goal-directed control. Specifically, in the tasks used in the current experiments, as well as in the typical version of this task (Folk et al., 1992) observers were always told the specific stimulus attributes to both attend to and ignore. Observers may, at a minimum, have to voluntarily search for a specific target features and ignore specific distractor features in order to produce the pattern of control typically observed in this task. For example, voluntarily allocating attention toward relevant and away from irrelevant attributes of target and distractor stimuli, respectively, may underlie the learned control observed in this task. Thus, even though explicit control on the basis of an observer’s intentions is not sufficient for effective control, it may be necessary for effective control, and this possibility is addressed in Chapter 3.
CHAPTER 3

ASSESSING THE NECESSITY OF INTENTIONAL PROCESSES IN EXPERIENCE-DEPENDENT GOAL-DIRECTED CONTROL

The aim of the previous chapter was to provide initial evidence that in a case where goal-directed control is known to be effective in blocking capture, this effect emerges as a function of experience with a task, and more specifically with the distractor that is to be ignored. The current chapter examines more closely how the synergy between target and distractor information enables the feature-specific control typically observed in the Folk et al. (1992) cueing task. Recall that in this task observers are given an explicit instruction to search for a target on the basis of a particular defining feature (e.g., the color red) while ignoring a salient, task-irrelevant stimulus. It is typically demonstrated that only information that matches the target-defining dimension captures attention; when told to search for a red target, over time only red distractors capture attention, even if other salient distractors are present (Folk et al. 1992; Folk, Remington, & Wright, 1994; Folk & Remington, 1998; 2006). How is it that distractors possessing features that match those that define the target maintain the ability to capture attention whereas those that don’t possess these features do not, even when observers are explicitly told that the distractor is always irrelevant and should be ignored?

One possibility is provided by classic models of attentional control that propose the active maintenance of a target template in working memory drives goal-directed control processes (e.g., Olivers, 2009; Theeuwes, 2010; see also Duncan & Humphreys, 1989; Desimone & Duncan, 1995; Bundesen, 1995 for examples specific to search more
generally). However, based on the data from Experiments 1 through 4 above, it appears that working memory representation related to the target of search is insufficient in and of itself to drive effective control. Instead, observers need to tune the attention system to particular distractor features before they are able to effectively ignore stimuli possessing those features. This suggests that long-term learning of distractor information plays a critical role in the ability to ignore salient but irrelevant information, and suggests that a similar process may be at play with respect to the target of search. For example, just as observers require experience with particular distractor features in order to ignore them, they may need experience with particular target features to generate contingent capture for items that match the target of search.

In other words, it’s possible that the strong feature-based selectivity that is a hallmark of goal-directed control over attentional capture in this task may be driven, at least in part, on incidental regularities between task-relevant information (e.g., the target) and its defining properties (such as its color). Just as observers may tune the visual system to suppress features that define a distractor, as in Chapter 2, they may also tune the visual system to enhance feature dimensions that define the target. This would lead to a pattern of results identical to those typically observed in this task, but this mechanistic description of the results is much different than that offered by traditional views that emphasize the role of voluntary, intentional control in this selectivity.

To frame the question of interest in this chapter in a more concrete way: When observers are asked to search for a red target, is it the maintenance of an explicit goal to “search for red” or the repeated exposure to red search targets that allows target-consistent features to maintain the ability to capture attention? Given that in previous
demonstrations of this effect (e.g., Folk et al., 1992; 1994; 2002; Folk & Remington, 1998; 2006; Eimer & Kiss, 2008) the instructions given to observers and exposure to target defining features have been entirely confounded, it is hard to determine the relative contributions of each in generating the attentional control settings necessary for overcoming capture. For example, when observers are asked to search for a red target, is it the intention to search for a red target itself or the repeated exposure to the color red when attending to the target that drives feature-based control over capture? Thus, whereas in Chapter 21 I was interested in determining whether intentionality is a sufficient criterion for driving effective goal-directed control over capture, in Chapter 3 I examine the necessity of an observer's intentions in this process.

Overview of Experiments 5-10

Despite the fact that implicit visual learning in the spatial domain has been shown to influence attentional control (e.g. Chun & Jiang, 1998; 1999), the question of whether or not implicit visual learning can play a direct role in the cognitive control processes that mediate attentional capture has yet to be examined. As noted above, in previous studies of feature-based, goal-directed control over capture, task goals are confounded with the visual properties that define target and distractor information (observers are told to search for the red item). Thus, it is impossible to tell if the feature selectivity seen in tasks such as that of Folk et al. (1992) is due to an observer’s explicit goal to search for a target defined by a particular feature, to repeated exposure to the target-defining color itself during search, or some combination of the two. In this chapter, the goal is to decouple an observer’s goals from task-relevant target features in order to test the necessity of explicit processes in establishing precise, feature-based control over capture. Given the results
from Chapter 2 and the evidence outlined previously that 1) spatial and feature
regularities can be statistically extracted from visual scenes and 2) this information can
be used flexibly to guide the deployment of attention, it is possible that highly specific
goal-directed control can be acquired on the basis of incidentally encountered features
that are not explicitly represented in the search goals implemented by observers.

In order to test this possibility, I used an adapted version of Folk et al’s (1992)
cueing task (see Figure 9 for an example of the basic task used in the experiments in this
chapter). As outlined previously, in this task observers are typically instructed to search
for a target on the basis of a single visual feature (e.g., find the red target and report its
identity), and feature-based modulation of capture is measured by comparing the
magnitude of the cueing effect for cues that either match the feature defining the search
target (e.g., red) or do not (e.g., green). Cueing effects are typically larger for cues that
match the target-defining feature (red) than those that do not (green), the so called
“contingent capture” effect. In order to decouple explicit goals from target-defining
features in order to examine whether explicit goals regarding target-color associations are
necessary for driving contingent capture effects I have made some key changes to this
typical cueing paradigm for use in Experiments 5-10, outlined in turn below.

First, in the current experiments observers are told to search for the target on the
basis of letter form rather than color. Since in each experiment presented below target
color varies from trial to trial, I eliminated search for color as an effective means of
finding the target. However, in these experiments I manipulated the likelihood that the
target or distractor would appear in certain colors, and in this way provided an implicit
Observers were always told to search for a B or H target, and report its identity. The search display was preceded by a spatially non-predictive cue that could appear in either green or red. Given the non-predictive nature of the cue, observers were always told to ignore it and focus on the search task. Of interest in each of these experiments was whether asymmetries in the probability with which certain colors defined targets or distractors would lead to predictable modulation of capture effects by the colored cues.

Importantly, the likely defining feature of the target was manipulated in a manner orthogonal to the observers’ explicit goals, such that for a given observer the target would appear in the color red on most trials (80% of trials), whereas it would appear in green infrequently (20% of trials). This design allowed me to examine whether feature-based modulation of capture requires explicit control processes related to the goal of search, or...
if such modulation can be produced solely on the basis of probabilistic information regarding the target-defining features.

Second, in the experiments below I employed a two-location cueing task rather than the typical four-location cueing task used by Folk and colleagues (Folk et al., 1992; 1994). The primary reason for this is that in a typical four location contingent capture task the precue is equally likely to appear in any of the four locations, introducing an asymmetry in the spatial validity of the cue (i.e., with four locations, the cue is valid on 25% of trials and invalid on 75% of trials, as in the experiments in Chapter 2). Given that I was interested solely in the effect of probabilistic associations between a target and its color, the two location cueing task allowed me to eliminate any possible confounding effects of probability related to the location of the spatial precue. While these sorts of spatial contingencies exist in the real world and are likely exploited by observers to influence goal-directed control (e.g., Geng & Behrmann, 2005; Umemoto et al., 2010) in the current series of experiments I was solely interested in the effects of target and distractor-defining properties on capture effects, and as a result it was important to eliminate possibly confounding spatial probability information. Relatedly, given the choice of a two-location cueing task, it wasn’t possible to employ color-singleton cues such as those typically used to examine the influence of explicit settings for color on capture by color cues (as in Folk et al., 1992). Instead, I used abrupt onset cues that could appear in colors that either match or mismatch the target (similar to Experiments 3 and 4), and I have replicated the basic contingent attentional capture effect using these stimuli to show that these manipulations have little effect on the pattern of capture effects normally observed in this task (see Figure 10).
Finally, in order to probe observers’ knowledge of the probabilistic association between particular targets and their associated color, all observers were given a brief questionnaire following participation in the experiment that included both open-ended and two alternative forced choice questions about the stimulus-color associations present in the experiment, as well as questions regarding the explicit strategies employed while performing the task (see Appendix E). With this design, it was possible to test whether feature-based attentional control settings can be acquired and implemented incidentally on the basis of specific target-feature relationships, without explicit knowledge of these relationships.

![Graph](image)

**Figure 10.** Data from a basic replication of Folk et al.'s cueing task using my adapted design. A two-factor ANOVA showed a significant interaction between cue/target color match and cue validity, $F(1,13)= 11.4, p < .01, \eta^2 = .47$, and planned comparisons revealed a significant cueing effect on when the cue matched the target color, $t(13) = 3.15, p < .01.$
Experiment 5

Method

Observers. Observers were 16 University of Iowa undergraduates who participated for course credit. All had normal or corrected to normal vision and were not color blind.

Apparatus. Stimuli were presented on a 15” CRT monitor powered by a Macintosh Mini computer, using MATLAB and the Psychtoolbox (Brainard, 1997).

Stimuli & Design. Observers sat approximately 65 cm from the screen and viewed displays resembling those in Figure 9. The fixation display consisted of 2 placeholder boxes measuring 1.4° × 1.4°, positioned to the left and right of fixation. The distance from fixation to the center of each placeholder box was 5.2°. The placeholder boxes were light gray (RGB 160, 160, 160) on a black background. Cues consisted of a single set of 4 dots (radius .21°) centered on the edges of a placeholder box, with each dot positioned .46° peripheral to the side of the placeholder. The cues were spatially non-predictive and were equally likely to be presented in either red (RGB 255, 0, 0) or green (RGB 0, 128, 0), selected pseudorandomly on each trial. A single target symbol was presented on each trial, and was either a ‘B’ or an ‘H’ drawn in 56 pt Helvetica bold font, with identity being chosen pseudorandomly on each trial. The color of the target could be either red (RGB 255, 0, 0) or green (RGB 0, 128, 0), and the target always appeared within one of the two placeholder boxes on each trial.

Importantly, I introduced an asymmetry in the probability with which the target letter would appear in a particular color. Specifically, for half of the observers, the B/H target appeared in red on 80% of trials and in green on the remaining 20% of trials, with
this asymmetry being reversed for the other half of the observers. This manipulation allowed me to examine whether probabilistic relationships between a target and its defining features would lead to differences in the ability of either red or green cues to capture attention, similar to the effect seen in a typical version of this task (Folk et al., 1992). Concurrent with the target, a white non-target symbol was presented in the remaining placeholder box, with non-target identities being drawn randomly from a set of letters consisting of K,L,T,V, each of which were also drawn in a 56 pt Helvetica bold font.

Procedure. Observers completed the experiment in a single session lasting approximately 40 minutes, and prior to beginning were given oral instructions regarding the task. They were instructed to search for a target letter, which would be either a ‘B’ or an ‘H’ on each trial, while ignoring a distractor letter. They were informed that the cue would not reliably predict the target location, and as a result they were explicitly told to treat it as a distractor that could potentially interfere with performance. Observers were told to perform the task as quickly and accurately as possible.

On each trial, a fixation display was presented for 1000ms, followed by a spatially non-predictive, red or green onset cue for 50 ms, and then by a 100ms ISI in which only the fixation display was presented, producing a cue-target SOA of 150ms. Directly following this, the search display was presented for 50ms. The duration from the time of cue onset to the time of target onset was 200ms, a duration short enough to preclude eye movements to the cue or target locations. The fixation display was then presented until observers made a response using their index finger of each hand to press either the ‘Z’ or ‘M’ keys, with target-response mappings counterbalanced across observers. Observers
completed 6 blocks of 80 trials, for a total of 480 trials. In order to assess awareness of the target-color asymmetry present in this experiment, directly following completion of the task observers were given a short questionnaire to probe their awareness of the color manipulations present in the experiment (see Appendix E).

Results

Incorrect trials and trials with RTs greater than 3 SDs above individual means were excluded from further analysis, with outlier trimming resulting in a removal of approximately 2% of the total RT data. Observers’ overall mean correct reaction time (RT) is shown in Figure 11, and both RTs and error rate data are shown in Appendix B. Both reaction time (RT) and error rate data were entered into a two factor ANOVA with cue color (match likely (80%) target color vs. match unlikely (20%) target color) and cue validity (valid vs. invalid) as factors.

For RTs, a significant main effect of cue validity was observed, $F(1,15) = 32.62$, $p < .001$, $\eta^2 = .69$, indicating faster overall responses to validly cued than invalidly cued targets. The main effect of cue color was not significant, $F<1$, n.s. As would be predicted by the Folk et al.’s contingent involuntary orienting hypothesis, a significant interaction was observed between cue color and cue validity, $F(1,15) = 13.19$, $p < .01$, $\eta^2 = .48$, indicating that the magnitude of capture by the cue varied as a function of the cue’s color. To elaborate on this interaction, planned comparisons were performed between valid and invalid cues in each of the cue color conditions. This analysis revealed a significant cueing effect for cues that matched the more likely (80%) target color, $t(15) = 8.28$, $p < .0001$, but not for those that matched the less likely (20%) target color, $t(15) =$
Figure 11. Reaction time data from Experiment 5. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

1.96, $p = .07$, although there was a trend toward a significant cueing effect in this condition. Analysis of error rates showed neither main effects nor interactions.

Awareness analysis. In order to assess whether observers were aware of the target-color asymmetry present in this experiment, responses to the awareness questionnaire were reviewed. In this experiment, no observer accurately described the target color asymmetry correctly in the open-ended questions. Six of the sixteen observers answered the 2AFC question regarding the target asymmetry correctly, suggesting that the majority of observers were unaware of the color asymmetry. In order to assess whether the capture effects observed above varied depending on whether
observers answered the question regarding the color asymmetry correctly, the magnitude of the cueing effects driven by each cue color were compared separately for observers who correctly and incorrectly responded to the 2AFC question. This analysis showed significantly larger cueing effects for cues matching the more likely target color (as opposed to cues matching the less likely target color) in both groups (incorrect response group - n=10 - 32 ms vs. 9 ms, t(9) = 4.2, p < .01; correct response group - n = 6, 25 ms vs. 9 ms, t(5) = 6.3, p < .01). This indicates that the pattern of capture effects was similar regardless of observers’ answers on the 2AFC question used to assess awareness of the color asymmetry.

Discussion

These results show that when features likely to define the target are manipulated orthogonally to explicit search goals these features can still drive contingent attentional capture effects, whereby cues that match a more likely target color capture attention more strongly than those that match a less likely target color. Furthermore, observers were largely unaware of the asymmetry, with this effect emerging even in observers who incorrectly responded to the 2AFC question in which they were explicitly informed of the asymmetry. This argues that goal-directed control on the basis of target-defining features need not be a purely intentional effect, with explicit information regarding target-defining features being unnecessary to drive the contingent involuntary orienting effect typically observed in this task.

Experiment 6

In Experiment 5, both the target and cues could appear in one of two colors, either green or red on each trial. Although it is clear that attentional capture and subsequent
cueing effects were significantly larger for cues that matched the more probable target color, there was a trend toward a significant cueing effect even for the less probable target color. This suggests the possibility that observers learn and maintain multiple, graded attentional control settings such that features that are more or less likely to define the target are weighted more or less heavily, respectively, by the attention system to influence capture. Such an interpretation would readily explain the pattern cueing effects observed in Experiment 5. Given that other work in our lab and others has demonstrated that observers can maintain multiple explicit attentional control settings concurrently in a task similar to ours (Adamo et al., 2008; Moore & Weissman, 2010; Roper & Vecera, submitted), it is possible that observers can maintain control settings that are weighted probabilistically in terms of how well they match the target-defining attributes, leading to graded effects on attentional capture. In order to assess this possibility, in Experiment 6 I used a design nearly identical to that in Experiment 5, but in this case I included a third cue color that was never related to the target. For example, the target could appear in either red or green with one color being more likely to define the target, but cues could be red, green (both possible target colors), or blue (never a target color). If observers are maintaining multiple, probabilistically graded attentional control settings the largest cueing effects would be expected for cues matching the more probable target color, smaller cueing effects for the less probable target color, and negligible cueing effects for the irrelevant target color that has no relationship with the search target.
Method

Observers. Observers were 16 University of Iowa undergraduates who participated for course credit. All had normal or corrected to normal vision and were not color blind.

Stimuli & Procedure. The stimuli and procedure were identical to Experiment 5, with the exception that a third cue color was introduced. As in Experiment 5, the target could appear in two possible colors (selected from possible target colors red, green or blue, counterbalanced across observers), with one color defining the target on 80% of trials and the other color defining the target on 20% of trials. The only departure from the design of Experiment 5 is that the color cues could appear either in one of the target colors, or a completely irrelevant color, with equal probability (i.e., each appeared on 1/3 of trials). The introduction of this third, task-irrelevant cue color allowed for a comparison of capture by cues that either matched or did not match a possible target-defining color, a comparison I was unable to make in Experiment 5. Observers again completed 12 blocks of 40 trials, for a total of 480 trials, and completed a brief questionnaire following completion of the experiment.

Results

Incorrect trials and trials with RTs greater than 3 SDs above individual means were excluded from further analysis, with outlier trimming resulting in a removal of approximately 4% of the total RT data. Observers’ overall mean correct reaction time (RT) data are shown in Figure 12, and RT and error rate data are both shown in Appendix B. Both reaction time (RT) and error rate data were entered into a two factor ANOVA
with cue color (cue matched more likely (80%) target color vs. matched unlikely (20%) target color vs. did not match target color) and cue validity (valid vs. invalid) as factors.

For RTs, a significant main effect of cue validity was observed, $F(1,15) = 51.45$, $p < .001$, $\eta^2 = .77$, indicating faster responses to validly cued than invalidly cued targets. The main effect of cue color was not significant, $F<1$, n.s. A significant interaction was observed between cue color and cue validity, $F(2,30) = 13.19$, $p < .017$, $\eta^2 = .24$, indicating that the magnitude of capture by the cue varied as a function of the cue’s color. Planned comparisons were performed between valid and invalid cues in each of the cue color conditions in order to assess cueing effects for each cue type. Significant cueing effects were observed for cues that matched the more likely (80%) target color, $t(15) = 5.22$, $p < .0001$, those that matched the less likely (20%) target color, $t(15) = 5.65$, $p = .0001$, and those that appeared in color unrelated to the target, $t(15) = 2.79$, $p = .02$. To further elaborate the two-way interaction between cue color and cue validity, cueing effects were calculated for each of the cue conditions by subtracting valid RTs from invalid RTs, and these cueing effects were compared using Bonferroni corrected t-tests. This analysis revealed that cueing effects were significantly smaller when the cue appeared in the color that was unrelated to the target (11 ms) than when it appeared in either the more likely (32 ms), $t(15) = 2.57$, $p = .02$, or less likely (24 ms), $t(15) = 2.12$, $p = .05$, target color. However, in contrast to Experiment 5 there was no significant difference in cueing effects for cues that matched the likely or unlikely target colors, $t(15) = 1.38$, $p = .19$, indicating that cueing effects in these conditions were of roughly equal magnitude (as noted above, 32 vs 24 ms, respectively).
In order to determine whether this effect was the result of an increase in the ability of cues matching the less probable target color to capture attention, or a decrease in the ability of cues matching the more probable target color to capture attention relative to Experiment 5, cueing effects for cues matching both the more and less likely target color were compared between Experiment 5 and the current experiment using a between subjects t-test. This analysis showed significant differences between experiments in the magnitude of cueing effects for cues matching the less likely target color, \( t(15) = 2.69, p = .02 \), but not for those matching the more likely target color, \( t<1, \text{n.s.} \), indicating that in the current experiment capture for these cues increased when an unrelated cue color was added to the task. Analysis of error rates showed neither main effects nor interactions.

**Discussion**

These results provide further evidence that features likely to define the target can drive contingent attentional capture effects even when not explicitly relevant to the search task. However, the results of the current experiment demonstrate that target-color probability effects on capture are fundamentally altered when a cue that possesses an entirely task-irrelevant feature is present during learning. Despite the fact that the current experiment used the exact same target-color asymmetry as that in Experiment 5, the inclusion of a “neutral” cue color caused observers to implement a more general control setting than that in Experiment 5. More specifically, under these conditions it appears that instead of implementing precise, feature-specific control settings on the basis of relative feature probabilities observers developed a more general “target-like” vs. “non target-like” setting.
Figure 12. Reaction time data from Experiment 6. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

The fact that observers were entirely unaware of the color contingencies argues that this effect wasn’t driven explicitly by observers noticing the color symmetry, but instead arose implicitly based on the experience observers had with the search task. This bears some resemblance to effects in the category learning literature, in which observers can categorize information on the basis of similarity even when the rules driving this category assignment process are implicit (Smith & Grossman, 2008; Goldstone, 1994; Knowlton & Squire, 1993). The current results also suggest something about the level of representation at which learned control operates; Apparently, as the variability of the features present in a scene increases, the attentional system is more likely to use coarser,
higher-level categorical information (e.g., target-like vs. non target-like) in the control of attention instead of the more precise low-level information regarding the probability of individual target-feature associations.

**Experiment 7**

The data from Experiments 5 and 6 show that even when observers cannot set themselves to a specific color in order to find the target, cues that match more probable target colors are more likely to capture attention, producing larger capture effects. This effect appears to operate implicitly, since observers have little or no explicit knowledge of the target-color contingencies as demonstrated in Experiments 5 and 6. However, despite the fact that target colored was variable from trial to trial thus eliminating the ability to establish an explicit control setting for a specific color, in the design used in both of the experiments above observers may have set themselves either explicitly or implicitly to find the “colored letter” since the distractor letter was always white (which could be considered in a sense a “non-color”). Alternatively, it is possible that they set themselves to search for the “red or green letter” while ignoring the white distractor, a possibility compatible with the results of Experiment 6. Although such strategies would not explain the observed effect of target-color probability on the magnitude of capture in Experiment 5 or take away from the overall importance of the results presented above, they may point to a boundary condition whereby at a minimum observers need to have an attentional set for a particular superordinate target-defining *dimension* that differentiates target from non-target items (e.g., similar to Müller, Heller, & Zeigler, 1995; Müller, Krummenacher, Geyer, & Zehetleitner, 2009). In the context of the results of Experiment 5 and 6, the possibility that observers may have set themselves to find a
target in the color dimension while ignoring the “non-colored” distractor letter may have been a critical factor in driving the learned control in these experiments. Such an effect may modulate the likelihood that probabilistic associations are acquired and used by the attention system to control capture, and it is possible that probability information is extracted only from items that match an attended target dimension (see Jiang & Leung, 2005, for related logic in a contextual cueing task; Turk-Browne et al., 2005 in a visual statistical learning task).

In order to examine this possibility, in Experiment 7 I used a task identical to that in Experiment 5, but in this case on each trial both the target and distractor appeared in either red or green. This manipulation eliminates the ability of observers to use a strategy such as that outlined above, and with color being entirely uninformative with respect to the possible target dimension observers are forced to search for the target solely on the basis of its identity. Importantly, as in Experiment 1 I introduced a color asymmetry for only the target item – on 80% of trials, the target appeared in one color (e.g., red) and on the other 20% of trials it appeared in the other color (e.g., green). Conversely, there was no probability manipulation with respect to the color of the distractor item, with the distractor being equally likely to appear either in red or green. As in Experiment 5, cues were equally likely to appear in either red or green. If a superordinate dimensional set for “color” is necessary for driving the statistical learning of control settings observed in Experiments 5 and 6, then we would expect the effect of target-color associations on capture to be absent in the current experiment since this strategy can no longer be employed by observers to perform the search task. Conversely, if such a dimensional set is not necessary for driving these effects we would expect a pattern of data similar to that
in Experiment 5, with cues matching the more probable target color capturing attention to a greater extent than those that do not.

*Method*

*Observers.* Observers were 16 University of Iowa undergraduates who participated for course credit. All had normal or corrected to normal vision and were not color blind.

*Stimuli & Procedure.* The stimuli and procedure were identical to Experiment 5, with the exception that the distractor letter now appeared in red or green with equal probability, rather than white. Observers again completed 12 blocks of 40 trials, for a total of 480 trials, and completed a brief questionnaire following completion of the experiment.

*Results*

Incorrect trials and trials with RTs greater than 3 SDs above individual means were excluded from further analysis, with outlier trimming resulting in a removal of approximately 4% of the total RT data. Observers’ overall mean correct reaction time (RT) data appear in Figure 14, and both RT and error rate data are presented in Table. Both reaction time (RT) and error rate data were entered into a two factor ANOVA with cue color (match more likely (80%) target color vs. match less likely (20%) target color) and cue validity (valid vs. invalid) as factors.

For RTs, a significant main effect of cue validity was observed, $F(1,15) = 10.09$, $p < .01$, $\eta^2 = .40$, indicating faster responses to validly cued than invalidly cued targets. Again, the main effect of cue color was not significant, $F(1,15) = 2.91$, $p = .11$. However, a significant interaction was observed between cue color and cue validity,
$F(1,15) = 7.55, p < .02, \eta^2 = .36$, indicating again that the magnitude of capture by the
cue varied as a function of the cue’s color. Planned comparisons were performed
between valid and invalid cues in each of the cue color conditions in order to assess
cueing effects for each cue type. Significant cueing effects were observed for cues that
matched the more likely target color, $t(15) = 4.41, p < .001$, but not those that matched
the less likely target color, $t(15) = 1.95, p = .07$. Analysis of error rates showed neither
main effects nor interactions.

Figure 13. Reaction time data from Experiment 7. Error bars represent 95% within-
subjects confidence intervals (Loftus & Masson, 1994).
Awareness analysis. In order to assess whether observers were aware of the target-color asymmetry present in this experiment, responses to the awareness questionnaire were reviewed as in the previous experiments. In this experiment, no observer accurately described the target-color asymmetry correctly in the open-ended questions. Eight of the sixteen observers answered the 2AFC question regarding the target asymmetry correctly, with performance on this question therefore falling exactly at chance. In order to assess whether the capture effects observed above varied depending on answers to the question regarding the color, the magnitude of the cueing effects driven by each cue color were compared separately for observers who correctly and incorrectly responded to the 2AFC question. This analysis showed significantly larger cueing effects for cues matching the more likely target color (compared to cues matching the less likely target color) in both groups, (incorrect response group - n=8 - 24 ms vs. 5 ms, t(7) = 2.9, p = .03; correct response group - n = 8, 22 ms vs. 12 ms, t(7) = 2.5, p = .04). This indicates that the pattern of capture effects was similar regardless of observers’ answers on the 2AFC question.

Discussion

These results show that even when observers are prevented from adopting a dimensional set for color, the probability with which a target will appear in a particular color can generate contingent attentional capture effects. This argues against the notion that observers need to attend to the color dimension more generally in order to generate the learned control effects observed in Experiments 5 and 5 above. Instead, it appears that observers can implicitly track information regarding likely goal-relevant (i.e., target-defining) features, and this information can be used to drive goal-directed control over
capture even in the absence of explicit intentions to attend or ignore these learned features.

**Experiment 8**

In Experiments 5 through 7, I have demonstrated that observers are able to acquire feature-based attentional control settings implicitly on the basis of learned associations between a target and its probable color. Thus it appears that when particular features are more or less likely to define a target, the attention system can use this information to modulate capture by salient information in a top-down manner. Although I have argued that such an effect is most likely the result of longer-term visual learning mechanisms, alternative mechanistic explanations exist. For example, recent work has demonstrated that attentional control settings can be activated transiently on trial by trial basis, with some positing that the traditional contingent capture effect itself represent a form of bottom-up inter-trial priming (Theeuwes, Reimann, & Mortier, 2006; Belopolsky, Schreij, & Theeuwes, 2010).

A similar effect could have played at least some role in driving the effects observed above, although it is unlikely to entirely account for the feature-specific relationship between learned target colors and capture effects since targets could appear in either color on a trial by trial basis. However, if the effects of feature probability observed in these previous experiments emerged as a result of longer-term, associative learning processes we would expect them to persist even once the probability asymmetry between targets and particular colors is removed, whereas more simple explanations on the basis of inter-trial priming effects would predict no such transfer. To this end, in Experiment 8, I directly tested this account of my results by having observers perform a
task identical to that in Experiment 5, followed by a testing session in which the targets were equally likely to appear in either possible target color. If goal-directed control on the basis of target-color associations results from visual associative learning mechanisms, we would expect robust carryover effects when observers are transferred to the equal probability test block, with observers showing increased capture by cues presented in a color matching that which was more likely to define the search target during training relative to cues presented in a color matching the less probable target color. However, if the effect observed in Experiments 5-7 is the result of simple inter-trial priming effects, we would expect no carryover and thus no difference in capture for cues presented in either color.

**Method**

*Observers.* Observers were 16 University of Iowa undergraduates who participated for course credit. All had normal or corrected to normal vision and were not color blind.

*Stimuli & Procedure.* For the training session, the stimuli and procedure were identical in every respect to those in Experiment 5, with observers completing 12 blocks of 40 trials (480 total trials). Directly following the twelfth training block, observers completed a test session of 160 trials (4 blocks of 40 trials each) in which the asymmetry in target-color probability was removed.

*Results*  
Incorrect trials and trials with RTs greater than 3 SDs above individual means in both the training and testing data (treated separately) were excluded from further analysis, with outlier trimming resulting in a removal of approximately 4% of the RT
data from the training session and 2% of the RT data from the testing session. Observers’ overall mean correct reaction time (RT) data for the training session appear in Figure 14, and RT data from the testing session appear in Figure 15. RT and error rate data for both the training and testing sessions are also shown in Appendix B. For both sessions, reaction time (RT) and error rate data were entered into a two factor ANOVA with cue color (match more likely (80%) target color vs. match less likely (20%) target color) and cue validity (valid vs. invalid) as factors.

**Training Data.** For RTs, a significant main effect of cue validity was observed, $F(1,15) = 16.5, p < .001, \eta^2 = .52$, indicating faster responses to validly cued than invalidly cued targets. The main effect of cue color was not significant, $F(1,15) = 1.48, p = .24$. However, a significant interaction was observed between cue color and cue validity, $F(1,15) = 10.5, p < .01, \eta^2 = .41$, indicating again that the magnitude of capture by the cue varied as a function of the cue’s color. Planned comparisons were performed between valid and invalid cues in each of the cue color conditions in order to assess cueing effects for each cue type. Significant cueing effects were observed for cues that matched the more likely target color, $t(15) = 4.24, p < .001$, as well as those that matched the less likely target color, $t(15) = 1.68, p = .05$. Analysis of error rates showed a significant main effect of validity on error rate, $F(1,15) = 5.1, p = .04, \eta^2 = .25$, with overall error rates being slightly higher on invalid trials (3.2%) than on valid trials (2.2%). Neither the main effect of cue color nor the interaction between cue color and validity were significant. These data provide a direct replication of Experiment 5, showing that the effect of learned target-color contingencies on the ability of the cue to capture attention is robust and replicable.
Testing Data. For RTs, a significant main effect of cue validity was observed, $F(1,15) = 30.7, p < .0001, \eta^2 = .56$, indicating faster responses to validly cued than invalidly cued targets. The main effect of cue color was not significant, $F<1, p = n.s.$ Importantly, a significant interaction was observed between cue color and cue validity, $F(1,15) = 7.6, p = .01, \eta^2 = .34$, indicating that the magnitude of capture by the cue varied as a function of the cue’s color. Planned comparisons were performed between valid and invalid cues in each of the cue color conditions in order to assess cueing effects for each cue type in the testing block. Significant cueing effects were observed for cues that

Figure 14. Reaction time data from the training portion of Experiment 8. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).
matched the likely target color, $t(15) = 5.45, p < .001$, and those that matched the less likely target color, $t(15) = 2.71, p = .02$. Analysis of error rates showed no significant main effect or interactions.

![Figure 15](image-url)  
Figure 15. Reaction time data from the testing portion of Experiment 8. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

**Awareness analysis.** In order to assess whether observers were aware of the target-color asymmetry present in this experiment, responses to the awareness questionnaire were reviewed as in the previous experiments. In Experiment 8, the awareness questionnaire was completed following the testing block, but it was emphasized to observers that the questionnaire questions only pertained to the initial
training session. In this experiment, two observers accurately described the color contingency on the open ended questions. However, only one of these observers showed a larger cueing effect for the more probable target color during the test session (38 vs. 10 ms) with the other showing no difference in cueing effects across cue colors (22 vs. 21 ms). Ten of the sixteen observers answered the 2AFC question regarding the target asymmetry correctly, with performance on this question therefore falling slightly above chance. In order to assess whether the capture effects varied depending on answers to the question regarding the color, the magnitude of the cueing effects driven by each cue color were compared separately for observers who correctly and incorrectly responded to the 2AFC question. Again, this analysis showed significantly larger cueing effects for cues matching the more likely target color compared to cues matching the less likely target color in both groups (incorrect response group - n=6 - 22 ms vs. 8 ms, t(5) = 2.8, p = .04; correct response group - n = 10, 19 ms vs. 8 ms, t(9) = 2.3, p < .05). As in the previous experiments, this provides strong evidence the asymmetry in capture effects observed across target colors did not depend on observers’ subjective awareness of the target-color asymmetry.

Discussion

The results of the current experiment suggest that the effect of target-color associations on capture observed in Experiments 5-6 arises as the result of visual learning process, and is not simply due to inter-trial priming effects. The results of the training session directly replicated the results of Experiment 4, indicating that the finding observed in that experiment are robust and can be easily replicated. Importantly, the data from the testing session provides, to my knowledge, the first demonstration that learned
contingencies between goal-relevant elements of a task (e.g., the target of search) its defining features can be acquired implicitly used to control the likelihood of capture upon future encounters with a stimulus even after the contingency is no longer present. This provides the strongest demonstration yet that simple contingencies learned by the visual system can have a direct influence on relatively high-level cognitive control processes presumed to modulate attentional capture.

**Experiment 9**

Within the cueing task used in Experiments 5-8, in addition to contingencies between the target and a particular color feature, other contingencies can be informative with respect to increasing the efficiency of task performance. Having shown that learned contingencies between a target and a particular color feature can affect capture, I now turn attention to whether similar feature-specific learning related to the cue itself can affect the likelihood that it will capture attention. In Experiments 5-8, cue location was always non-predictive with respect to both the location in which it appeared and the color it appeared in. In a typical case, these types of cues capture attention in an automatic manner as noted in the introductory section (e.g., Posner, 1980; Posner, Snyder, & Davidson, 1980). However, when the location of the spatial precue is predictive that is, when the spatial location of the cue predicts the location of a target with high certainty (e.g., 80% of trials) capture effects are increased due to the increased “usefulness” of the cue (e.g., Jonides, 1981).

When particular features are learned to be predictive of the target identity, as in Experiments 5-8, capture by spatial cues is attenuated unless they match the likely target color. What has yet to be tested is whether spatially predictive features associated with a
spatially non-predictive cue can affect that cue’s ability to capture attention. For example, if the cue itself is equally likely to appear at a target or non-target location, but when it appears at the target location it is usually red, will this result in greater capture for red cues? Given that I have shown that cue-related learning is possible (Experiments 1-4), it seems plausible that detailed information about cue features and the likelihood that they will predict the target location can be learned and used to influence the capture of attention.

In order to examine this possibility, in Experiment 9 observers performed a cueing task nearly identical to that in the experiments above. However, in this case, both targets (B vs. H) and non-targets (K, L, T, or V) were always presented in white on a black background, and spatially non-predictive cues were presented in either red or green on each trial. Central to the current question, in this experiment I manipulated the likelihood that cues defined by specific features validly or invalidly cued the location of the target. Specifically, even though cues were always spatially non-predictive with respect to target location (i.e., they were equally likely to appear in target or distractor locations), one color was associated with spatially valid cues on 80% of trials, while the other cue was associated with spatially invalid cues on 20% of trials.

For example, a given observer would see colored onset cues that were spatially non-predictive, but when the cue was valid it was 80% likely to be presented in the color red (20% in the color green). If observers are able to learn the associations between cue validity and cue color, we may expect that they would show larger capture effects for cues defined by a color that predicts the target location on a large proportion of trials (the red cue in this example).
Method

Observers. Observers were 16 University of Iowa undergraduates who participated for course credit. All had normal or corrected to normal vision and were not color blind.

Stimuli & Procedure. The stimuli and procedure were identical to those in Experiment 5, with the following exceptions. In the current experiment, both target and distractor letters were always presented in white. Spatially non-predictive cues were presented in either red or green with equal probability – on half of trials the cue was red and on the other half of trials the cue was green. However, one color was 80% likely to be associated with spatially valid cues (and 20% likely to be associated with spatially invalid cues), with the other being 80% likely to be associated with spatially invalid cues (and 20% likely to be associated with spatially valid cues). Observers completed 10 blocks of 40 trials, for a total of 400 trials. As in the previous experiments observers completed a brief questionnaire following completion of the experiment in order to assess their awareness of the color contingencies present in this task.

Results

Incorrect trials and trials with RTs greater than 3 SDs above individual means in both the training and testing data (treated separately) were excluded from further analysis, with outlier trimming resulting in a removal of approximately 3% of the RT data. Observers’ overall mean correct reaction time (RT) data appear in Figure 16, and both RT and error rate data are also shown in Table. Reaction time (RT) and error rate
Data were entered into a two factor ANOVA with cue color (spatially predictive vs. spatially anti-predictive) and cue validity (valid vs. invalid) as factors.

Figure 16. Reaction time data from Experiment 9. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

For RTs, a significant main effect of cue validity was observed, $F(1,15) = 14.3$, $p < .01$, $\eta^2 = .48$, indicating faster responses to validly cued than invalidly cued targets. The main effect of cue color was not significant, $F<1$, $p = n.s.$ However, a significant interaction was observed between cue color and cue validity, $F(1,15) = 5.5$, $p = .03$, $\eta^2 = .27$, indicating that the magnitude of capture by the cue varied as a function of its color. Planned comparisons were performed between valid and invalid cues in each of the cue
color conditions in order to assess cueing effects for both “spatially predictive” and “spatially non-predictive” cue colors. Significant cueing effects were observed for cues that matched the spatially predictive color, $t(15) = 4.0, p = .001$, but not those that matched the spatially non-predictive color, $t(15) = 1.95, p = .07$. Analysis of error rates showed no main effects or interactions.

Awareness analysis. In this experiment, no observers accurately described the cue-color contingency accurately on the open-ended questions. Eight of the sixteen observers answered the 2AFC question regarding the target asymmetry correctly, with performance on this question being at chance. Analyses in both groups showed results that paralleled those observed in the aggregate, with both groups showing a trend toward larger capture effects for cues that matched the predictive color (incorrect response group - n=8 - 36 ms vs. 13 ms, $t(7) = 2.1, p = .06$; correct response group - n = 8, 30 ms vs. 12 ms, $t(7) = 1.9, p = .09$).

Discussion

Whereas the results of Experiments 5-8 showed that contingencies between the target of search and its defining features could be learned and used to influence attentional capture, the results of the current experiment provide evidence that a similar process operates with respect to the task-irrelevant cue. Specifically, even though the cue was spatially non-predictive with respect to its absolute location, cues associated with a color that was 80% predictive of the upcoming target location produced larger capture effects than those that were predictive of the target location on only 20% of trials.

In other words, observers came to learn that some cue colors were useful and others were not, and this learning was reflected in the different magnitude of capture
effects for each color cue. These results are consistent with the observation in Experiments 3 & 4 of Chapter 2 that observers learn to associate particular features with the cue, and the amount of capture depends on these learned cue-feature associations. Thus, even in cases where observers are told to ignore the task irrelevant cue, they implicitly extract information regarding its surface features, and in the event that this information is useful it is used to control the deployment of attention and the likelihood of capture.

**Experiments 10a and 10b**

The data from Experiment 8 suggest that when a salient but spatially non-predictive cue is associated with a spatially predictive feature, this feature information affects the likelihood that the cue will capture attention. Given that attentional control settings are typically discussed in terms of relationships between targets and their associated features, the data from Experiment 9 provide a novel demonstration that control settings can be based not only on a task-relevant target but also on a task-irrelevant, non-predictive peripheral cue that observers are told to actively ignore. This begs the question of whether information regarding both target and cue features can be entered simultaneously into a more “holistic” control setting for a given task. For example, cues that don’t match the explicitly defined target color (as in the typical version of this task Folk et al., 1992), but that are associated with a color that can facilitate task performance by predicting the location of the target, may still exert a capture effect in the face of an explicit control setting against them.

In support of such a view, recall that in Experiments 1-4 the ability to ignore a salient distractor depended on observers learning the particular features associated with it.
This would seem to suggest that such synergistic effects of target and distractor information are not only possible, but are necessary for effective goal-directed control over capture in the typical version of this task. In order to test the interaction between target and cue related processes in affecting capture, in Experiment 10a and 10b observers performed a cueing task similar to that used in each of the previous experiments, but in both cases observers were provided with instructions identical to those in the typical Folk et al. (1992) cueing task, explicitly instructing them search for a target of a specific color (e.g., red), and report its identity (B vs. H), while ignoring the onset cue.

However, I also manipulated the probability that valid and invalid cues would appear in specific colors in a manner identical to that in the Experiment 9. In Experiment 10a, I examined what would happen in the case in which explicit control settings for the target (search for red) were consistent with the predictive cue color (also red). For example, observers were told to search for a red target, and red cues were also more likely (80%) to predict the target location. In experiment 10b, I examined a case in which explicit settings were inconsistent with the predictive cue color. For example, observers were told to search for a red target, but green cues were more likely (80%) to predict the target location. Of particular interest was the pattern of cueing effects in Experiment 10b, because in this case I directly pitted an explicit set for the target against a learned set for the cue.

To reiterate, when observers explicitly search for a target of a particular color, only cues that match that color capture attention (Folk et al., 1992). However, the data from Experiment 9 show that a similar effect is observed when a particular cue feature is
learned to be predictive with respect to the upcoming target location – cues possessing features that are more likely to predict the location of an upcoming target are more likely to capture attention than those that do not. Thus, in a case where explicit settings related to the target and implicit settings related to the cue color are “consistent” with one another (Experiment 10a), we may expect a normal or exaggerated contingent capture effect – if the explicit control setting with respect to the target (e.g., red) matches the learned control setting with respect to the cue (e.g., valid cues are red 80% of the time), red cues should drive larger capture effects than green cues since in both cases observers should be set against the color green.

On the other hand, in a case where explicit target related settings and implicit cue-related settings are “inconsistent” with one another (Experiment 10b) a number of interesting patterns of data may emerge. For example, the explicit set for a particular target color (e.g., red) may cause red cues to capture attention as in the typical version of this task. However, if in this case green cues are more likely to predict the target location, this may allow green cues to retain their ability to capture attention in the face of an explicit set for the color red. Such a finding would argue that explicit control settings related to the target of search are insufficient to attenuate capture, by showing that a cue that doesn’t match the target color can continue to capture attention so long as the cue’s color maintains relevance by being predictive of the target location on a large proportion of trials. Alternatively, it may be possible that as observers learn that green cues are more likely to predict the target location (and thus red cues are less likely to predict the target location), green cues may dominate those that match the target color to determine capture effects.
Method

Observers. Observers were 32 University of Iowa undergraduates (16 each in Experiment 10a and 10b) who participated for course credit. All had normal or corrected to normal vision and were not color blind.

Stimuli & Procedure. The stimuli and procedure were identical to those in Experiment 5, with the following exceptions. In both Experiments 10a and 10b, targets were presented in a single color, either red or green (counterbalanced across observers), and observers were always explicitly told to search for targets on the basis of their color. On each trial, spatially non-predictive cues were presented in either red or green with equal probability. However, as in Experiment 9 one color was 80% likely to be associated with spatially valid cues (and thus 20% likely to be associated with spatially invalid cues), with the other being 80% likely to be associated with spatially invalid cues (and thus 20% likely to be associated with spatially valid cues). In Experiment 10a, the explicit setting for target color was consistent with the implicit setting for cue color. For example, observers were told to search for the red target, and red cues were also more likely to validly predict the target location.

In Experiment 10b, I pitted an explicit setting for target color against an implicit setting for cue color. For example, observers were told to search for the red target, but green cues were more likely to validly predict the target location. In each experiment, observers completed 10 blocks of 40 trials, for a total of 400 trials. As in the previous experiments observers completed a brief questionnaire following completion of the experiment in order to assess their awareness of the color contingencies present in this task.
Results

Incorrect trials and trials with RTs greater than 3 SDs above individual means in both the training and testing data (treated separately) were excluded from further analysis, with outlier trimming resulting in a removal of approximately 1% of the RT data. Observers’ overall mean correct reaction time (RT) appear in Figures 17 (Experiment 10a) and 18 (Experiment 10b), and both RT and error rate data appear in Appendix B. Reaction time (RT) and error rate data from Experiment 10a and 10b were entered into separate two factor ANOVAs with cue color (spatially predictive vs. spatially anti-predictive) and cue validity (valid vs. invalid) as factors.

Experiment 10a. In Experiment 10a, the spatially predictive cue color was consistent with the explicit set for color, and the RT data is presented in Figure 17. For RTs, a significant main effect of cue validity was observed, $F(1, 15) = 18.1$, $p < .01$, $\eta^2 = .54$, indicating faster responses to validly cued than invalidly cued targets. The main effect of cue color was not significant, $F<1$, $p = n.s$. However, a significant interaction was observed between cue color and cue validity, $F(1, 15) = 54.3$, $p < .0001$, $\eta^2 = .78$, indicating that the magnitude of capture by the cue varied as a function of its color. Planned comparisons were performed between valid and invalid cues in each of the cue color conditions in order to assess cueing effects for 1) cues that were both consistent with the target color and associated with “spatially predictive” color, and 2) cues that were both inconsistent with the target color and “spatially anti-predictive.” Significant cueing effects were observed for the former, $t(15) = 7.5$, $p < .001$, but not those that matched the spatially non-predictive color, $t <1$, $p = n.s$. Analysis of error rates showed a pattern that mirrored that of RTs, with a significant main effect of cue validity, $F(1, 15) =$
18.1, \(p < .01\), \(\eta^2 = .54\), but not cue color, \(F < 1, p = n.s\), and a significant interaction between cue color and cue validity, \(F(1,15) = 54.3, p < .0001, \eta^2 = .78\), indicating that the effect of the cue on error rates depended on its color. Again, as in the RT data planned comparisons showed a significant cueing effect on RTs for cues that were both consistent with the target color and associated with “spatially predictive” cues, \(t(15) = 2.6, p < .02\), but not cues that were both inconsistent with the target color and “spatially anti-predictive” \(t < 1, p = n.s\).

**Awareness analysis.** In this experiment, no observers accurately described the cue-color contingency accurately on the open-ended questions. Only six of the sixteen observers answered the 2AFC question regarding the target asymmetry correctly, with performance on this question therefore falling below chance. Analyses in both groups showed results that paralleled those in observed in the aggregate, with both groups showing larger cueing effects for cues consistent with the explicit target color/predictive cue color than for cues inconsistent with the explicit target color/predictive cue color; incorrect response group (n=10 - 52 ms vs. 6 ms, \(t(9) = 4.5, p < .01\)) correct response group (n = 6, 55 ms vs. -3 ms, \(t(5) = 8.9, p < .001\)).

**Experiment 10b.** In Experiment 10b, the spatially predictive cue color was in opposition to the explicit set for color, and RT data is presented in Figure 18. For RTs, a significant main effect of cue validity was observed, \(F(1,15) = 13.9, p < .01, \eta^2 = .48\), indicating faster responses to validly cued than invalidly cued targets. The main effect of cue color was not significant, \(F = 2.45, p = .14\). In contrast to Experiment 10a, there was no significant interaction between cue color and cue validity, \(F < 1, p = n.s\), indicating that there was no difference in the magnitude of the cueing effect for either cue color.
Figure 17. Reaction time data from Experiment 10a. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Planned comparisons were performed between valid and invalid cues in each of the cue color conditions in order to assess cueing effects for 1) cues that were inconsistent with the target color but associated with the “spatially predictive” color, and 2) cues that were consistent with the target color and “spatially anti-predictive;”

Significant cueing effects were observed in both cases, $t(15) = 3.7, p < .01$, and $t(15) = 3.4, p < .01$, respectively. Analysis of error rates showed a pattern that mirrored that of RTs, with a significant main effect of cue validity, $F(1,15) = 18.1, p < .01, \eta^2 = .54$, but not cue color, $F<1, p = n.s..$, and a significant interaction between cue color and cue validity, $F(1,15) = 54.3, p < .0001, \eta^2 = .78$, indicating that the effect of the cue on error
rates depended on its color. Analysis of error rates showed no main effects or interactions.

Figure 18. Reaction time data from Experiment 10b. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

*Awareness analysis.* In this experiment, no observers accurately described the cue-color contingency accurately on the open-ended questions. Nine of the sixteen observers answered the 2AFC question regarding the target asymmetry correctly, with performance on this question therefore falling slightly above chance. Analyses in both groups showed results that paralleled those in observed in the aggregate, with neither group showing a difference in cueing effects on the basis of cue color; incorrect response
group (n=7 - 26 ms vs. 31 ms, t<1, n.s.) correct response group (n = 9, 29 ms vs. 34 ms, , t<1, n.s). As in the previous experiments, this provides strong evidence the asymmetry in capture effects observed across target colors did not depend on observers’ subjective awareness of the target-color asymmetry.

Discussion

The results of the current experiment provide a clear demonstration that learned contingencies can operate in a synergistic manner with explicit goals in order to drive feature-based control over capture effects. In Experiment 10b, the fact that green cues were more likely to predict the target location allowed them to continue to capture attention in the face of an explicit setting for the target color. Furthermore, the fact that the observers were able to learn these contingencies despite the fact that they were both explicitly told to ignore the distractor and search for a target of a particular feature suggests that the learning process operating in this task is not sensitive to explicit instructional manipulations. This provides further evidence for the automatic nature of both the learning and implementation of goal-directed control on the basis of feature regularities, and suggests an adaptive mechanism by which observers are able to pick up on environmental contingencies even when they do not explicitly attend to the dimension in which those contingencies occur (Saffran et al., 1997; Fiser & Aslin, 2001; 2002a; Turk-Browne et al., 2005; 2008; Chun & Jiang, 1998; 1999).

In addition to the results of Experiment 10b, the results of Experiment 10a provide evidence for an additive effect when learned contingencies are compatible with explicit goals related to the target. Specifically, a supplementary analysis (between subjects t-test) was conducted on the magnitude of the cueing effect when the cue
matched the target color in my replication of Folk et al., (1992) (Figure 10; mean cueing effect = 19ms) and that in Experiment 10a (mean = 54ms), and revealed a significant difference in the magnitude of the cueing effect \( t(26) = 3.7, p < .01 \). This supports the notion that features related to the target of search and those related to the distractors are learned independently, and can have independent and additive effects on the extent of attentional capture in this task.

**Chapter 3 Discussion**

The main purpose of the experiments in this chapter was to probe the necessity of explicit goals in establishing the feature-based control over capture that is a hallmark of a broad class of tasks used to study goal-directed attentional control. The results of Experiments 5-10 provide strong evidence that highly specific attentional control settings can be generated without explicit goals or intentions on the part of the observer. Instead, the visual system’s ability to extract probabilistic relationships between particular stimuli and the task-relevance of their defining features is sufficient for driving this type of control, and these relationships interact directly with explicit goals to determine the extent of capture. These results fit well with studies showing that visual learning can occur passively, without explicit awareness of (e.g., Seitz & Watanabe, 2003; Watanabe et al., 2001) or attention to (e.g., in an unsupervised manner; Fiser & Aslin, 2001; 2005; Turk-Browne, 2005; Chun & Jiang, 1998; 1999) the specific stimulus information being learned.

The results of Experiment 8 further showed that these implicitly learned contingencies affect attentional capture even when they are no longer present in the visual environment, suggesting that this information can be learned in a highly specific,
long-term manner and need not depend on any sort of intentional, voluntary process. In fact, the results of both Experiment 9 and Experiment 10 demonstrate that observers can 1) learn attributes of stimuli that they are explicitly told to ignore, even when this information doesn’t match their explicit set and 2) this information critically determines which incoming sensory information will capture attention and affect behavior. These results, taken together, begin to paint a much different picture of goal-directed control than that proposed by most common conceptualizations of attentional control that propose a central role for the voluntary allocation of attention on the basis of search goals or target information represented in working memory (Olivers, Peters, Houtkamp, & Roelfsma, 2011; Soto, Hodsoll, Rotshtein, & Humphreys, 2008; Theeuwes, 2010).

In particular, theories proposing that goal-directed control need be a voluntary process that operates through the active rehearsal of an attentional control setting or target template would predict that this process is both necessary and sufficient for effective goal-directed control, an idea that the experiments in Chapters 2 and 3 have provided little support for. Instead, based on these data I propose that the representations responsible for goal-directed control should be viewed as being more “holistic” and long-term in nature. Thus, these representations should necessarily be reliant on the visual system’s ability to extract and utilize relational information about attributes of stimuli in the environment regardless of whether the process occurs explicitly or implicitly. This is not to say that working memory processes or an observer’s intentions play no role in goal-directed control, but that, based on the current data, it appears that common mechanistic descriptions of control do not adequately address the inherent complexity of the representations driving efficient goal-directed behavior. Thus, it may be more
accurate to think of “short-term” processes related to an observer’s intentions as one component of a multifaceted control system that utilizes information from various sources, rather than the primary mechanism used to control attention on a moment to moment basis. This idea will be elaborated further in the General Discussion.
CHAPTER 4
CONTROL ON THE BASIS OF LEARNED CONTEXT

The experiments in the previous 2 chapters have demonstrated that goal-directed control can be viewed as an acquired skill, showing that experience with particular features of goal-relevant information is not only necessary but is also sufficient to drive goal-directed control even when this learning occurs over stimuli that are unrelated to the explicit goals of a task. Based on these results, I have argued that goal-directed control over capture may be best viewed as a long-term memory phenomenon, whereby the accumulation of experience with a task and its context are necessary to overcome distraction by salient, task-irrelevant information in the environment. Chapters 2 and 3 of this thesis have focused on how more local or “low-level” learning of feature properties affect goal-directed control over capture in a case where global task context is held more or less constant. However, it is likely that learned control is also affected by the learning of higher-order associative relationships between low-level stimulus attributes and the broader task context in which they were learned.

For example, at a global level features alone provide little information about goal relevance, given that the same features can be associated with multiple tasks, sometimes being relevant to task performance and other times not. Thus feature information in isolation is likely not enough to drive the instantiation of effective goal-directed control, with this ability necessarily relying on the association between features and the larger task context in which they occur. The primary goal of Chapter 4 is to examine the link between the types of learned control demonstrated in Chapters 2 and 3 and the context in
which such control is learned. A secondary goal of this chapter is to provide evidence that the learned control over capture demonstrated above generalizes to another popular task used to study attentional capture, Theeuwes’ additional singleton task.

Given that the bulk of the work in the capture literature uses a variant of either the Folk cueing task used in Chapters 2 and 3 or the additional singleton task employed here, demonstrating similar learning effects across tasks will provide strong evidence that the learned control view can reconcile theoretical differences in the capture literature, by showing similar effects across tasks that typically produce opposing results.

*The role of learned search strategies in goal-directed control*

In Chapters 2 and 3, Folk and colleagues’ “contingent capture” task was discussed at length, and this task has been used to provide the bulk of the evidence for my “learned control” view of capture. However, another popular task used to examine attentional capture is Theeuwes’ “additional singleton” task (Theeuwes, 1991; 1992; 1994). In this task, observers view a search display similar to that in Figure 19, and are asked to search a display for a target circle presented among homogeneous non-target items (usually diamonds), and report the orientation of a line contained inside of it. Critically, on half of the trials, one of the distractor items in the display is presented in red, generating a salient, task-irrelevant signal that the observer must ignore in order to find the target. Observers are always told in advance that to ignore the red item if it appears, because it will never appear at the target location. Despite this instruction, observers are slower to respond to the target when the salient distractor is present than when it is not. This result has been taken as evidence that the task-irrelevant item captures attention in a bottom-up manner, interfering with observers’ ability to shift attention to the target even though they
know that the salient distractor item will never be the target and thus should have a strong intention to ignore it (Theeuwes, 1991; 1992; 1994; 2004).

Figure 19. Theeuwes' additional singleton task. In this task observers are asked to search for a circle and report the orientation of a line contained inside of it, while ignoring a task-irrelevant color singleton distractor that appears on half of trials. Typically RTs are slower when a distractor is present than when it is absent.

Despite the fact that results from Theeuwes’ additional singleton task have been taken as strong evidence for stimulus-driven capture, subsequent studies have argued that elements of this task actually bias observers to employ goal-directed control strategies that are responsible for driving the capture observed in this task. Specifically, Bacon & Egeth (1994) argued that in this task, since observers are set to search for a target that is itself a shape singleton (i.e., it is a circle target among homogeneous diamond distractors), observers may adopt a “singleton search mode” whereby they explicitly search for the target based on its status as a shape singleton, rather than its defining feature. Importantly, they argued that this explicit goal to search for singletons in turn leads to capture by any singleton in the visual environment, and this is responsible for the
capture effect typically observed in this task (following the ideas advanced in Folk’s contingent involuntary orienting hypothesis).

The logic for such an interpretation is simple – in the additional singleton task, observers have the option of using either a *singleton search mode* in which they search for the “different shaped item” in the search display to locate the target, or a more specific *feature search mode* in which they search for the target defining feature, in this case a circle (Bacon & Egeth, 1994). Even though observers are typically told to search for a target matching a specific feature dimension, (e.g., “find the circle”) they may default to a singleton search mode, given that singleton detection is arguably less difficult for observers to implement than search for a specific feature (Bacon & Egeth, 1994; Leber & Egeth, 2006b; Kawahara, 2010). Thus it is possible that when given the option to use either the easier singleton detection strategy or the more difficult feature-search strategy, observers opt to use the less demanding singleton detection strategy. Observers’ “set” for different items may in turn allow the singleton to capture attention, producing the characteristic slowing of RTs on distractor present trials.

In order to provide evidence for such an interpretation, Bacon & Egeth (1994) had observers perform a task similar to that used by Theeuwes (1992), but manipulated the strategies available to observers to perform the search task. Specifically, observers performed either a version of the task identical to that used in Theeuwes (1992) where they were asked to search for a singleton circle target among homogeneously shaped diamond non-targets, or a similar version in which the target was still a circle but the non-targets were heterogeneous (diamonds, triangles and squares, Figure 20), thus eliminating the target’s status as a singleton and the option of using a singleton search
mode. The logic of such a manipulation is that as the search display increases in heterogeneity, the singleton detection strategy is no longer an effective means for finding the target, since the target is no longer a singleton. This forces a shift in the attentional control settings used by observers to find the target, from a more general “singleton search mode” (i.e., search for the different item) to a more specific “feature search mode” (i.e., search for the circle).

![Figure 20](image)

Figure 20. Bacon & Egeth's (1994) adapted version of the additional singleton task.

Bacon & Egeth (1994) showed that when observers were allowed to adopt a singleton search mode (displays similar to figure 19), the presence of task-irrelevant color singletons slowed responses to the target, replicating the results of Theeuwes (1992). However, when observers were forced to adopt a feature-search mode (displays similar to Figure 20), the task-irrelevant color singleton failed to capture attention, consistent with the view that capture in Theeuwes’ task is under top-down control (Bacon & Egeth, 1994; Leber & Egeth, 2006a). These results suggest that attentional capture by color singletons is contingent not only on goals that include a search for specific feature values
(e.g., Folk et al., 1992), but also on the more abstract search strategies employed by observers (e.g., Bacon & Egeth, 1994). This ability to alter observers’ search strategies on the basis of changes in display properties (specifically, changes in the identity of the no-target items) will be the primary focus of the experiments outlined below.

Evidence for task-specific learning of Search Modes

A handful of recent studies have indicated that the search strategies described above can be learned in a long-term manner (Leber & Egeth, 2006a; 2006b; Leber, Kawahara, & Gabari, 2009). For example, Leber & Egeth (2006a), showed a transfer of learned search strategies across tasks. In their study, Leber & Egeth (2006a) had one group of observers train on a “singleton search” task where they were instructed to search for the differently shaped target item, and another group train on a “feature search” task where they were instructed to search for a specific target item (a circle), in both cases reporting the orientation of a line contained within this target shape (see sample displays in Figure 21). Following training, observers in both groups participated in a testing phase (so called “option” trials) where they performed a similar search task in which there was an option of using either the more general “singleton search mode” or the more specific “feature search mode.” Importantly, instructions for both groups were identical in the testing phase – all observers were always told to search for the green circle and report the orientation of a line presented inside of it. These were termed “option” trials because the circle target was always embedded in an array of homogeneous non-target items, and as a result observers could use either a “feature search” strategy where they searched for the particular target feature (a circle) or the more general “singleton search” strategy, where they searched for the differently shaped item to find the target. Of primary interest was
whether observers in each training group would continue to use the strategy they had used during training, leading to systematic differences in capture effects across the two groups in the testing session.

Figure 21. Example of the task used by Leber & Egeth (2006) to examine carryover of search strategies. During the training session, one group of observers always searched for a specific target (the circle) among heterogeneous non-targets, and another group always searched for the “different shaped” item among homogeneous non-targets. During testing both groups searched a homogeneous display for circle target, and thus had the option of using either strategy. Of interest was whether learning a particular strategy during training would cause observers to use the same strategy in the testing session.

The results of this experiment showed that observers who had trained on the
singleton search task were captured strongly by the task-irrelevant color singleton
distractor during the testing phase, but that those who had trained on the feature search
task showed no evidence of capture. This asymmetry in capture was observed despite the
fact that during the testing phase the search task and instructions were identical between
the two groups, suggesting that observers who trained on the feature search task learned a
“feature search strategy” and employed such a strategy even in displays that would allow
the use of the simpler singleton search strategy. Importantly, such an effect was not the
result of some sort of conscious, perseverative bias resulting from the close temporal
proximity between training and testing sessions – if training and test sessions are
separated by delays of one day or one week, a similar pattern of data is observed (Leber,
Kawahara, & Gabari, 2009).

Based on this data, Leber and colleagues have argued that observers learn specific
strategies for implementing goal directed control in a long-term manner, and have
proposed that this learning may be context dependent (Leber et al., 2009). For example,
learning to use a particular search strategy in a particular context may bias their choice of
strategy upon future encounters with a similar task context – even if the learned strategy
is arguably more effortful than other strategies at their disposal (Leber & Egeth, 2006a;
2006b; Kawahara, 2010). Such an interpretation fits with the types of “context
dependent” learning effects demonstrated in the memory literature, and raises the
possibility that context can directly affect attentional capture.

However, although the results of Leber and colleagues demonstrate that strategy-
specific learning can influence the effectiveness of control across situations, they did not
provide a direct test of whether these specific cognitive strategies can come to be linked
with a particular behavioral context, and testing this possibility will be the focus of the experiments in this chapter. Before jumping into the current experiments, it is worth briefly reviewing previous studies of context learning in order to better frame the approach I will take to examining contextual influences on visual distraction in this chapter.

The effect of context on learning, memory, and attention

The study of how context affects learning and memory processes has a long history, with a number of studies examining the influence of contextual information on the formation and retrieval of memories (e.g., Carr, 1925; Dallett & Wilcox, 1968; Godden & Baddeley, 1975; for reviews see Smith, 1988; Smith & Vela, 2001). Generally, these studies have shown a tight linkage between learned information and the context in which it is learned, and in later work context has been shown to affect memory in such disparate tasks as maze learning in rats (Carr, 1925; see Ainge, Dudchenko, & Wood, 2008 for a review), basic discrimination learning (Wright & Shea, 1991), word list learning (Godden & Baddeley, 1975; 1980), visual search (Chun & Jiang, 1998), and task-switching (Mayr & Bryck, 2005; Leboe et al., 2008; Crump & Logan, 2010).

In a now classic study, Godden & Baddeley (1975) provided one of the first direct tests of whether memory recall is affected by changes in learned context. Godden & Baddeley had trained divers listen to word lists either on the shore or under water, and then asked them to recall as many words as possible from the lists. The primary finding was that whereas recall was unaffected by initial learning environment (i.e., memory was as good when lists were learned and recalled under water as they were when they were learned and recalled on shore), recall performance was significantly lower when
observers were asked to perform the recall task in a different context than that in which the list was initially learned. In other words, recall performance was highly context dependent even though the context in which the memory task was learned had nothing to do with the primary goal of the task. These effects of environmental context on learning and recall have been subsequently demonstrated across a number of domains, arguing for a powerful role of context on learning and memory (see Smith & Vela, 2001 for a review and meta-analysis).

Whereas context effects have been demonstrated numerous times in studies examining basic learning and memory processes, there have been very few examinations of the effects of context on attentional processes. However, as noted in the introduction there has recently been intense interest in how spatial context affects the allocation of attention using the so-called “contextual cueing” task (Chun & Jiang, 1998). Recall that in this adapted visual search task that the spatial layout of targets and distractors are repeated for some displays but not others. Under these conditions, observers learn information about the spatial positions of targets and distractors in the repeated displays and use this information to increase the efficiency of search despite having no explicit knowledge for these target distractor relationships. In this case, experience with particular contexts can affect the deployment of attention in scenes, such that previous experience with specific search contexts can facilitate future performance. Similar phenomena have been demonstrated during natural scene viewing, where observers tend to use contextual information to guide search toward regions of a display in which particular information is likely to be found (e.g., when told to search for a traffic light in a street scene, observers often preferentially scan the upper region of the display; Torralba
et al., 2006; Neider & Zelinsky, 2006; see also Hollingworth, Weeks, & Henderson, 1999).

However, there has been some debate over whether these context effects are the result of memory for relationships between local items in a display (i.e., the “target” of search and immediately surrounding items; Brady & Chun, 2007; Jiang & Wagner, 2004) or the global properties of the display (i.e., the spatial gestalt of the arrays, including all items and their locations; Brockmole, Castelhano, & Henderson, 2006). A recent study by Brooks, Rasmussen, & Hollingworth (2010) showed that the types of contextual effects noted above appear to depend directly on the global contextual properties of the display, so long as this context is relatively stable.

In their study, Brooks et al. (2010) had observers perform a typical contextual cueing task (e.g., Chun & Phelps, 1998), but during learning manipulated the global context in which the search array appeared by embedding the arrays within a task irrelevant scene. In this way, Brooks et al. (2010) were able to decouple the local information coding for relationships between features, objects, and their locations from the more global scene properties. During a transfer session, observers saw both novel and previously learned search arrays, and learned search arrays were embedded within either the scenes in which they had originally been learned or in a novel scene.

The primary finding of interest for the current work is that in this transfer session robust contextual cueing effects were only observed when the repeated arrays were presented in their learned (scene) context, despite the fact the spatial relationship between individual items in the search array was identical in both cases. In other words, normal contextual cueing effects were observed only when the global context was maintained
across training and test. This suggests that learned information regarding particular objects of interest in a scene (e.g., color, location, identity) is coded within a specific global context. Of interest in the current experiments is whether, in addition to linking particular stimulus attributes (i.e., the identity and location of items) to particular environmental contexts, the attention system can also link specific types of cognitive control strategies to specific contexts, and whether this can directly influence the extent of capture. Since multiple cognitive strategies exist, and these strategies often vary systematically with the environment, or context in which they are performed, it seems likely that a great deal of cognitive control may occur on the basis of these types of learned strategy-context associations.

Overview of Current Experiments

Given that previous work has shown that there are at least two possible search modes available to observers in the additional singleton task (Bacon & Egeth, 1994), and that the choice of which is employed can be influenced by experience (Leber & Egeth, 2006a; 2006b), this task provides a means for assessing whether particular search strategies (and subsequent capture effects) can come to be linked with specific task contexts, much in the way that learned context can affect the recall of basic information such as word lists (a la Godden & Baddeley, 1975), or spatial relationships (Brooks et al., 2010). In the following experiments, I was interested in whether context could influence the choice of cognitive strategy and subsequent susceptibility to capture by task-irrelevant information. More specifically, if observers encounter a situation in which multiple search strategies can be used to perform a task, as in the option trials of Leber & Egeth (2006a), will simply reinstating the context in which a particular strategy was
learned lead to an automatic activation of the associated search strategy?

In the experiments below, I used a task nearly identical to that used by Leber & Egeth (2006a), combined with a scene-context manipulation similar to that used by Brooks et al., (2010). Whereas Leber & Egeth (2006a; 2006b) had different groups of observers train on the use of different search strategies to examine how this training influenced choice of strategy and capture effects during an “option” task in which either strategy could be employed, I was interested in whether, within an individual, the choice of strategy in the option task can be influenced by learned context-strategy associations.

In Experiments 11 and 12, observers completed a training session in which they were trained to use both singleton and feature search modes, with each search mode being paired with a specific context (i.e., on each trial the search task was embedded within a task irrelevant scene as in Brooks et al., 2010). During testing, observers performed the same “option” search task employed by Leber & Egeth (2006a) in order to assess choice of search mode. Importantly, during testing the search display was embedded within scenes that had been paired with one of the two search modes during training. In both experiments, the central question was whether during these “option” trials if the choice of search mode (and thus the extent of capture) would depend directly on the task-irrelevant scene in which the search array was embedded.

**Experiment 11**

In Experiment 11, during training observers alternately performed blocks of “feature search” trials in which they were told to search for a specific shape and “singleton search” trials in which they searched for the “different” shape. Importantly, each type of search was linked with a specific set of task-irrelevant scene surrounds.
During testing, observers performed “option trials” in which they were always told to search for a circle target in an array of homogeneous diamond non-targets, and this search array was embedded within task irrelevant scenes that matched those paired with either feature search or singleton search modes during training (see Figure 22).

![Schematic diagram of the task used in Experiment 11](image)

Figure 22. Schematic diagram of the task used in Experiment 11. During the training session, observers alternated between singleton search and feature search blocks, and each type of search was paired with a unique set of images. During testing, observers always searched a homogeneous array of non-targets for a circle, and thus had the option of using either a singleton search or feature search strategy. Of interest was whether the task-irrelevant images associated with each strategy during training would cause observers to re-instantiate the associated search strategy during the option trials. Of primary interest was whether, in these option trials, the appearance of a scene
previously associated with only one of the two trained search modes would be sufficient to bias search strategy on a trial by trial basis. Given that capture effects are larger when observers employ a singleton search mode relative to a case in which they employ a feature search mode, if scene context can directly influence choice of search strategy, capture effects in option trials should be larger for trials in which the search array is embedded in a scene that was associated with “singleton search” strategy during training relative to when the array is embedded in a scene that was associated with “feature search” strategy during training.

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 22. A white fixation dot with a diameter of 0.3° was positioned at the center of the screen. Search displays consisted of six outline shapes equally spaced around the circumference of an imaginary circle with a radius of 3° that was centered around fixation. The outline shapes were drawn with a stroke of 0.1° 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 outline shapes were colored green (0, 255, 0), except for the singleton distractor, which always appeared in red (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 x 768) photographs of either forests or city streets (3 photographs from each class, for a
total of 6 individual photographs). On each trial, search displays appeared within a $10^\circ \times 10^\circ$ black box centered on each photograph.

**Design.** During the training phase, observers performed a version of the additional singleton task using two different search strategies, in separate blocks of trials. During “singleton search” trials, observers were instructed to search for the *different shaped* item on each trial, and this item could be either a circle, square, or diamond, chosen randomly on each trial. The target was always presented among a homogeneous array of six diamond-shaped non-targets, allowing the target to “pop-out” from its background. During “feature search” trials, observers were instructed to search for a circle on each trial, and the target was always presented among a heterogeneous array of six non-target items, which always included at least one diamond, one square, and one triangle, with the other two non-targets being chosen at random on each trial with the constraint that both items weren’t the same shape. On half of the trials, one of the non-target items (identity and location chosen randomly), appeared in red as a salient color singleton distractor.

In both the singleton and feature search trials, the spatial positions of target and distractor items were randomly determined, and each item in the display contained a white line segment oriented either horizontally or vertically, with observers’ response being to report the orientation of the line contained within the target item on each trial. Importantly, during training feature search and singleton search trials the search arrays were always embedded within scenes of a specific category. For example, half the observers always performed singleton search trials embedded within “forest” scenes, and
feature search trials embedded within “city street” scenes, with the other half of observers receiving the opposite pairing.

The testing phase was similar to the training phase, but during testing observers were told to search for a circle target on every trial, and the target was presented among an array of homogeneous diamond shaped non-targets items. Thus in the testing phase, either search strategy provided an effective means of locating the target – observers could either search for the “different” item or for the specific feature that defined the target (a circle). During testing, the search arrays were always embedded within either the forest or street scenes encountered during training, but in this case the scenes were intermixed and presented pseudo-randomly and equiprobably on each trial. As in the training session, on half of the trials, one of the non-target items (identity and location chosen randomly) appeared in red on as a salient color singleton distractor. 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 observers’ choice of search strategy toward that associated with the scenes during training.

Procedure. As described above, during the training phase observers were instructed to search for either a different shaped item among homogeneous non-targets (singleton search condition) or a specific shape (a circle) among heterogeneous non-target items (feature search condition), ignoring the salient distractor when it appeared. In both cases, 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, with each key corresponding to either horizontal or vertical line orientation, counterbalanced across
observers. The search array was always embedded within a task-irrelevant scene from one of the two categories, with each scene category being paired with a specific type of search. At the beginning of each trial, the task irrelevant scene appeared along with the empty black box that would eventually contain the search array, for 1000ms. Next, the search array appeared for 1500ms or until observers responded, whichever came first, with trials in which observers failed to respond within 1500ms being counted as errors. Observers performed 4 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.

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 always embedded within the same forest or street scenes as during the training sessions, but in this case scene identity was chosen randomly on each trial. Observers completed 3 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 reaction time (RT) and data for each portion of the experiment are shown in Figure 23 (training data), and Figure 24 (testing data), and both RT and error rate data are shown in Appendix C. Reaction time (RT) and error rate data from both the training and testing portions of Experiment 11 were entered into separate two factor ANOVAs, with the factors Search Type (singleton vs. feature) and
distractor presence (present vs. absent) for the training data, and Scene Type (associated with singleton vs. associated with feature search) and distractor presence (present vs. absent) as factors for the testing data.

**Training Data.** For training data, a significant main effect of search type was observed, $F(1,16) = 53.2, p < .001, \eta^2 = .77$, indicating faster overall responses on feature search (780ms) than on singleton search (1,028ms) trials. This is consistent with previous studies showing that search for a known target feature is faster than search for an unknown target feature (Bravo & Nakayama, 1992; Leber & Egeth, 2006a). The main effect of distractor presence was also significant, $F(1,16) = 53.2, p < .001, \eta^2 = .77$, with slower RTs on trials in which a distractor was present (923ms) vs. when it was absent (886ms). Importantly, 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, 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, $t(16) = 1.5, p = .15$. For the error rate data, no significant main effects or interactions were observed. These results indicate that the manipulation of search type was effective in modulating capture by a salient distractor, replicating previous studies using similar search tasks (Bacon & Egeth, 1994; Leber & Egeth, 2006a).
Figure 23. Data from the testing session of Experiment 11. In the feature search condition, observers searched for a circle among heterogeneous non-targets. In the singleton search condition, observers searched for a “different shaped” target (either a circle, square or triangle on a given trial) among homogeneous diamond distractors. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Testing Data. 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, a significant interaction between scene type and distractor presence was observed, $F(1,16) = 6.0$, $p < .03$, $\eta^2 = .27$, 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 in both cases. 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 in which the scene matched those associated with feature search during training, \( t<1, \text{n.s.} \). There were no significant main effects or interactions in the error rate data, \( F<2.4, \text{ps}<.14 \).

Figure 24. Reaction time data from the testing portion of Experiment 11. 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 feature search or singleton search during the training session. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

**Discussion**

These results demonstrate a clear influence of learned context on choice of search strategy, directly influencing the likelihood of capture. Scenes associated with singleton search during training biased observers to use a singleton search mode during the option
trials, as evidenced by larger capture effects in this condition. Conversely, scenes associated with feature search mode during training biased observers to use a feature search mode during the option trials, evidenced by the lack of capture effects in this condition. The fact that the choice of search strategies could be directly influenced on a trial by trial basis simply by reinstantiating particular contextual information demonstrates the high level of specificity in the types of representations that drive the learned control effects demonstrated here. This parallels results showing similar effects of context on basic learning and memory processes, and provides support for the notion that through experience, observers can learn to link particular search strategies with particular contexts, even when the context itself is not directly relevant to performing the task at hand (e.g. as suggested by Leber et al., 2006b, 2009).

Furthermore, the fact that main effect of search type on overall RTs during training but not during testing suggests that the control processes responsible for the context-dependent modulation of distraction are at least partially separate from those involved in search. Recall that the common explanation for the asymmetry in capture for feature and singleton search strategies has to do with how the observer chooses to search for the target – forcing an observing to search for a target on the basis of a particular feature eliminates capture by salient distractors that don’t match this feature (Bacon & Egeth, 1994). Although this explanation makes intuitive sense, if solely because the search instructions differ between the singleton (“search for the different shape”) and feature search (“search for the circle”) conditions it has not received definitive support, leaving such an effect open to alternative explanations.

Specifically, in addition to differences in the strategy used to find the target in
feature and singleton search tasks, there is also a difference in the stimuli composing the
search arrays in each of these tasks. As a result, it may be these differences in the
composition of the search arrays, rather than the explicit strategy employed by observers
that may alter the effectiveness of control in each case. Specifically, during singleton
search observers always search for a target through homogeneous non-target items, and
during feature search observers always search through heterogeneous non-target items.
As a result, a confound exists between the instructed search strategy (search for circle vs.
search for different item) and the display properties of each task. This makes it difficult
to tell if the differences in capture between these tasks result from differences in the
explicit strategies used by observers differences related to the search arrays themselves
(see Theeuwes, 2004 for a similar argument).

Such a distinction is not trivial, because both search efficiency and subsequent
distractor processing have been shown to depend on display properties, such that
heterogeneous search displays engender more effective goal-directed control over
distractor processing than homogeneous arrays (e.g., Duncan & Humphreys, 1989; 
Northdurft, 1993; Torralbo & Beck, 2008; Beck & Kastner, 2009; Cosman & Vecera, 
2009; 2010a; Roper, Cosman, Mordkoff, & Vecera., submitted). This difference has
been proposed to result from differences in competitive stimulus-stimulus interactions in
visual cortex, with goal-directed control being increasingly effective as these lower-level
competitive interactions increase (Beck & Kastner, 2005; 2009; McMains & Kastner, 
2011). Specifically, in homogeneous search arrays in which the target “pops out” and
there is very little bottom-up competition, goal-directed control processes have been
shown to operate only weakly. This, in turn, may lead to an increase in distractor
processing because the salient distractor is better able to compete with the target in the absence of strong top-down mechanisms that resolve competition in favor of the target. In contrast, in heterogeneous search arrays there is a great deal of competition for representation, and as a result top-down control processes operate more effectively to resolve competition in favor of the target, leading to less distraction by task-irrelevant distractors (Reynolds & Desimone, 2003; Beck & Kastner, 2008; 2009; McMains & Kastner, 2011). This same logic could be readily applied to explain both the results of Bacon & Egeth (1994), as well as the results of Experiment 11. In Experiment 12, I attempted to differentiate between these possible alternatives, as well as extend the results of the current experiment, using an adapted version of my context learning task.

**Experiment 12**

In Experiment 12, I used a design similar to that in Experiment 11, adapted to de-confound search instructions (search for the different item vs. search for the circle) from the differences in the search arrays in feature search and singleton search tasks. During training, homogeneous and heterogeneous search arrays were paired with either forest or street scenes as in Experiment 11. However, in the current experiment I held task instructions constant across training, such that observers were always told to search for a circle target appearing within either heterogeneous or homogeneous search arrays. This design enabled me to examine the same context-dependent effects on capture as those examined in Experiment 11, but in relation to display type rather than explicit search mode. Furthermore, in the current experiment homogeneous and heterogeneous displays were intermixed during training, allowing us to examine whether the segregation of each
search type (into separate blocks of trials as in Experiment 11) during training is a necessary precursor for the emergence of context-dependent control effects.

If context dependent modulation of capture is observed during the test session, similar to Experiment 11, then I can conclude that the differences in capture effects observed in feature and singleton search tasks is due to stimulus differences across the two tasks, because the search strategy was held constant throughout training and test. Furthermore, if effects similar to those in Experiment 11 are seen in the current “intermixed” design, it will provide stronger evidence for context dependent control by showing that the two search strategies need not be segregated from one another during training in order to be linked effectively with a given context. However, since it’s possible (though unlikely) that such a replication could also arise by observers intentionally switching search strategies on a trial to trial basis during training, observers completed a brief questionnaire following the training task to assess the strategies they employed during the training session.

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 & Procedure. The stimuli and procedure were identical to those in Experiment 11, with the exception that during training observers were always told to search for a circle target. I varied the composition of the non-target items in the search arrays in a manner identical to that in the singleton and feature search conditions in Experiment 11, such that observers always searched for a circle target through either
homogeneous (all diamond non-targets) or heterogeneous (diamonds, squares, and triangle non-targets) arrays. Importantly, during training homogeneous arrays were always paired with one type of scene and heterogeneous arrays were always paired with the other (forest vs. street scene, counterbalanced across observers). Furthermore, given that the search target was constant across the entire experiment, I was able to provide a stronger test of the automaticity of this type of control by intermixing search types, such that on any given trial observers were equally likely to perform the search through either homogeneous or heterogeneous arrays. The testing session was identical to that in Experiment 11. Thus the only difference between the current experiment and Experiment 11 is that in this experiment observers were always explicitly told to search for a circle and search type was entirely intermixed during training.

In Experiment 12, observers were also given a questionnaire in order to assess the strategies used to perform the search task during the training session. For example, it is entirely possible that observers realize during training that they can use singleton search in some arrays, whereas in other arrays they need to search for the specific feature. Although this strategy seems unlikely, following the training block observers were probed on the strategies they used to perform the search task. First, they were given an open ended question and asked if they used any strategies to find the target during the search task, and it was stressed that this applied to the entire search task, including training and test sessions. Following their response to the open ended question, they were asked “which of the following strategies best describes how you searched for the target during this task,” and were given the choice of selecting 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. Thus, of primary interest were observers’ answer to the final question of the questionnaire.

As in Experiment 11 Observers performed 144 training trials for each search type, or 288 total training trials. Observers then completed 3 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 reaction time (RT) data for each portion of the experiment are shown in Figure 25 (training session) and Figure 26 (testing session), and both RT and error rate data appear in Appendix C. Reaction time (RT) and error rate data from both the training and testing portions of Experiment 12 were entered into separate two factor ANOVAs, with the factors Search Type (homogeneous non-target vs. heterogeneous non-targets) 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 to those made in Experiment 11.

**Training Data.** For training data, there were trends toward significant main effects of search type, $F(1,14) = 3.9, p < .06, \eta^2 = .23$, indicating faster overall responses when searching through homogeneous arrays (654ms) compared to heterogeneous arrays (667ms), consistent with previous studies showing a decrease in search efficiency in heterogeneous arrays (Duncan & Humphreys 1989). The main effect of distractor presence also approached significance, $F(1,14) = 4.0, p < .06, \eta^2 = .23$, with slower RTs
Figure 25. Reaction time data from the training portion of Experiment 12. In this task, observers always searched for a circle, but on 50% of the trials the non-targets were homogeneous (all diamonds), and on 50% of trials the non-targets were heterogeneous (diamonds, squares, or triangles). Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

on trials in which a distractor was present (665ms) vs. when it was absent (656ms).

There was no significant interaction between search type and distractor presence, $F<1$, n.s.. However, given my specific interest in the presence vs. 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 the homogeneous search condition, $t(14) = 2.2, p = .04$, but not the heterogeneous search condition, $t(14) = 1.0, p = .32$, replicating
the asymmetry in capture effects seen in Experiment 11, as well as previous studies using a similar task (Leber & Egeth, 2006a; Bacon & Egeth, 1994). There were no main effects or interactions in the error rate data, all $F$s<1.

![Figure 26](image.png)

Figure 26. Reaction time data from the testing portion of Experiment 12. 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 heterogeneous search arrays or homogeneous search arrays during the training session. Error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

**Testing Data.** For the testing data, there was no main effect of scene type, $F$<1, n.s., but a main effect of distractor presence was observed, $F(1,14) = 16.1$, $p = .01$, $\eta^2 = .54$, with faster RTs on singleton absent trials (570ms) than singleton present trials.
Additionally, a significant interaction between scene type and distractor presence was observed, $F(1, 14) = 4.6, p < .05, \eta^2 = .25$, indicating that the effect of the singleton distractor varied as a function of the type of scene in which the search array was embedded. 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 feature search during training, $t(14) = 1.3, p = .22$. There were no significant main effects or interactions in the error rate data, $Fs<1.3, ps<.26$.

*Questionnaire Data.* For the questionnaire data, no observers described using a complex switching strategy during training in the open-ended question, nor did any observers choose the “both” option when given explicit choice of strategies. This argues that it is unlikely observers used an explicit “rapid-switching” strategy during training. Data from the more specific question generally supported the prediction that most observers would search for a specific feature as instructed, with 10 of 15 observers selecting “searched for the circle” from the list of possible strategy choices. The remaining 5 observers selected “searched for the different shaped item.” This answer may seem odd given that observers searched heterogeneous arrays on 50% of trials, however even in the heterogeneous search displays such a strategy is plausible because the circle is the only shape with round edges (it appeared among triangle, square and diamonds distractors). Although it is not clear how this difference in strategy during training would systematically affect the current results, in order to determine whether this difference in strategy affected performance, I performed planned comparisons on capture effects for each search condition within each group during the test session. Consistent
with the notion that the context effects observed in the current experiment are not due to
differences in search strategies used by observers during training, in both groups there
was a significant interference effect when the search array was embedded within scenes
associated with search through a homogeneous array, (“searched for circle group” - $t(4) = 3.4, p = .02$, “searched for different shape” group - $t(9) = 3.9, p < .01$), whereas there
were no significant capture effects when the search array was embedded within scenes
associated with search through a heterogeneous array (in both groups $ts < 1, n.s.$).

Discussion

These data provide a general replication of those observed in Experiment 11,
showing that observers can come to link particular search strategies with specific contexts
through experience. The fact that this effect was observed even though observers’
explicit search goals were held constant across the entire task (i.e., they were always told
to search for the circle), and observer’s did not appear to use a rapid switching strategy to
search for the target, seems to suggest that the form of context-specific goal-directed
control learned in this task does not rely on explicit, intentional processes related to the
target of search (e.g., as proposed by Bacon & Egeth, 1994; Leber & Egeth, 2006a;
2006b).

Instead, it appears that characteristics of the search arrays themselves can cause a
change in the effectiveness of goal-directed control, altering the likelihood of capture.
Specifically, it appears that there is an increased likelihood of capture by an irrelevant
distractor when searching through homogeneous, as opposed to heterogeneous, search
arrays. This fits well with previous work showing increased distractor processing when
competition between stimuli in a search array is reduced (Torrlabo & Beck, 2008;
Cosman & Vecera, 2009; 2010; Roper et al., unpublished) or the scale of attention is increased (Theeuwes, 2004; Belopolsky et al. 2007; 2010). Thus it appears that searching through heterogeneous and homogeneous search arrays can fundamentally alter the effectiveness of goal-directed control over capture, and given sufficient experience performing each type of search in different “contexts,” these changes in goal-directed control can come to be linked with particular behavioral contexts to influence future behavior.

Chapter 4 Discussion

Taken together, the results from Chapter 3 demonstrate that learned context can directly affect the extent of capture. In a case where multiple strategies for performing a search task are available, the strategy observers choose to use is dependent on the context in which the task is performed; if the context matched that associated with a search for a singleton target among homogeneous non-targets, capture was increased relative to a case in which the context matched that associated with a search for a specific feature among heterogeneous distractors. This provides an extension of work showing that contextual information can influence basic memory and attention processes (e.g., Godden & Baddeley, 1975; Chun & Jiang, 1998) by showing that, within a task and within an individual, context can synergistically affect both memory and attention processes to determine the extent of attentional capture by salient, task irrelevant distractors. Thus, in addition to goal-directed control on the basis of learned associations between particular stimuli and relatively low-level visual information (e.g., basic color features, as in Chapters 2 and 3), control can also be driven by higher-level associations between a task and its learned context.
This ability to link particular search strategies with specific contexts could be considered adaptive, in that it provides the attentional system flexibility in the types of long-term representations that contribute to goal-directed control across different situations. For example, in Chapters 2 and 3, I showed that learned associations between specific features and their relevance to performing a task could modulate capture effects - when searching for a target that happened to be red on a large proportion of trials, red items became more likely to capture attention, whereas non-red items became less likely to capture attention. This is similar to previous studies of visual learning that have demonstrated a high level of specificity in the types learned representations that contribute to experience-dependent visual performance improvements (e.g., Ball & Sekuler, 1981; Fahle, Edelman, & Poggio; 1995; Crist, Li, & Gilbert, 2001; Seitz et al., 2005). As important as this specificity is, it could also be detrimental if it were unaffected by the context in which learning occurred, because relevance is a relative term – things that are relevant in some situations are irrelevant in others, and vice-versa. Thus, the context-dependent nature of learned control allows the visual-attentional system to tune to specific low-level visual properties, while at the same maintaining the flexibility to cope with the constantly changing task demands encountered in daily life (see, e.g., Petrov, Dosher, & Lu, 2005; Crist, Kapadia, Westheimer, & Gilbert, 1997, for evidence of context specificity in traditional visual perceptual learning tasks).

Additionally, the acquisition of these context-dependent strategies need not be explicit, with these associations arising in a more or less automatic manner on the basis of experience with particular stimulus attributes. Even when observers search for the same target-defining feature throughout training and test, differences in the stimulus properties
of the search displays (homogeneous vs. heterogeneous non-target items) lead to
differences in the effectiveness of goal-directed control over capture, and these
differences can be retained and used to affect the likelihood of capture in the future. This
argues against the view that the asymmetric patterns of capture seen between observers
employing singleton search and feature search strategies are solely the result of an
explicit goal to search for singletons or features per se (e.g., Bacon & Egeth, 1994; Leber
& Egeth, 2006a), further questioning the distinction between stimulus-driven and goal-
directed control as automatic and intentional processes, respectively.

Instead, it appears that differences in search demands between singleton and
feature search tasks lead to differences in goal-directed control processes responsible for
target selection and distractor rejection, in turn affecting the strength with which goal-
directed control processes operate across tasks (Duncan & Humphreys, 1989; Theeuwes,
2004; Beck & Kastner, 2008; Torralbo & Beck, 2008). Taken together, the results of
Chapter 4 provide a means by which experience with specific stimulus attributes can lead
to changes in the operation of goal-directed control processes, and these changes can
come to be linked with particular task contexts. Importantly, as in the previous chapters,
it appears that experience is the key to driving these effects, and that the explicit search
goals of an observer have little bearing on how effective goal-directed control processes
are at overcoming distraction by salient, task-irrelevant information.
CHAPTER 5
EXAMINING THE MEMORY MECHANISMS UNDERLYING LEARNED CONTROL

In Chapters 2-4, I have attempted to establish a central role for task-specific learning in overcoming visual distraction, showing that goal-directed control over attentional capture can emerge over time as a result of experience with the visual environment. This implicates a close relationship between the attentional processes responsible for instantiating goal-directed control and the long-term memory processes supporting the acquisition and maintenance of learned behaviors. Based on the behavioral data presented above, it is possible to make some predictions about the learning mechanisms involved in generating each of these effects.

First, as was demonstrated in Chapters 2 and 4, learning can occur over specific attributes of stimuli used in a given task. In Chapter 2, capture effects depended on experience with specific distractor identities, suggesting that associative learning processes are directly involved in learned control over capture. In Chapter 3, a similar associative learning process was shown to occur for both target and distractor defining features, but in this case the associations were learned on the basis of implicit probabilistic relationships between these items and their defining features. Thus, in addition to basic associative learning processes that are necessary for linking particular task attributes to one another (as in Chapter 2), processes involved in probability learning were also at play in the learning effects observed in the experiments in Chapter 3.

Second, in Chapter 4 I showed that observers can come to link particular search strategies with particular environmental contexts through experience, and that this context-dependent learning effect directly influenced the likelihood that a salient
distractor would capture attention. Thus, in Chapter 4, in addition to learning information about specific features of a task (as in Chapters 2 & 3), observers had to link this information, as well as particular high-level search strategies, with the context in which they were learned. Thus it appears that learning can occur at two specific levels of processing in the visual system, one that operates over relatively low-level feature information (e.g., color or location) and another in which learned strategies become associated with the context in which they are performed. As I have argued above, in combination these two processes can account for a great deal of the specificity (or lack thereof) in selective attention mechanisms across tasks, and as a result viewing goal-directed control as an emergent property of basic learning mechanisms provides a parsimonious way of synthesizing disparate results from the attentional capture literature.

This proposed linkage between selective attention and memory processes necessarily implies that the neural mechanisms participating in basic learning and memory phenomena should also play a role in experience-dependent goal-directed control. The motivation for the learned control view advocated here came primarily from studies of basic visual and skill learning, with the current work trying to better understand how different forms of visual learning may support specific skills such as the ability to overcome distraction. Given that a great deal is known about the neural systems that subserve the different types of learning described in the previous two paragraphs, it is possible to make some predictions regarding the role of different memory systems in the types of learned control observed in the experiments in Chapters 2-4.

Given my emphasis on the fact that learned control appears to rely on learned relationships between elements of a task, their probability of behavioral relevance, and
their learned context, it seems plausible that memory systems involved in acquiring and maintaining these particular types of information would play a role in experience-dependent goal-directed control. In particular, the medial temporal lobe (MTL) system has been implicated in each of these processes, and as a result may be necessary for successfully generating the types of holistic task representations responsible for instantiating learned control. As I have demonstrated throughout this thesis, in a typical attentional capture task attributes of targets, non-targets, and salient distractors, (including their identities, surface features, and possible locations), their relevance to task performance, and the context in which the task is carried out can come to be associated with one another to support goal-directed control over distraction. Thus the mechanisms responsible for learned control must have the ability to link disparate sources of information with one another into a bound representation that can be used to guide behavior.

This description is entirely consistent with the role of the medial temporal lobe system, which has been proposed to play an important role in general relational and associative learning (see Cohen & Eichenbaum, 1993; Davachi & Wagner, 2002; Mayes, Montaldi, & Migo, 2007; Chua, Schacter, & Sperling, 2007). Furthermore, a number of recent studies have directly implicated the MTL system in both probabilistic and visual perceptual learning (Chun & Phelps, 1999; Manns & Squire, 2001; Turk-Browne et al., 2009; 2010; Dickerson, Li, & Delgado, 2011; Graham et al., 2006). Thus, there is a strong possibility that the types of learning and memory processes involved in generating learned control are subserved by the medial temporal lobes, and as a result it is possible that the MTL system is directly involved in learned control.
At the same time, the MTL memory system is complemented by other systems such as the Basal Ganglia (Packard & Knowlton, 2002) and various neocortical learning mechanisms (e.g. Keane, Gabrieli, Mapstone, Johnson, & Corkin, 1995; McClelland, McNaughton, & O’Reilly, 1995; Schwartz, Maquet, & Frith, 2002). With respect to visual perceptual learning (VPL) in particular, changes in neural function induced by visual learning appear to occur almost exclusively within striate and extrastriate visual cortex, resulting from changes in local connections between neurons within these visual areas (Crist, Li, & Gilbert, 2001; Schwartz et al., 2002; Sasaki, Nanez, Watanabi, 2010). In visual perceptual learning tasks, as in the studies described in this thesis, exposure to particular stimuli and stimulus configurations leads to lasting changes in visual performance across a number of domains. In the context of the current experiments, the learning effects seen in Chapters 2 and 3 could be thought of as a type of perceptual expertise that directly influences the likelihood a particular stimulus will capture attention and cause distraction. Importantly, the behavioral and neural mechanisms that subserve attention have been shown to interact with those subserving visual perceptual learning, such that attentional processes can directly influence the strength or specificity of learning (e.g., Ahissar & Hochstein, 2004; Ito, Westheimer, & Gilbert, 1998) and perceptual learning can affect later attentional processes (e.g., Green & Bavalier, 2007; Beste, Wascher, Güntürkün, & Dinse, 2011). Viewed in this context, it is possible that the learned control effects result at least in part from the operation of neocortical learning systems involved in basic visual perceptual learning processes.

The goal of Chapter 5 is to determine whether the MTL memory system is necessary for the learned control over capture demonstrated in Chapters 2-4, in order to
take a first step in understanding the memory systems critical for implementing goal-directed control on the basis of experience. To this end, patients with severe amnesia as a result of bilateral medial temporal lobe damage, as well as normal comparison observers, completed two different capture tasks similar to those employed in Chapters 3 and 4. To anticipate the results, amnesic patients showed normal learned control effects in a case where control was learned on the basis of probabilistic associations between a target and its defining color features (in a task identical to that used in Experiment 8), suggesting intact learning of basic probabilistic associations between a target and its features (and resultant influences on attentional control) in amnesic patients.

However, when performing a search task similar to that used in Experiments 11 and 12, patients did not show a normal carryover effect between training and testing sessions, suggesting a selective impairment in control on the basis of learned context. The results are discussed in terms of the different learning requirements of each task, as well as how these types of learning relate to the specialized functions of medial temporal lobe and neocortical memory systems.

**Experiment 13**

It is well established that MTL structures play an important role in memory, with the MTL being necessary for successful encoding and retrieval of various types of memory (see Squire, 1992; 2004; Moscovitch, 2008 for reviews). Given that MTL structures have bi-directional connections with neocortical sites important for processing attributes of objects, including properties such as color, shape, and identity, as well as their corresponding spatial locations, the MTL has been proposed as a candidate for the binding of multitude environmental information into single representations in which
arbitrary relations among items are stored in a bound form (Cohen & Eichenbaum, 1993; Cohen et al., 1999; Eichenbaum, Yonelinas, & Ranganath, 2007; Davachi, 2006; Shimamura, 2010).

This view of MTL function would suggest that in any case in which relationships between multiple attributes of information in the environment must be bound into holistic representations, MTL structures should be necessary for successful binding of these components. Such a description of the MTL as a general relational coding system has received support from both neuropsychological and neuroimaging studies, with a number of studies demonstrating a role for the MTL in learning relationships between co-occurring pieces of visual information (see Konkel, et al., 2008; Hannula & Ranganath, 2008; Hannula et al., 2006; Turriziana et al., 2004; Davachi, Mitchell, & Wagner, 2003, Prince et al., 2005, for examples most relevant to the current thesis). Furthermore, as noted above the MTL system has recently been implicated in observers’ ability to extract visual regularities, spanning across the spatial, temporal, and feature domains (Chun & Phelps, 1999; Turk-Browne et al., 2009; 2010; Fiser et al., 2010; Dickerson, Li, & Delgado, 2011).

Given that the learned control observed in Chapter 3 required observers to learn associative relationships between targets and their defining features in a probabilistic manner, the instantiation of this form of control requires both associative learning and the extraction of visual regularities (e.g., observers have to learn “the target item is usually red”). Since the MTL system has been implicated in each of these processes, it is plausible that observers with MTL damage would show an impairment in feature-based learned control over capture relative to a comparison group when performing a capture
task like that used in Experiment 8.

Recall that in this task, as observers learn to associate the target with its likely color, and only distractors that match this target color retain the ability to capture attention, with salient distractors presented in other colors failing to capture attention (similar to the results of Folk et al., 1992;2002). Thus, normal performance on this task is indicated by increased capture for distractors that match the more likely target color relative to those that match the less likely target color. Conversely, impairment in the ability to learn the relationship between the target and its likely color would lead to a “non-selective” pattern of capture effects, whereby any salient distractor would capture attention regardless of its color.

Method

Observers. Two patients with bilateral damage confined to the medial temporal lobes, both densely amnesic, completed a task identical to that in Experiment 8. The etiologies of each patient differed, with one acquiring damage due to an anoxic event (patient 2563) and the other acquiring damage secondary to herpes simplex encephalitis (patient 2308). Neuropsychological test scores summarizing the severity of the patients’ memory impairment, as well as basic demographic information, can be seen in Appendix D. Performance was compared with a group of neurologically normal, young comparison observers (n=10) recruited from the elementary psychology database, who participated for course credit.

Stimuli & Procedure. The stimuli and procedure were identical to those in Experiment 8 (see FIGURE). Both patients and comparison observers completed 12 blocks of 40 trials (480 total trials). Directly following the twelfth training block, both
completed a test session of 160 trials (4 blocks of 40 trials each) in which the asymmetry in target-color probability was removed.

Results

Incorrect trials and trials with RTs greater than 3 SDs above individual means in both the training and testing data (treated separately) were excluded from further analysis. Reaction time data for normal comparisons appear in Figures 27 (training) and 28 (testing). Data for patients appear in Figures 29 (training) and 30 (testing).

Training Data – Normal Comparisons. For both sessions, reaction time (RT) and error rate data were entered into a two factor ANOVA with cue color (match likely target color vs. match unlikely target color) and cue validity (valid vs. invalid) as factors (see Figure 26). For RTs, a significant main effect of cue validity was observed, $F(1,9) = 10.2, p = .01, \eta^2 = .53$, indicating faster responses to validly cued (513ms) than invalidly cued (529ms) targets. The main effect of cue color was not significant, $F < 1, n.s.$ However, a significant interaction was observed between cue color and cue validity, $F(1,9) = 22.6, p < .01, \eta^2 = .72$, indicating again that the magnitude of capture varied as a function of the cue’s color. Planned comparisons were performed between valid and invalid cues in each of the cue color conditions in order to assess cueing effects for each cue type. Significant cueing effects were observed for cues that matched the likely target color, $t(9) = 4.2, p < .01$, but not those that matched the less likely target color, $t(9) = 1.7, p = .13$. Analysis of error rates showed a significant main effect of validity, $F(1,9) = 7.6, p = .02, \eta^2 = .25$, with overall error rates being slightly higher on invalid trials (2.5%) than on valid trials (1.5%). Neither the main effect of cue color nor the interaction between cue color and validity were significant. These data provide a direct replication
of Experiment 8, again showing that the effect of learned target-color contingencies on the ability of the cue to capture attention is robust and replicable.

![Graph showing reaction time data for normal comparisons in the training portion of Experiment 13. Error rates appear in white at the base of the graph, and error bars represent +/- 1 standard error.]

**Figure 27.** Reaction time data for normal comparisons in the training portion of Experiment 13. Error rates appear in white at the base of the graph, and error bars represent +/- 1 standard error.

**Testing Data – Normal Comparisons.** Mean error rate and RT data appear in Figure 28. For RTs, a significant main effect of cue validity was observed, $F(1,9) = 18.1$, $p < .01$, $\eta^2 = .67$, indicating faster responses to validly cued than invalidly cued targets. The main effect of cue color was not significant, $F<1$, n.s. Importantly, a significant interaction was observed between cue color and cue validity, $F(1,9) = 8.5$, $p = .02$, $\eta^2 = .48$, indicating that the magnitude of capture by the cue varied as a function of the cue’s color. Planned comparisons were performed between valid and invalid cues in each of
the cue color conditions in order to assess cueing effects for each cue type in the testing block. Significant cueing effects were observed for cues that matched the likely target color, $t(9) = 4.4, p < .01$, but not those that matched the less likely target color, $t(9) = 1.7, p = .12$. Analysis of error rates showed no significant main effect or interactions, all $F$s < 2.5, $p$s > .15.

Figure 28. Reaction time data for normal comparisons in the testing portion of Experiment 13. Error rates appear in white at the base of the graph, and error bars represent +/- 1 standard error.

Training Data – Patients. Training data for amnesic patients appear in Figure 29). Given that only two patients completed this task, data was analyzed on an individual basis to provide a more meaningful picture of performance in each patient relative to
comparison observers. Recall that the data from normal comparison observers in both this experiment and in Experiment 8 showed significant cueing effects only when the cue matched the more probable target color. Given the specific pattern of data I wished to compare between groups, in the patient group planned t-tests were performed on individual RTs and Error rate between valid and invalid trials in both 1) the case in which the cue matched the more probable target color and 2) the case in which the cue matched the less probable target color (see Vecera & Rizzo, 2004; 2006 for similar approach).

Figure 29. Reaction time data for amnesic patients during the training session of Experiment 13. Error rates appear in white at the base of the graph, and error bars represent +/- 1 standard error.
During training, both patients showed a significant cueing effect when the cue matched the more probable target color (patient 2563 – $t(205) = 2.9$, $p < .01$; patient 2308 – $t(223) = 2.8$, $p < .01$), whereas neither showed a significant cueing effect when the cue matched the less probable target color (patient 2563 – $t(211) = 1.1$, $p = .27$; patient 2308 – $t < 1$, n.s.). There were no significant effects observed in the error rate data for either patient, all $ts < 1$, n.s.

![Reaction time data for amnesic patients during the training session of Experiment 13. Error rates appear in white at the base of the graph, and error bars represent +/- 1 standard error.](image)

Figure 30. Reaction time data for amnesic patients during the training session of Experiment 13. Error rates appear in white at the base of the graph, and error bars represent +/- 1 standard error.

**Testing Data – Patients.** Patient data appear in Figure 30. Analyses identical to those performed on training data were carried out for RTs and Error rate in the testing
data. As in training, during testing both patients showed a significant cueing effect when the cue matched the more probable target color, even with this asymmetry was no longer present (patient 2563 – $t(65) = 2.0$, $p < .05$; patient 2308 – $t(69) = 2.1$, $p < .05$), whereas neither showed a significant cueing effect when the cue matched the less probable target color (both patient 2563 and patient 2308 – $t < 1$, n.s.). As in the training session, there were no significant effects observed in the error rate data for either patient, all $ts < 1$, n.s.

Discussion

Given that previous work has shown involvement of MTL structures in both the ability to extract visual probabilistic relationships (e.g., Turk-Browne et al., 2009; 2010) and in the ability to bind multiple dimensions of simple visual objects (e.g., Warren et al., 2010; Barense et al., 2007), it seemed plausible that in a task that requires both of these processes amnesic patients would be impaired in the acquisition of learned control over capture relative to normal observers. However, the amnesic patients showed a pattern of data nearly identical to that of normal comparisons, suggesting that the medial temporal lobe learning system is not necessary for the type of learning that drives the effects seen in this task.

On the one hand, this result is surprising because, as noted above, a growing body of recent work has implicated MTL memory structures in visual binding processes (Warren et al., 2010; Olson, 2006a; 2006b), as well as the extraction of probabilistic visual relationships (Chun & Jiang, 1998; Manns & Squire, 2001; Greene et al., 2007; Turk-Browne et al., 2009; 2010). At the same time, traditional views of MTL function would have likely predicted a result similar to that observed here, given that these views emphasize the role of MTL in explicit (declarative) memory processes, and posit little
role for the MTL in the types of perceptual learning required in this task (see Suzuki, 2009, for a review specific to the role of the MTL in visual-perceptual processes).

It is worth noting here that in parallel work (Cosman & Vecera, in preparation), using a task identical to that used in neuroimaging studies of visual statistical learning (Turk-Browne et al., 2009), we have shown an intact ability to extract temporal probabilities in these same two patients, whereas the imaging data of Turk-Browne et al. (2009) showed robust activation of the hippocampus in particular during performance of the same task. This suggests a dissociation in the mechanisms necessary for learning visual probabilities and those sufficient for such learning. Interestingly, the imaging study of Turk-Browne et al. also showed changes in activation during probability learning in the lateral occipital complex (LOC), an object selective region of visual cortex. Thus, rather than participating directly in probabilistic visual learning the hippocampus may be more strongly involved in consolidating probability dependent changes in connectivity in visual cortex. For example, intermediate-term changes in cortical structure or function may be sufficient to produce the effects seen here, but the consolidation of these changes into a more robust long-term representation may be critically dependent on an intact medial temporal lobe. Alternatively (or additionally), the hippocampus may be involved in processes related to awareness of the probability structure and/or the encoding this information into episodic or semantic memory, both of which are heavily hippocampus dependent.

Along these same lines, studies examining the neural correlates of visual perceptual learning have typically shown that changes in neural function induced by exposure to low-level visual features occur almost exclusively within striate and
extrastriate visual cortex (Crist, Li, & Gilbert, 2001; Schwartz et al., 2002; Sasaki, Nanez, Watanabi, 2010). This is not to say that higher-level regions of the brain do not participate in the acquisition of visual skills acquired through perceptual learning (e.g., see Walsh, Ashbridge, & Cowey, 1998, Giovanelli et al., 2010), but that neocortical changes appear critical for the maintenance of these skills in the intermediate to long-term.

This idea that experience-dependent changes in visual cortex can lead to changes in subsequent visual processing has been applied to explain feature-based attentional selection in particular, with recent models of visual search attempting to show that performance improvements resulting from repetition of particular target features can be explained by changes in the weights that the attentional system assigns to these features (Wolfe, Butcher, Lee, & Hyle, 2003; Lee, Mozer, & Vecera, 2009; Mozer, Shettel, & Vecera, 2006). In these models, features likely to define the target of search are strengthened relative to those that are less likely to define the target, resulting in increased detection for these features upon future encounters (Wolfe et al., 2003).

Furthermore, these changes in feature weights occur in a probabilistic manner, such that more probable target features receive increased feature weights, affording benefits in detection when they appear upon future encounters (Mozer et al., 2006). Importantly, the master map of features responsible for maintaining such changes has been hypothesized to reside in regions of the frontal lobes (specifically, frontal eye field (FEF); Thompson & Bichot, 2005) or visual cortex (Li, 2002), with feature weights likely being represented at multiple levels of processing in the brain (Fecteau & Munoz, 2006). Taken together, then, it seems likely that the type of learning responsible for the effects
observed both in Chapter 3 and in the current experiment is akin to a form of long-term visual priming (Cave, 1999; Fiser & Biederman, 2001). However, it is important to note that the operation of this form of priming is different than that typically encountered in the study of visual attention, in that it persists even when the probabilistic relationship between particular the target and particular features is removed (as in Experiment 8 and the current experiment). This suggests that this type of priming is less fragile than that resulting from simple inter-trial priming effects, and as a result may rely on different underlying mechanisms (e.g., Maljkovic & Nakayama, 1994; Hickey et al., 2011).

Finally, it is worth noting that the distinction between priming and more traditional (declarative) long-term memory formation may be a matter of degree, where priming effects, given sufficient time, may reach awareness and provide the scaffold for more robust, conscious forms of memory (e.g., Berry, Shanks, & Henson, 2008; Gupta & Cohen, 2002). For example, during the task used here and in Experiment 8, observers were unaware that the target was more likely to appear in a particular color than other colors. However, if I were to bring observers back to the lab every day for two weeks and have them perform the same task, it is likely that they would eventually realize the contingency between the target and its color. This realization and the resultant conscious memory trace would likely rely on MTL memory structures, and may fundamentally alter the way the task is approached in the future. Thus, even though the attentional system can acquire information over time and use it to optimize attentional performance even when this information is retained outside of the scope of conscious awareness or observers’ intentions, this form of control may ultimately interact with or enable explicit control processes.
Experiment 14

The results of the previous experiment suggest that not all forms of learned control rely critically on the medial temporal lobe memory system. However, as demonstrated in Experiments 11 and 12, the associations that drive learned control can also be formed between higher-level representations such as cognitive strategies and the context in which they were learned. Given that the MTL system is critically involved in the formation of associations between stimuli and spatial (Chun & Phelps, 1999), temporal (St. Jacques et al., 2008; Jenkins & Ranganath, 2010) and scene (Bar, 2004) context, it seems possible that the type of contextual learning observed in Experiments 11 and 12 above may also rely on the MTL system (see Davachi, 2006; Eichenbaum, Yonelinas, & Ranganath, 2007). Furthermore, damage to the medial temporal lobes has been shown to affect the operation of covert and overt attention on the basis of learned contextual or relational information (Ryan et al., 2000; Chun & Phelps, 1999; Manns & Squire, 2001), suggesting a direct relationship between the medial temporal lobes and attentional control on the basis of context.

As discussed at length above, Leber and colleagues (2006a; 2006b; see also Leber et al., 2009) have provided a number of behavioral demonstrations that in tasks where multiple cognitive strategies are available observers choose strategies that match those learned previously when in a similar context, a notion that I have verified using a direct manipulation of context in Experiments 11 and 12. Recall that in the original version of this task (described in detail on p. 83; see Figure 21), two groups of observers completed training sessions in which they were told to either search heterogeneous arrays for a specific shape (e.g., a circle), or search homogeneous arrays for a singleton shape that
varied from trial to trial (with each group performing only one of these tasks during training). During a testing session in which either strategy could be used, it was shown that observers persisted in using the same strategy used in the training session, suggesting that past experience directly affects the choice of strategy when multiple strategies exist (a finding I replicated and extended above). In follow-up experiments, this effect was shown to persist over delays of one week, suggesting the operation of a long-term, contextual learning mechanism (Leber et al., 2009).

In Experiment 14, I was interested in examining whether this learning of cognitive strategies relies on the MTL memory system, by having both a group of amnesic patients and matched comparisons complete a task nearly identical to that used by Leber & Egeth, 2006a. Given my specific interest in learned goal-directed control, I examined whether amnesic observers who had been taught to use effective control during a training session (by implementing a “feature search” strategy) would retain this ability in subsequent task in which multiple strategies could be used. To this end, both amnesic patients and comparisons completed a training session in which they were told to search for a specific feature (a circle) among heterogeneous distractor items (Figure 31; left panel), a condition known to induce effective control (Bacon & Egeth, 1994; Leber & Egeth, 2006a; Experiments 10 and 11 above). Of primary interest was the effect that this training would have on the degree of capture during a testing block in which, in the absence of such training, capture effects are robust (Leber & Egeth, 2006a; Theeuwes, 1992; see Figure 31, right panel).

If the MTL system is necessary for this form of learned control, we may expect various abnormalities in the data from this task. First, if the MTL is necessary to
instantiate goal directed control in this task more generally, we may expect robust capture effects in the amnesic patients both during training and testing, indicating that these patients are generally more distractible in this particular task. On the other hand, if the MTL is uniquely involved in the ability to transfer control strategies learned during the training session to a novel but similar task context, we would expect the amnesic patients to show normal attenuation of capture during training, but large capture effects during testing. This would indicate that the medial temporal lobes are uniquely involved in applying previously acquired strategies to novel behavioral contexts.

**Method**

**Observers.** Four patients with bilateral damage confined to the medial temporal lobes (3 male, 1 female, mean age 53.5 yrs.; SD = 3.6), all densely amnesic, completed a task similar to that used by Leber & Egeth, 2006a and Experiments 11 and 12 above. The etiologies of the patients differed, with three acquiring damage due to an anoxic event (patients 1846, 2563, and 2363) and the other acquiring damage secondary to herpes simplex encephalitis (patient 2308). Neuropsychological test scores summarizing the severity of the patients’ memory impairment, as well as basic demographic information, can be seen in Appendix D. Performance was compared with a group of neurologically normal age and sex matched observers (3 male, 1 female; mean age 53.3 yrs.; SD = 3.5). **Stimuli.** Observers sat approximately 65 cm from the screen, and viewed displays resembling those in Figure 31. Stimuli always appeared on a black background, and a white fixation dot with a diameter of 0.3° was always positioned at the center of the screen. Search displays consisted of six outline shapes equally spaced around the circumference of an imaginary circle with a radius of 3° that was centered around
fixation. The outline shapes were drawn with a stroke of $0.1^\circ$ and could be a circle (radius $0.7^\circ$), a square ($1.5^\circ$ per side), a diamond ($1.5^\circ$ per side), or an equilateral triangle (pointing upward, $1.5^\circ$ per side). The outline shapes were colored green (0, 255, 0), except for the singleton distractor, which always appeared in red (255, 0, 0) when present. A white vertical or horizontal line segment ($0.5^\circ$ long, $0.1^\circ$ stroke) was centered inside of each shape.

![Figure 31. Schematic diagram of the task used in Experiment 14.](image)

**Training**

“Feature Search”

Search for circle among heterogeneous non-targets

**Testing**

“Option Trials”

Search for circle among homogeneous non-targets

*Design.* During the training phase, observers in both groups performed a version of the additional singleton task in which they were instructed to search for a circle on each trial, and the target was always presented among a heterogeneous array of six non-target items, which always included at least one diamond, one square, and one triangle, with the other two distractor items being chosen at random on each trial with the constraint that both items weren’t the same shape. On half of the trials, one of the non-
target items (identity and location chosen randomly), appeared in red as a salient color singleton distractor. The spatial positions of target and distractor items were randomly determined, and each item in the display contained a white line segment oriented either horizontally or vertically, with observers’ response being to report the orientation of the line contained within the target item on each trial.

The testing phase was similar to the training phase, with observers told to search for a circle target on each trial. However, during testing the circle target was always presented in an array of homogeneous diamond shaped distractor items. Thus in the testing phase, observers had the option of searching for either the “different” item or for the specific feature that defined the target (a circle). As in the training session, on half of the trials, one of the non-target items (identity and location chosen randomly) appeared in red on as a salient color singleton distractor. Of primary interest during the testing session was whether damage to the MTL would 1) influence the likelihood that observers could attenuate capture during training on the feature search task and 2) if they were able to implement such a strategy during training, whether they would continue to use this strategy during testing as is typically observed in this task.

Procedure. As described above, during the training phase observers were instructed to search for a circle among heterogeneous non-target items (i.e., a feature search condition). 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, with each key corresponding to either horizontal or vertical line orientation, counterbalanced across observers. At the beginning of each trial, a fixation screen appeared for 1000ms. Next, the search array appeared until observers responded. Observers performed a block
of 56 practice trials prior to performing the training blocks, which consisted of 3 blocks of 56 trials each, for a total of 224 training trials.

During the testing session observers were always told to search for a circle among homogeneous diamond non-target items and report the orientation of the line contained inside of the target, while ignoring the salient red distractor when it appeared. Observers completed 3 blocks of 56 trials each for a total of 168 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

Overall mean correct reaction time (RT) and error rate data for each group of observers during training and testing sessions are shown in Figure 32 (training) and Figure 33 (testing). Correct reaction times greater than 3SDs above individual means were eliminated from further analysis in each group, resulting in a loss of <1% of the data in normal comparison observers (resulting in 320 analyzed trials) and 2% of the data in the patient group (resulting in 309 analyzed trials). Both RT and error rate data from Experiment 14 were entered into an omnibus mixed-model ANOVA with Session (Training vs. Testing) and Distractor Presence as within-subjects factors, and Group (Patient vs. Comparison) as a between-subjects factor.

This analysis revealed a significant main effect of session, $F(1,6) = 12.9$ $p = .01$, $\eta^2 = .68$, with slower overall RTs during training (1324 ms) than practice (1125 ms), and Group, $F(1,6) = 109.8$ $p < .001$, $\eta^2 = .94$, with slower RTs in the patient group than the comparison group. No other main effects were significant, and none of the two-way interactions were significant all $Fs < 1$, n.s. However, a significant three way interaction
was observed, $F(1, 6) = 6.8$, $p = .04$, $\eta^2 = .53$. There were no significant main effects or interaction in the error rate data, (all $F$s $< 2.2$, all $p$s $> .18$).

Given our specific interest in capture effects during training and test in both groups, in order to elaborate on the three-way interaction observed in the RT analysis I performed separate two-factor ANOVAs on RTs for training and testing sessions, with Group (Patient vs. Comparison) and Distractor Presence (Present vs. Absent) as factors.

![Figure 32. Reaction time data for both normal comparisons and amnesic patients during the training session of Experiment 14. Error rates appear in white at the base of the graph, and error bars represent +/- 1 standard error.](image)

For training RTs, a significant main effect of Group was observed, $F(1, 6) = 91.8$, $p < .001$, $\eta^2 = .93$, with patients responding slower overall (1575 ms) than normal comparisons (1073 ms). Neither the main effect of distractor presence, nor the
interaction of group and distractor presence were significant (both \( F < 1, \text{n.s.} \)) indicating that during training capture effects were similar in the patient group (-10 ms) and the comparison group (5 ms).

![Graph showing reaction times](image)

Figure 33. Reaction time data for both normal comparisons and amnesic patients during the testing session of Experiment 14. Error rates appear in white at the base of the graph, and error bars represent +/- 1 standard error.

For testing RTs, a significant main effect of Group was observed, \( F(1,6) = 129.4 \) \( p < .001, \eta^2 = .95 \), with patients responding slower overall (1285 ms) than normal comparisons (965 ms). The main effect of distractor presence was not significant, \( F(1,6) = 3.8 \) \( p = .11 \). However, a significant interaction was observed between group and distractor presence, \( F(1,6) = 6.2 \) \( p < .05, \eta^2 = .51 \) with much larger capture effects in the
amnesic patient group (131 ms) than the comparison group (-15 ms), suggesting that whereas normal comparisons continued to use the feature search strategy learned during training the amnesic patients did not.

Discussion

The results in the normal comparison group provide a basic replication of the results of Leber & Egeth, 2006a, showing that learned search strategies can carry over and affect performance on a similar task in which multiple search strategies exist. However, such a carryover effect was absent in the amnesic patients, suggesting a role for the medial temporal lobe memory system in this form of learned control. It is important to point out that such a result cannot be explained on the basis of amnesics being generally more distractible than the comparison observers; Both amnesics and comparisions were able to effectively overcome capture during training, suggesting a selective deficit in the patients’ ability to implement learned control when the task changes. Given that this effect has been hypothesized to arise on the basis of learned associations between a particular search strategy and its context, (Leber & Egeth, 2006a; 2006b; Leber et al., 2009 – a notion I directly tested and verified in Chapter 4), the deficit observed here may be related to general deficits in context learning observed in these patients (see Chun & Phelps, 1999; Manns & Squire, 2001 for examples most relevant to the current work).

Alternatively, it may be the case that the mechanisms driving the carryover effect seen in normal observers relies on a explicit memory process, whereby these observers decide in a conscious manner, based on how they performed the task during training, to continue using a similar strategy during the test block. Given that medial temporal lobe
damage is known to cause severe problems in the ability to form explicit, declarative memories, this explanation could parsimoniously account for the current results. Although there is no way to rule this possibility out in the current work, the data from the experiments in Chapter 4 would seem to suggest this is likely not the case. Specifically, recall that observers’ subjective descriptions of search strategy used during training did little to affect the pattern of capture effects observed during test, arguing that implicit stimulus factors are more important for dictating the pattern of capture than the explicit strategy employed by observers to find the target.

Previous work from our lab and others would also argue against this explanation. For example, it has been demonstrated that increased perceptual search demands lead to a better ability of observers to block distraction, even in particular populations of individuals who are normally highly distractible (see Maylor & Lavie, 1998; Forster & Lavie, 2007; 2008; Cosman & Vecera, 2009; 2010). In the context of the amnesic patients, this would explain why during training they showed a normal ability to overcome capture; heterogeneous displays may increase task-relevant processing demands, leading to a decrease in capture. In fact, we have shown exactly this effect in a series of studies designed to examine the effect of perceptual search demands on attentional capture (Cosman & Vecera, 2009). Thus, whereas high demand search tasks may allow all observers to overcome distraction equally well, transferring this ability to a case in which search demands are relaxed appears to be selectively impaired in amnesia.

CHAPTER 6
GENERAL DISCUSSION

Traditional views of attentional capture have traditionally been split between
theories that propose that attentional capture is driven primarily by stimulus salience (Theeuwes, 1992; 2004; 2010) and those proposing that attentional capture is driven primarily by the explicit goals of an observer (Folk et al., 1992; 1993; 1994; Folk & Remington, 1998; 2008; Bacon & Egeth, 1994; Leber & Egeth, 2006a; 2006b). The approach used distinguish between these views has traditionally relied heavily on the intentionality criterion of automatic processes; to the extent that observers are able to ignore something they were told to ignore, it is inferred that voluntary, goal-directed control was effectively employed, and to the extent that they are not it is inferred that automatic capture occurred. This approach leads to the basic prediction that an observer’s intentions should be both necessary and sufficient to overcome capture, especially in cases where goal-directed control is known to be effective. The motivation for the current studies was to show that this logic is flawed, in that not all goal-directed processes are necessarily the result of intentional processes. The experiments in Chapters 2-5 provide support for this notion, calling into question the usefulness of intentionality in differentiating between stimulus-driven and goal-directed control over capture.

In Chapter 2, I demonstrated that in a case where goal-directed control over capture is known to be effective, explicit knowledge regarding what to attend to or ignore is insufficient for observers to overcome capture – simply telling someone not to pay attention to something has little effect on their ability to ignore it. Instead, observers appear to learn what information is both relevant and irrelevant through experience with the task, with this knowledge being critical in their ability to overcome capture. Furthermore, in these experiments observers learned highly specific information related to salient, task-irrelevant distractors themselves, suggesting a high degree of specificity in
the types of representations responsible for goal-directed control. This establishes that, at a minimum, observers must learn something about the target and distractor attributes in order to avoid attentional capture, arguing against a strict dichotomy between stimulus-driven and goal-directed capture effects as being driven by “automatic” vs. “intentional” processes, respectively.

In light of these results, in Chapter 3 I asked whether explicit goals were necessary for driving learned control effects, examining whether goal-directed control could arise implicitly on the basis of learned contingencies between targets, distractors, and their defining features. In Experiments 5-10 I manipulated “goal-relevant” features of targets or distractors orthogonally to observers’ explicit goals to test whether the pattern of goal-directed control typically observed in the cueing task of Folk and colleagues (as well as the experiments in Chapter 2) could be established without explicit knowledge of the target-color or distractor-color contingencies. Across these experiments, observers were able to learn that certain information was more or less likely to define particular task-relevant and task-irrelevant items, and this learning directly influenced the magnitude of capture effects despite the fact that observers were not explicitly aware of the contingencies driving these effects.

In Chapter 4, I used manipulations of search demands to induce particular search strategies, and showed that these strategies could be learned and bound to specific task contexts. Together with the results of Chapters 2 and 3, this suggests a highly flexible mechanism of learned control in which specific low-level stimulus information can come to be linked with the context in which it is learned. Importantly, this linkage ensures that the high degree of specificity characteristic of learned control does not have detrimental
effects when the behavioral context changes. In other words, the relevance of stimulus-defining features is not concrete; it changes with context, and an effective mechanism of learned control needs to have the ability to cope with such changes.

Finally, in Chapter 5 I examined whether specific aspects of learned control were dependent on the medial temporal lobe (MTL) memory system by testing a group of observers with amnesia due to bilateral MTL damage. Whereas learned control on the basis of stimulus-feature associations (such as that observed in Chapter 3) was intact in these patients, higher level control on the basis of learned search strategies (Chapter 4) was impaired, suggesting a dissociation in the mechanisms underlying each of these forms of learned control. Based on these results I argued that the effects of simple stimulus-feature associations on control likely arise on the as the result of long-term visual priming mechanisms, not unlike those proposed to underlie basic visual perceptual learning. On the other hand, the disrupted ability of the amnesic patients to transfer learned search strategies across tasks suggests that the MTL system is important for the arguably higher-level stimulus-context associations seen in Chapter 4.

Taken together, the current results suggest that rather than being determined by the effectiveness of explicit, intentional control processes, the likelihood that one will observe stimulus-driven or goal-directed capture effects is determined by 1) the amount of experience and observer has with a particular task, and 2) the type of experience an observer has with a task. More specifically, the current results argue that, generally speaking, the amount of experience an observer has with a search task directly determines the effectiveness of goal-directed control. On the other hand, experience alone may be insufficient for effective control; in a case where search demands are low or the relevance
of particular stimulus features is ambiguous (e.g., following a color change), control is more likely to operate on the basis of salience. Thus, experience coupled with particular attributes of the task combine to determine the likelihood of capture, and this effect appears to emerge regardless of the intentions of an observer. More specifically, experience interacts with stimulus attributes in a highly specific manner to determine the effectiveness of goal-directed control across situations.

Relationship to other studies examining the effects of experience on attentional capture

The current thesis focused on using two widely employed attentional capture task to demonstrate that conflicting results from these two tasks, as well as within the capture literature as a whole, could be reconciled by viewing goal-directed control as a dynamic process that emerges on the basis of task experience. Although the work presented here provides the most complete examination of this idea, similar notions have been tested in previous studies, and each of these lines of work will be briefly discussed in order to situate the current results within the context of practice effects on attentional capture, in addition to providing further data to support the claims made throughout this thesis. In general, there have been two approaches taken when examining the effects of experience in attentional control – those that look for effective control in tasks that normally show capture, and those that look for capture in tasks that normally show effective control. Each approach and relevant results are covered in turn below.

The effect of experience in tasks known to show capture effects

As discussed previously, results from Theeuwes’s additional singleton task
have been used to argue for capture as a purely stimulus-driven process, because in this task observers are always told to ignore the singleton distractor, and despite this RTs are typically slower for distractor present than distractor absent trials. My learned control account may suggest, however, that given sufficient experience with the task observers may be able overcome capture by the irrelevant distractor. This idea was first tested by Theeuwes (1992), in which he gave observers extensive practice with the additional singleton task and examined capture effects over time, similar to the approach I have taken throughout this thesis. However, contrary to the current results, Theeuwes showed no influence of practice on capture effects; capture effects continued to be observed even after nearly 2000 trials of practice. Although this would seemingly argue against the learned control view, as I have shown in Experiment 12 stimulus factors in this task are not conducive to control (see also Bacon & Egeth, 1994; Cosman & Vecera, 2010a; 2010b for similar arguments).

More specifically, it has been argued that top-down control processes are less likely to operate in situations in which search demands are minimal (Lavie, 1995; Lavie et al., 2004; Reynolds et al., 1999; Beck & Kastner, 2005; 2009; McMains & Kastner, 2011). Theeuwes’ additional singleton task would fall into this category, since observers search a homogeneous distractor array for a singleton target. Thus, one may not expect control over capture in this task regardless of the level of experience, because stimulus factors in this task are not conducive to effective control. A number of extant theories of attention propose just such a relationship between search demands and the level of task-irrelevant information processing, In particular, these theories posit that in cases where search demands are low task-irrelevant information processing proceeds unimpeded.
However, as search demands increase distractor processing becomes more strongly attenuated (Lavie et al., 1995; Torralbo & Beck, 2008; Cosman & Vecera, 2009; 2010a; 2010b Roper et al., unpublished).

In past work I have proposed and directly tested this possibility, with respect to attentional capture in particular. Specifically, we have shown that varying search demands systematically affects the likelihood that a salient distractor will capture attention (Cosman & Vecera, 2009; 2010a; 2010b). When observers search for a singleton target among homogeneous distractors (as in Theeuwes’ additional singleton task), capture is unavoidable and persists throughout the task. However, when the target is embedded within a heterogeneous search display (as in Bacon & Egeth’s “feature search” task), the salient distractor no longer captures attention, suggesting that the properties of the stimuli in the search display directly affect the likelihood of capture. It is likely that the reason practice did little to affect capture in Theeuwes’ (1992) experiments is because the demands of this search task are not conducive to generating the strong goal-directed control required to overcome capture. This interpretation fits with a number of more general theories of selective attention that propose a central role for stimulus factors in determining the effectiveness of attentional control (Duncan, 1980; Desimone & Duncan, 1995; Kastner et al., 2001; Kastner & Ungerleider, 2000; Beck & Kastner, 2005; 2009). This suggests that experience alone is insufficient to drive control; instead, experience with specific stimulus attributes or configurations are critical for the emergence of effective control. To the extent that stimulus factors are not conducive to effective control, capture may be the norm regardless of the level of task experience.

*The effect of experience in tasks known to show...*
Whereas the approach taken by Theeuwes (1992) was to see whether increased experience with a task would lead to a concurrent decrease in stimulus-driven capture, other researchers have taken the complementary approach – take a task in which goal-directed control is known to be effective, and see if decreased exposure to elements of the task leads to a concurrent increase in capture. The bulk of the experiments presented in the current thesis fall into this category, and the current results are generally consistent with those of prior studies in showing that decreasing exposure to particular elements of a task leads to increased attentional capture.

For example, when attention is focused on a particular target location prior to the appearance of an abrupt onset distractor (by using a 100% predictive central cue), this distractor fails to capture attention despite its salience (Theeuwes, 1991; Yantis & Jonides, 1990). This effect has been taken as evidence that focused attention is one mechanism through which goal-directed control may operate – to the extent that salient information falls outside of the focus of attention, it will not capture despite its salience (Belopolsky et al., 2007; Theeuwes, 1991; 2004; 2010; Yantis & Jonides, 1990). In order to test whether exposure to the task-irrelevant distractor was necessary in generating these effects, Neo and Chua (2006) manipulated the probability with which the onset distractor appeared across experiments. When the distractor appeared on 75% of trials as in previous studies capture effects were attenuated (Theeuwes, 1991; Yantis & Jonides, 1990). However, when the frequency of onset distractors was reduced to ~20% of trials, robust capture effects were observed throughout the experiment, suggesting that limiting exposure to the distractor enabled it to maintain its ability to capture attention.
Similarly, as mentioned previously we have shown that increasing search demands by embedding a target within a heterogeneous display leads to attenuated capture by salient distractors relative to a case in which the target is a singleton in a homogeneous search display (Cosman & Vecera, 2009; 2010a; 2010b). However, using a frequency manipulation similar to that of Neo & Chua, we have demonstrated that limiting exposure to the task-irrelevant distractor allows it to retain the ability to capture attention even when search demands are high (Cosman & Vecera, 2010b). Specifically, we showed that when observers perform a demanding search for target through heterogeneous displays, the salient distractor maintains the ability to capture attention so long as it is presented infrequently (20% of trials). A similar effect has been observed in Bacon & Egeth’s feature search task (Vaterott & Vecera, unpublished), as well as in Folk et al.’s cueing task (Experiments 1-4; see also Liao & Yeh, 2011). Taken together, it appears that in cases where goal-directed control is known to be effective, this control emerges over time and directly from gaining sufficient experience with the particular attributes of the task. In particular, to the extent that observers’ exposure to distracting stimuli is limited, capture effects will be observed in the face of manipulations known to typically attenuate capture.

**Formalizing the learned control approach**

Taken together, both the current work and the results of previous studies provide evidence that experience with particular attributes of a task is the critical determinant of whether or not capture will be observed in a given situation. Whereas an approach to understanding capture effects on the basis of an observer’s intentions traditionally provided a number of insights into the nature of attentional control processes, it no longer
has the explanatory power to describe the complex interaction of stimulus factors and goals that appear to influence the ability of salient information to capture attention and cause distraction. Instead, it appears that observers learn to control attention in a highly specific manner, relying on learning mechanisms similar to those subserving basic visual skill learning. This suggests that simple principles of visual learning and memory can do an adequate job of explaining capture effects, without unnecessarily involving the arguably nebulous intentionality criterion. Furthermore, this view provides a number of novel, testable hypotheses regarding when and how attentional capture should occur.

Based on the data presented in this thesis, as well as the data from past studies of capture, it appears that there are two primary factors that directly determine whether capture effects will be observed in a given task. The first is the amount of exposure an observer has to a task. Generally speaking, this view would predict that practice with the specific attributes of to be attended and to be ignored information should lead to a general increase in the effectiveness of goal-directed control. On the other hand, decreasing the level of practice or changing the defining attributes of stimuli used in a task should lead to an increased likelihood of capture. Importantly, in each case these effects can occur independent of explicit search goals, with task-specific learning of stimulus attributes being more critical to determining capture than search goals per se.

At the same time, experience alone isn’t sufficient for overcoming capture, and must be coupled with stimulus factors that engender effective control. Specifically, in a case where stimulus factors are sufficient to drive efficient task performance (e.g., as when observers perform a search for a singleton target in a homogeneous search display), the visual system will adopt a mode of processing in which stimulus information is
emphasized, leading to an increased likelihood that stimulus-driven capture will occur. In other words, when search demands are low control can be outsourced to the environment, and as a result salient stimuli will have an increased ability to capture attention. Although there are not necessarily well accepted definitions of what may constitute changes in either search demands or experience, previous work provides a starting point for operationalizing each of these factors within the context of visual search.

For example, manipulations that increase the conspicuity of the target (items that make the target easier to find) should increase the likelihood that capture will be observed, whereas manipulations that decrease the efficiency of search should decrease the likelihood that capture will be observed. In other words, manipulations that somehow alter search demands should lead to predictable modulation of capture effects, similar to the idea of a feature search and singleton detection modes proposed by Bacon & Egeth (1994) and others (Pashler, 1988; LaBerge & Brown, 1989; Bravo & Nakayama, 1992).

However, whereas these theories propose that changing search demands lead to changes in the explicit strategies observers employ to find the target, my own work and that of others have shown that this is not necessarily the case; Instead, such an effect may result from changes in stimulus-stimulus competition (Reynolds et al., 1999; Beck & Kastner, 2005; 2009; McMains & Kastner, 2011), or in the perceptual load of the displays (Lavie, 1995; Lavie et al., 2004; Cosman & Vecera, 2009; 2010a). These possibilities may not be mutually exclusive and may all represent the operation of similar processes, with the current model being agnostic to exactly how each of these effects arises. The important point is that manipulations of search demands should lead to
predictable effects on capture, such that increasing search demands should lead to decreases in capture, and decreasing search demands should lead to increases in capture.

Similarly, it is important to operationalize what is meant by “task experience” in the current theory, given that this could be interpreted in a number of ways. In the context of the current model, I operationalize task experience as cumulative exposure to particular task configurations; For example, in Experiments 3 and 4, even when observers had a great deal of experience with the search task itself, changes to the color of a distractor caused a transient increase in capture. In this case, it is possible that the introduction of new information forced a “relearning” of the effective control that was acquired in response to the previous stimulus configuration. Thus, changing critical attributes of a task configuration (e.g., timing parameters, stimulus-defining features, locations, or stimulus identity) result in a resetting of cumulative experience to some zero point, regardless of previous experience with the task as a whole.

In this way, the current theory is similar to theories of skill learning that propose a role for holistic task representations in the control of behavior (Anderson, 1982; Logan 1988; 2002). In the event that some aspect of these representations changes, control will be disrupted and the learning process must begin anew. Consistent with this view, in follow-up work to that presented in Chapter 2, I have shown that switching possible stimulus locations, distractor identities, or stimulus-response mappings is sufficient to disrupt control processes, leading to a transient increase in capture effects despite the fact that none of these changes is critical to the more general goals of the search task itself. Thus it appears that the representations used to guide attention on a moment to moment basis are complex and distributed, including information about the task space as a whole.
This view is much different than the traditional “target-centric” descriptions of the representations driving attentional control, and stands as a testable alternative to these models.

Figure 34. A diagrammatic depiction of the learned control model. When either task experience or search demands are sufficiently low, stimulus-driven control should predominate. In order to implement effective goal-directed control, both sufficient experience and sufficiently high search demands are necessary.

With these definitions in mind, the learned control view proposes that a confluence of stimulus factors and experience dictate whether capture will occur in a given scenario. In a simple sense, this view and the predictions resulting from it can be summarized in a manner similar to that in Figure 34. Even though this diagram is likely overly simplistic, it captures the strong predictions of the learned control view well. To reiterate: under this view, any time search demands, task experience, or both are low, the likelihood that control proceeds in a stimulus-driven manner is increased. The strong prediction of this model is that both task experience and search demands must be
sufficiently high in order for effective control to be observed, and the goal of ongoing research is to test the limits of this model.

**The capture debate revisited**

The primary point of contention with respect to the debate over the nature of capture effects is whether top-down factors can influence the initial attentional selection process. Proponents of a strong, stimulus-driven view of capture argue that attention is always allocated involuntarily to the most salient item in a scene, with top-down factors related to an observer’s goals operating after this initial selection processes (Theeuwes, 2010; 2004; 1992; 1994). On the other hand, proponents of a strong, goal-directed view of capture argue that attention is *only* captured by information that matches the task goals of an observer; to the extent that salient information is present in the environment that is incongruent with one’s goals, it will not capture attention (Folk et al., 1992; 1994; Folk & Remington, 1998; 2008). These views are extreme, and it has been hard to reconcile the two within a unified framework because it isn’t clear mechanistically speaking how the two views could co-exist.

However, the current model has little problem accommodating the general tenets of both views, because it proposes a dynamic interaction of stimulus factors and goal relevance across time. For example, in the experiments of Chapter 2 the task irrelevant distractor/cue captured attention during the first few trials of the task, but observers were quickly able to attenuate this task-irrelevant information. The fact that spatial cueing effects were observed early in this task shows that the salient cue is capturing spatial attention, rather than simply generating some sort of more general filtering costs related to the introduction of the onset (Kahneman, Treisman, & Burkell, 1983; Folk &
Remington, 1998). Furthermore, I was able to push around the effectiveness of control by simply changing the attributes of the distracting information. Based on this data, it appears that stimulus-driven capture represents the default in situations in which one has little experience with a particular task context or configuration. This is compatible with stimulus-driven views of capture, in that it demonstrates a potent effect of stimulus salience in novel task contexts.

At the same time, the strong goal-directed control exhibited after relatively little exposure to these tasks suggests that control on the basis of salience is short-lived and can be easily overridden with minimal exposure to a task and its stimuli. Given that many of the tasks we perform on a daily basis are highly practiced and occur in familiar contexts, it is likely that goal-directed control may predominate in most situations. Thus, although stimulus-driven control may represent the default mode of control in a novel situation, goal-directed control may actually be more common. However, the current view does not endorse the view that a goal needs to be explicit in order to influence capture in response to ongoing search goals (e.g., Folk et al., 1992; 1993); Instead, I propose that the implementation of goal-directed control arises directly through experience with specific stimulus attributes. In this way, the current theory views stimulus-driven capture as necessary for the emergence of effective goal-directed control.

This interplay between stimulus factors and goals likely provides the flexibility necessary for an organism to adapt to the changing task demands encountered on a moment to moment basis in the environment. The initial stimulus-driven selection process leads the organism to attend to a possibly critical stimulus or situation, and this information can then be evaluated and either enhanced or discounted in an identity
dependent manner, influencing future orienting behavior. This simple, experience-dependent description provides a parsimonious resolution to the debate over the nature of attentional capture effects by proposing that stimulus factors are a necessary contributor to effective goal-directed control.

**Limitations**

Strictly speaking the current theory can only speak to cases in which the task in question requires search processes. Although this doesn’t take away from the general impact of the current work, it does limit the conclusions that can be drawn. Recall the example used at the beginning of this thesis, for example. There is very little “search” involved in reading a paper in a crowded coffeehouse, yet these are some of the very types of situations in which capture is observed in daily life. In this case, the task experience component of the current model would likely apply, but here it is also possible that demands specific to the task of reading, or the context in which the reading is performed, may contribute to capture in a way that isn’t captured in the “search demands” component of the current model. To make an analogy to search, it is possible that when the environment is generally “quiet” control processes are generally more relaxed and irrelevant information may be more likely to capture attention. Much in the way a distractor may appear more salient when the search task is easy, a conversation at the table next to you may be more salient in a quiet coffee house than in a loud, bustling one simply by virtue of the fact that there is less “noise” to overcome when focusing on the task of reading in the former as opposed to the latter case. Thus, although the current model applies specifically to the task of search, it could be easily extended to other domains using similar principles.
Another limitation is that the current experiments were confined to the visual domain, even though capture occurs within and is affected by other modalities (Dalton & Lavie, 2004; Koelwijn, Bronkhorst, & Theeuwes, 2009; Santangelo, Olivetti-Belardinelli, Spence, & Macaluso, 2009). For example, in certain situations where the capture of visual information is attenuated, auditory information maintains the ability to capture attention under certain conditions (Santangelo et al., 2009; Santangelo, Ho, & Spence, 2008). Thus it is likely that the types of representations that are ultimately responsible for overcoming attentional capture in daily life are multi-modal in nature, and are more complex than those examined in the current work. Nevertheless, the principles applied here could easily be adapted to account for effects in other domains, providing a fruitful avenue for future research.

**Conclusion**

Despite the general limitations above, the learned control model provides a first step toward reconciling the disparate results in the capture literature by proposing an alternative approach to attentional capture effects that doesn’t rely on a fundamental difference in the processes responsible for stimulus-driven and goal-directed control. Instead, by viewing attentional control through the lens of basic learning memory principles each mode of control is seen as operating along a continuum, interacting to dictate what information will ultimately capture our attention. Thus, the ability to control attention is not unlike any other skill, allowing us to optimize our attentional behavior in a dynamic, complex visual world.
## APPENDIX A

### CHAPTER 2 REACTION TIME AND ERROR RATE DATA

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APPENDIX B

CHAPTER 3 REACTION TIME AND ERROR RATE DATA

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### CHAPTER 4 REACTION TIME AND ERROR RATE DATA

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## APPENDIX D

### PATIENT DEMOGRAPHIC DATA

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APPENDIX E

EXAMPLE AWARENESS QUESTIONS

1. Did you notice any regularities in the task?

2. Did you notice any regularities in the colors used in the task?

3. Did you notice whether the target was one color more often than the other?
   
   If yes, which color (Circle One)  Red       Green

4. The target was one color more often than the other. What color was more likely to be the target color? (Circle One)  Red       Green

*Note that during administration each question was presented individually in sequence, and observers were not exposed to all questions at once as depicted above.*
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